



Models 5205 & 5206

Lock-in Amplifiers

Instruction Manual

Notice:

This manual is made available as a convenience to users of the EG&G Models 5205 and 5206. These products have been obsolete since 1983 and as such we can offer no service or further support for them.

SIGNAL RECOVERY

...part of **AMETEK**® Advanced Measurement Technology

MODELS 5205/06 LOCK-IN AMPLIFIERS

OPERATING AND SERVICE MANUAL



SHOULD YOUR EQUIPMENT REQUIRE SERVICE

- A. Contact the factory (609/452-2111) or your local factory representative to discuss the problem. In many cases it will be possible to expedite servicing by localizing the problem.
- B. If it is necessary to send any equipment back to the factory, we need the following information.
- (1) Model number and serial number.
 - (2) Your name (instrument user).
 - (3) Your address.
 - (4) Address to which instrument should be returned.
 - (5) Your telephone number and extension.
 - (6) Symptoms (in detail, including control settings).
 - (7) Your purchase order number for repair charges (does not apply to repairs in warranty).
 - (8) Shipping instructions (if you wish to authorize shipment by any method other than normal surface transportation).
- C. U.S. CUSTOMERS—Ship the equipment being returned to:
- EG&G PRINCETON APPLIED RESEARCH
7 Roszel Road
(Off Alexander Road, East of Route 1)
Princeton, New Jersey 08540
- D. CUSTOMERS OUTSIDE OF U.S.A.—To avoid delay in customs clearance of equipment being returned, please contact the factory or the nearest factory distributor for complete shipping information.
- E. Address correspondence to:

EG&G PRINCETON APPLIED RESEARCH
P. O. Box 2565
Princeton, NJ 08540

Phone: 609/452-2111
TELEX: 843409

WARRANTY

EG&G PRINCETON APPLIED RESEARCH warrants each instrument of its manufacture to be free from defects in material and workmanship. Obligations under this Warranty shall be limited to replacing, repairing or giving credit for the purchase price, at our option, of any instrument returned, freight prepaid, to our factory within ONE year of delivery to the original purchaser, provided prior authorization for such return has been given by our authorized representative.

This Warranty shall not apply to any instrument which our inspection shall disclose to our satisfaction, has become defective or unworkable due to abuse, mishandling, misuse, accident, alteration, negligence, improper installation or other causes beyond our control. Instruments manufactured by others, and included in or supplied with our equipment, are not covered by this Warranty but carry the original manufacturer's warranty which is extended to our customers and may be more restrictive. Certain subassemblies, accessories or components may be specifically excluded from this Warranty, in which case such exclusions are listed in the Instruction Manual supplied with each instrument.

We reserve the right to make changes in design at any time without incurring any obligation to install same on units previously purchased.

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SECTION I CHARACTERISTICS

1.1 SAFETY CONSIDERATIONS (Read before operating instrument)

1.1A INTRODUCTION

The apparatus to which this instruction manual applies has been supplied in a safe condition. This manual contains some information and warnings which have to be followed by the user to ensure safe operation and to retain the apparatus in a safe condition. The described apparatus has been designed for indoor use.

1.1B INSPECTION

Newly received apparatus should be inspected for shipping damage. If any is noted, notify EG&G PARC and file a claim with the carrier. The shipping container should be saved for possible inspection by the carrier.

WARNING!

THE PROTECTIVE GROUNDING COULD BE RENDERED INEFFECTIVE IN DAMAGED APPARATUS. DAMAGED APPARATUS SHOULD NOT BE OPERATED UNTIL ITS SAFETY HAS BEEN VERIFIED BY QUALIFIED PERSONNEL. DAMAGED APPARATUS WAITING FOR SAFETY VERIFICATION SHOULD BE TAGGED TO INDICATE TO A POTENTIAL USER THAT IT MAY BE UNSAFE AND THAT IT SHOULD NOT BE OPERATED.

1.1C SAFETY MECHANISM

As defined in IEC Publication 348 (*Safety Requirements for Electronic Measuring Apparatus*), this is Class I apparatus, that is, this apparatus depends on connection to a protective conductor to earth ground for equipment and operator safety. Before any other connection is made to the apparatus, the protective earth terminal shall be connected to a protective conductor. The protective connection is made via the earth ground prong of the power cord plug. The power cord plug shall only be inserted in a socket outlet provided with the required earth ground contact. The protective action must not be negated by the use of an extension cord without a protective conductor, by use of an "adapter" that doesn't maintain earth ground continuity, or by any other means.

The power cord plug provided is of the type illustrated in Figure I-1. If this plug is not compatible with the available power sockets, the plug or power cord should be replaced with an approved type of compatible design.

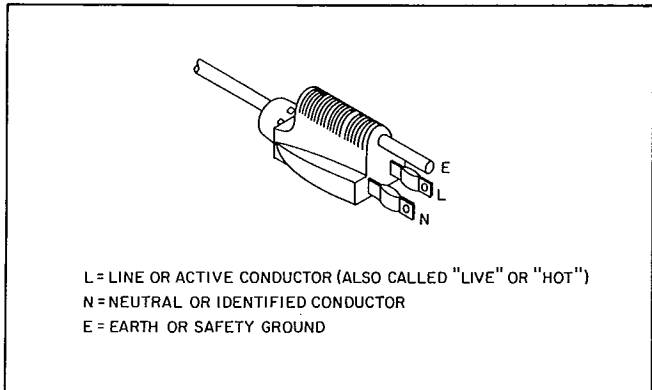


Figure I-1. POWER CORD PLUG WITH POLARITY INDICATORS

WARNING!

IF IT IS NECESSARY TO REPLACE THE POWER CORD OR THE POWER PLUG, THE REPLACEMENT CORD OR PLUG MUST HAVE THE SAME POLARITY AS THE ORIGINAL. OTHERWISE A SAFETY HAZARD FROM ELECTRICAL SHOCK, WHICH COULD RESULT IN PERSONAL INJURY OR DEATH, MIGHT RESULT.

1.1D POWER VOLTAGE SELECTION AND LINE FUSES

Before plugging in the power cord, make sure that the equipment is set to the voltage of the ac power supply.

CAUTION!

THE APPARATUS DESCRIBED IN THIS MANUAL MAY BE DAMAGED IF IT IS SET FOR OPERATION FROM 110 V AC AND TURNED ON WITH 220 V AC APPLIED TO THE POWER INPUT CONNECTOR.

A detailed discussion of how to check and, if necessary, change the power voltage setting follows.

The line voltage is selected by means of a rear-panel switch. FOR SAFETY, UNPLUG THE POWER CORD WHEN CHECKING THE LINE VOLTAGE SETTING OR WHEN CHECKING THE FUSES. FUSES SHOULD ONLY BE CHANGED BY QUALIFIED SERVICE PERSONNEL WHO ARE AWARE OF THE HAZARDS INVOLVED. Depending on the switch position, either "115" or "230" (both are printed on the switch) will be visible to the viewer. For operation from a line voltage in the

range of 95 V to 130 V, 50-60 Hz, "115" should show in the switch "window". For operation from a voltage in the range of 190 V to 260 V, 50-60 Hz, "230" should show.

The line fuse holder is located at the rear panel as well. For operation from a line voltage of nominally 115 V, use a slow-blow fuse rated at 1 A (voltage rating 250 V or higher). For operation from a line voltage of nominally 230 V, use a slow-blow fuse rated at 500 mA (voltage rating of 250 V or higher).

WARNING!

TO AVOID THE POSSIBILITY OF A SAFETY HAZARD FROM ELECTRICAL SHOCK, WHICH COULD RESULT IN PERSONAL INJURY OR DEATH, DISCONNECT THE POWER CORD BEFORE REMOVING OR INSTALLING A FUSE.

Make sure that only fuses with the required rated current and of the specified type are used for replacement. The use of makeshift fuses and the short-circuiting of fuseholders are prohibited.

1.1E VENTILLATION

Neither the Model 5205 nor the Model 5206 incorporates forced air ventilation. With a power consumption of less than 60 watts, these instruments can be operated on any laboratory bench. Alternatively, they can be rack mounted, if desired, the only requirement being that the ambient temperature be restricted to the range of 10°C to 40°C.

1.1F DEFECTS

Whenever it is likely that the protection provided by the connection to earth ground has been impaired, the apparatus should be made inoperative and secured against unintended operation. The protection is likely to be impaired if, for example, the apparatus:

- (1) Shows visible damage,
- (2) Fails to perform the intended measurements,
- (3) Has been subjected to prolonged storage under unfavorable conditions, or
- (4) Has been subjected to severe transport stresses.

Such apparatus should not be used until its safety has been verified by qualified servicing personnel.

1.2 TRANSIENT SENSITIVITY

Generally speaking, the design and construction techniques used in equipment manufactured by EG&G are conducive to assuring normal operation

in the presence of moderate transient levels. Although these provisions are sufficient for operation in most places where this equipment is used, it is certainly possible for the transient levels in particular environments to be so severe as to make reliable operation uncertain. High-level transients are usually of the following types.

- (1) **STATIC DISCHARGE TRANSIENTS:** These generally affect input or output circuits. Input circuits that include MOS field-effect transistors to achieve a high input impedance are particularly susceptible to damage from this source. Damage typically occurs when the charge built up on a user's body discharges into an input or output connector as a connection is being made. Among the factors determining the tendency for charges to build are the kind of clothing fabrics worn, shoe materials, and the materials in the floor or floor covering.
- (2) **TRANSIENTS ARISING IN NEARBY EQUIPMENT:** Such transients almost always enter the instrument via the line cord. Possible sources include heavy-duty electric motors, rf equipment, lasers, diathermy machines, arc welders, spark chambers, etc.
- (3) **LIGHTNING:** Unless the equipment is connected to remote sensors, or other devices so located as to be vulnerable to lightning strikes, transients caused by lightning almost always enter the instrument via the line cord.

If a user is having problems due to transient interference, or if operation in a high-transient environment is anticipated, steps should be taken to minimize the transient problem. Static discharge problems can be sometimes avoided by judiciously selecting one's clothing and shoes, or by altering the floor covering in the work area. The simplest approach to the problem is to discharge one's body by touching a grounded metal object immediately prior to touching the instrument, particularly when making connections to it. Transients entering the instrument via the line cord can generally be suppressed by means of external line-transient filters. Suitable devices are commercially available.

1.3 THIS APPARATUS AS A SOURCE OF RADIO FREQUENCY INTERFERENCE

In a typical application, it is unlikely that this apparatus will act as a source of noticeable radio frequency interference. However, when operated near particularly sensitive equipment, interference emanating from this apparatus could be a problem. Should this be the case, steps can be taken to minimize that interference. A discussion of the recommended steps follows.

Interference below about 10 MHz is most likely to be caused by radio-frequency currents flowing in the input and output cables, in the digital interface cables, or in the power line cord. The use of coaxial cables in making the analog signal input/output connection will usually prevent these lines from becoming a source of "below 10 MHz" radio frequency interference. Two approaches are suggested for reducing interference that has its source in the digital interface cables. The first is simply to shield these cables. The second is to provide a heavy ground connection between the grounds of all equipment sharing the interface bus. Practically, this is accomplished by strapping the chassis together with a metal braided or solid strap (solid strap does a better job but is more clumsy; copper, aluminum, or brass are the recommended materials). Because the M5205/6 has an internal low-pass filter connected to the power line, the ac line cord is unlikely to be a source of radio frequency interference. If the internal filter seems to be inadequate, try decoupling the power line with an external filter. At frequencies below 100 kHz, an external isolation transformer could be helpful.

WARNING!

TO REDUCE THE RISK OF POTENTIALLY DANGEROUS ELECTRICAL SHOCK, THIS WORK SHOULD ONLY BE PERFORMED BY A QUALIFIED SERVICE TECHNICIAN, AND THEN ONLY WITH THE INSTRUMENT DISCONNECTED FROM ALL SOURCES OF POWER.

At frequencies above 10 MHz, these measures may not suffice to prevent radiation from being a problem, particularly at the VHF frequencies. Additional measures will then be required. Shielding is generally effective. A suitable shield can be constructed using metal foil, wire screening, or similar materials. Once the apparatus is completely surrounded by the shield (taking care not to unduly restrict ventilation), the only additional requirement is to install low pass filters where lines pass through the shield (all openings through the shield should be as small as possible). A capacitor between a line and the shield can function as a suitable low-pass filter. The leads of the capacitor should be as short as possible. This requirement is optimally satisfied by using coaxial feed-through capacitors. In the case of a signal lead, it is essential that the capacitor's value be such as to attenuate the interference frequencies without unduly attenuating critical frequency components of the signal itself. The need to keep filter capacitor leads short cannot be overemphasized. Long leads establish sizable ground loops and may additionally act as radiating antennae.

Coaxial cables are a special case in that the cable shield acts as an extension of the enclosure shield. This being the case, the filter can be mounted in a shielded box fitted with coaxial connectors without undue concern for keeping the box extremely close to the enclosure. If more convenient to do so, it can be located at some distance from the enclosure as long as the integrity of the coaxial shield is maintained.

The techniques described are extraordinary measures that should be required for unusual cases only. If they are applied with care, radio frequency interference should be reduced to an acceptably low level in all but the most critical applications. However, if these techniques are applied incorrectly, the efforts to reduce the interference could prove disappointing. Users are advised to contact the factory for advice in the case of a problem that does not yield to these measures.

1.4 INTRODUCTION

The Model 5205 (single-phase) and the Model 5206 (two-phase) are the first commercial lock-in amplifiers that can be fully controlled by a computer. An optional Digital Interface allows total programmability of either model (via RS232C or IEEE-488 data links) and talk/listen operation with other devices on the bus. Computer-controllable functions include sensitivity, averaging time constant, phase, operating frequency, offset, dynamic reserve, display mode, and others. Standard features include auto-phasing, auto-ranging, and "sine-wave" response.

Both the Model 5205 and the Model 5206 have a built-in microprocessor that gives these instruments hitherto unavailable power combined with ease of operation. When the autofunction capability is enabled, these instruments can:

- (1) AUTO-SET: Automatically adjust their full-scale sensitivity and phase to match the signal of interest.
- (2) AUTO-NORMALIZE: Set a given output amplitude to represent 100% of full scale. Subsequent measurements are then quantified with respect to the full-scale level thus established.
- (3) AUTO-OFFSET: Automatically supply dc offset so that the output resulting from some given signal level is adjusted to zero.
- (4) AUTO-RANGE: Automatically adjust full-scale sensitivity to maintain maximum output.

Both units incorporate digital and analog displays. A large four-digit display presents measurement results conveniently in terms of voltage,

dB's, or degrees. Also displayable are operating parameters such as the internal-oscillator frequency, the amount of dc output suppression, and the phase shift. An analog meter augments the digital display to allow trend following; a second analog meter on the M5206 also allows simultaneous read-out of additional information. The two mixer channels of the Model 5206 allow it to simultaneously measure the in-phase (X) and quadrature (Y) components of a signal, or to measure the resultant magnitude and phase angle, all with respect to the applied reference. All display functions are under pushbutton control. Moreover, all processing, display modes, and commands associated with the front-panel push-buttons can be controlled by a computer through the optional Digital-Interface card.

Advanced technology has been used in these instruments to provide excellent performance and convenience. For example, "sine-wave" or harmonic-free response at higher operating frequencies is now achieved without degrading the specifications for dynamic reserve and dc output stability. Design innovations in the M5205/6 allow three band-determining cards to be housed simultaneously to achieve an operating frequency range of 0.2 Hz to 200 kHz. A front-panel pushbutton allows convenient selection of the operating band.

Lock-in amplifiers are now the keystone of many analytical and control systems. They are almost a necessity for recovering amplitude and phase information for signals overwhelmed by noise and interference. Together with associated accessories such as light choppers and waveform recorders, these new programmable lock-in amplifiers offer a new sophistication and freedom to both research and industry. With their versatility, precision, and measuring power, both the Model 5205 and the Model 5206 should prove invaluable wherever signal amplitude and phase characteristics are to be measured under difficult conditions.

1.5 SPECIFICATIONS

1.5A SIGNAL CHANNEL

FULL-SCALE SENSITIVITY:

- (1) Model 5205: 1 μ V to 5 V rms, 1-2-5 sequence. $\times 10$ output expansion increases the maximum full-scale sensitivity to 100 nV.
- (2) Model 5206:
 - (a) Channel 1: Same as for Model 5205.
 - (b) Channel 2: 1 μ V to 5 V rms, 1-2-5 sequence.

INPUT IMPEDANCE: AC coupled, 100 M Ω shunted

by 40 pF. Input Connector shell is 10 Ω above chassis ground.

INPUT MODES: Single-ended (A), or differential (A - B).

MAXIMUM DC INPUT: 100 V.

FREQUENCY RANGE: The frequency range is determined by plug-in cards, one for each of the three ranges, BROADBAND (BB), AUDIO FREQUENCY (AF), and LOW FREQUENCY (LF). One, two, or all three of these cards can be installed. A front-panel switch selects the "active" range. The limits for each range are:

BAND	SPECS APPLY	OPERATES OVER
BB	200 Hz-200 kHz	2 Hz-200 kHz
AF	20 Hz-20 kHz	2 Hz-20 kHz
LF	0.2 Hz-2 kHz	0.2 Hz-2 kHz*

Figures I-2, I-3, I-4, and I-5 show the effect the choice of F BAND has on the pre-PSD (phase-sensitive detector) characteristics of the instrument.

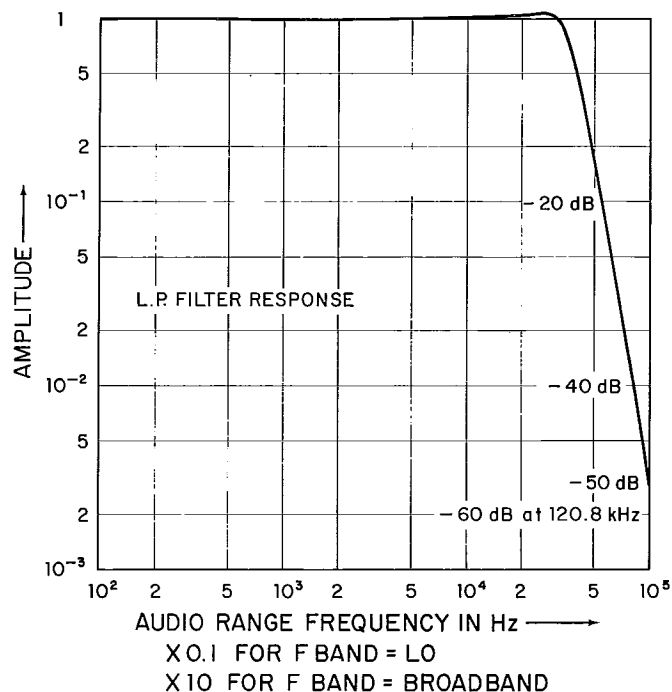


Figure I-2. TYPICAL LOW-PASS FILTER RESPONSE AS A FUNCTION OF F BAND

*The lower limit of the operational LF range is 2 Hz (standard) or 0.2 Hz (optional). Because the response time of the 0.2 Hz option is much slower than that of the 2 Hz standard LF card, users are advised to purchase the 2 Hz lower limit card unless they intend to operate below that frequency.

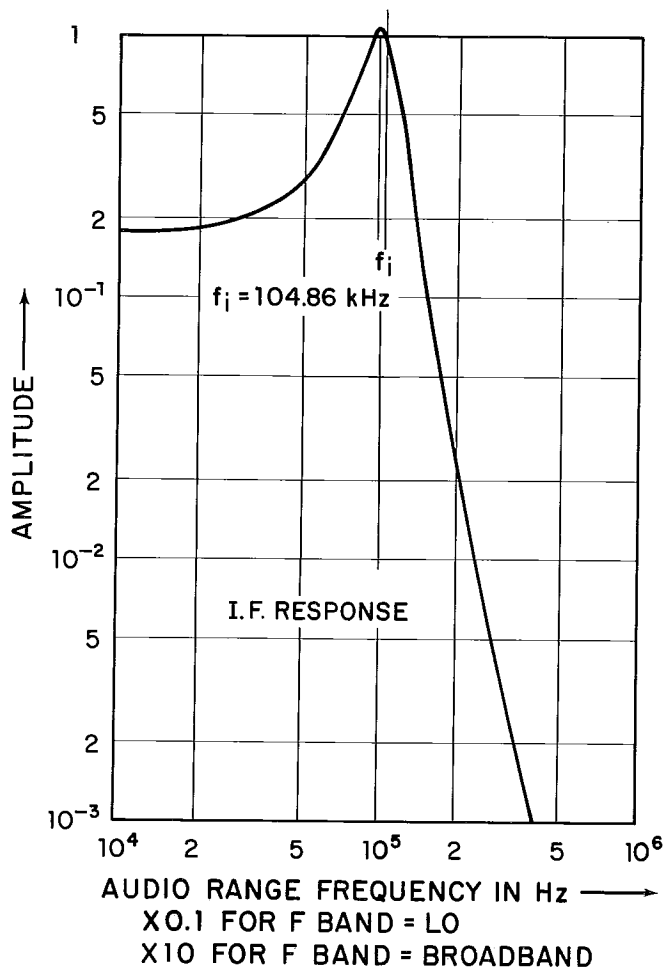


Figure I-3. TYPICAL I.F. AMPLIFIER RESPONSE AS A FUNCTION OF F BAND

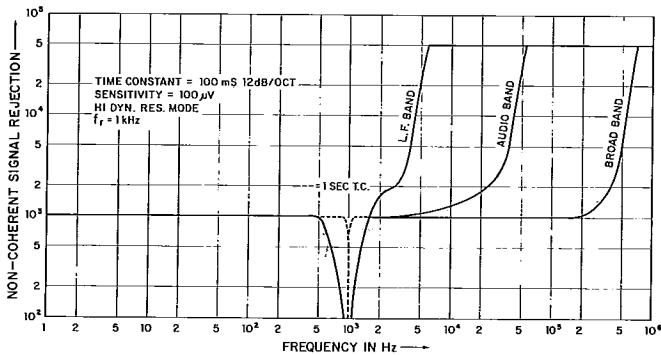


Figure I-4. TYPICAL NOISE REJECTION CHARACTERISTICS AS A FUNCTION OF F BAND

INTERNAL NOISE (shorted input): 5 nV rms per root Hz, typical, at 1 kHz.

COMMON-MODE REJECTION RATIO (CMRR): 100 dB at 1 kHz.

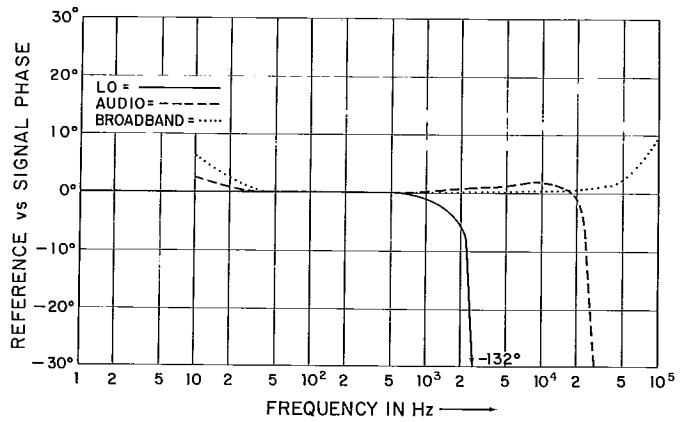


Figure I-5. TYPICAL PHASE SHIFT AS A FUNCTION OF F BAND

MAXIMUM COMMON-MODE INPUT: 5 V rms sine wave.

GAIN STABILITY: ± 200 ppm/°C; ± 200 ppm/24 hours.

DYNAMIC RESERVE:* Three different levels can be selected, as follows.

- (1) High Stability: 20 dB
- (2) Normal: 40 dB
- (3) High Reserve: 60 dB

1.5B REFERENCE CHANNEL

FREQUENCY RANGE: 0.2 Hz to 200 kHz; frequency coverage is determined by operator-selected cards (BB, AF, or LF).

MODES OF OPERATION:

- (1) EXTERNAL: Reference locks onto and tracks the frequency (2 Hz** to 200 kHz) of external reference source. There are two variations of this mode. "F", in which demodulation occurs with respect to the reference frequency, and "2F", in which demodulation occurs with respect to twice the reference frequency. Critical reference channel parameters are:

- (a) INPUT IMPEDANCE: 10 MΩ shunted by 30 pF.

*Dynamic Reserve is defined as the ratio, in decibels, of the maximum rms voltage of an interfering sine wave, just before overload, to the full-scale sensitivity setting. In no case should the interfering signal (noise) exceed 14 V pk-pk. Dynamic reserve depends on the sensitivity setting and the frequency structure of the interfering noise.

**When operating with LF card, range extends to 0.2 Hz.

- (b) **WAVEFORM REQUIREMENTS:** Symmetrical signals having equal excursions above and below ground.
- (c) **AMPLITUDE REQUIREMENTS:** 140 mV to 2 V pk-pk. Indicator light (REFERENCE LOW) glows if amplitude of applied reference signal is too low.
- (d) **ACQUISITION TIME:**
 100 Hz or higher: 5 s maximum.
 10 Hz: 18 s maximum.
 1.0 Hz: 60 s maximum.

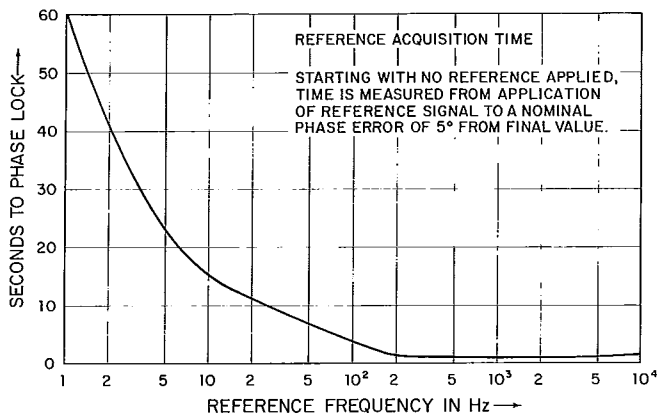


Figure I-6. TYPICAL ACQUISITION TIME

- (e) **MAX. SLEW RATE:** Externally derived reference signal can be slewed in frequency as fast as one decade per fifty seconds with no more than 5° phase offset while the frequency shift is in progress.

- (2) **INTERNAL (optional):** Reference channel is driven at the frequency (2 Hz to 100 kHz) of the internal oscillator. Specifications for oscillator option are provided in Subsection 1.5H.

PHASE-SHIFT CHARACTERISTICS:

- (1) **PHASE-SHIFT CONTROL:** 90° steps, accurate to 0.1°, and "continuous" control in 0.025° steps over the range of 0 to 359.975°. Advances phase of demodulator drive signal relative to signal-channel input.
- (2) **PHASE NOISE:** 5 millidegrees rms at 1 kHz, 300 ms time constant (-12 dB/octave).
- (3) **PHASE DRIFT:** 30 millidegrees per degree Celsius.
- (4) **PHASE ORTHOGONALITY (Model 5206):** The Channel 1 and Channel 2 demodulating signals are orthogonal. Deviation from true orthogonality (90°) depends on the selected frequency card, as follows.

CARD	ORTHOGONALITY
LOW FREQUENCY.....	90° + 0.1°
AUDIO FREQUENCY.....	90° + 0.2°
BROADBAND.....	90° + 0.5°

1.5C PHASE-SENSITIVE DETECTORS

DYNAMIC RESERVE/DC OUTPUT STABILITY: The following table applies to the Model 5205 and to Channel 1 of the Model 5206 (x10 Expand function "off"). If the x10 Expand function is "on", numbers are increased by x10 (add 20 dB to Dynamic Reserve values).

Dynamic Res. Setting	Dynamic Reserve (dB)	Output Drift (ppm/°C)
HIGH RES	60	1000
NORMAL	40	100
HIGH STAB	20	20

Table I-1. DYNAMIC RESERVE AND OUTPUT DRIFT

FILTER TIME CONSTANTS: 1 ms to 100 s in 1-3-10 sequence.

FILTER ATTENUATION RATE: -6 or -12 dB/octave, switchable.

ZERO SUPPRESSION: The signal in the Model 5205, and the Channel 1 signal ("X" and "R") in the Model 5206, can be offset as follows.

- (1) x10 Expansion OFF: ±1 x full scale.
- (2) x10 Expansion ON: ±10 x full scale.

HARMONIC REJECTION: 55 dB or higher.

OVERLOAD INDICATOR LIGHTS:

- (1) Model 5205: Signal pre-mixer channel and output.
- (2) Model 5206: Signal pre-mixer channel, "X" (in phase) output, and "Y" (quadrature) output.

1.5D AUTOMATIC FUNCTIONS

AUTORANGE: Provides automatic and continuous ranging of ac and dc gain.

AUTOSET: Automatically sets the M5206 initial phase and sensitivity. The phase setting can be read on the digital display.

AUTO-OFFSET: Automatically sets the output voltage to zero and holds the offset. The offset value may be read on the digital display.

AUTO-NORMALIZE: The output voltage is normalized to full scale when this function is selected. Subsequent readings are, therefore, referred to full scale, and the display annunciation is switched off.

1.5E MODEL 5205 OUTPUTS

ANALOG METER:

- (1) READINGS: Full-scale deflection for a full-scale input as determined by the combination of the input sensitivity setting and the output expansion.
- (2) METER STYLE: 3" mirrored center-zero scale, $\pm 2\%$ error (maximum).

DIGITAL METER:

- (1) Readings:
 - (a) Demodulator Output.
 - (b) Phase-shifter settings (0–359.9°).
 - (c) Internal-oscillator reference frequency.
 - (d) Zero Suppress Offset, 0 to 100% of full scale.
 - (e) Auxiliary outputs from plug-in options.
 - (f) Error Messages.
- (2) Meter Style: Four-digit display (0.56" high), with polarity sign.

BNC CONNECTOR: Parallels analog meter; full scale = ± 10 V dc, 600 Ω output impedance.

1.5F MODEL 5206 OUTPUTS

ANALOG METERS (two, one for each channel):

- (1) Channel 1 Readings:
 - (a) "X" (in-phase signal component).
 - (b) "R" (resultant or magnitude).
 - (c) Log R (dB reading of signal magnitude relative to full scale; 0 to –60 dB useful range).
- (2) Channel 2 Readings:
 - (a) "Y" (quadrature signal component).
 - (b) Phase angle: Phase of signal (with respect to reference) minus phase offset introduced with Phase controls.
- (3) Meter Style: Two-inch mirrored center-zero scale, $\pm 2\%$ error (max).

DIGITAL PANEL METER:

- (1) Displayable Parameters:
 - (a) "X", "Y", "R", log R, and Phase.

- (b) Phase shifter settings.
- (c) Internal-oscillator reference frequency.
- (d) Channel 1 Zero Suppress Offset, 0 to 100% of full scale.
- (e) Auxiliary outputs from plug-in options.
- (f) Error Messages.

- (2) Meter Style: Four-digit display (0.56" high), with polarity sign.

BNC CONNECTORS (Channel 1 and Channel 2): Connectors parallel corresponding analog meters; full scale = ± 10 V dc, 600 Ω output impedance. During log R operation, the calibration factor is –10 dB/volt (–60 dB max.). Phase readings are calibrated as ± 50 mV/degree (± 9 V max).

1.5G GENERAL

AUXILIARY POWER OUTPUT: ± 15 V, 50 mA for remote or plug-in preamplifier.

OPERATING TEMPERATURE RANGE: 10°C to 40°C.

POWER REQUIREMENTS: 95–130 V ac, 60 Hz; 190–260 V ac, 50 Hz; 60 watts.

SIZE: 17-1/2" W x 22" D x 5-1/4" H (44.5 x 55.9 x 13.3 cm).

WEIGHT: 25 lb (11.3 kg).

1.5H CHASSIS PLUG-IN OPTIONS

INTERNAL OSCILLATOR (Models 5205/94 and 5206/94):

- (1) FREQUENCY RANGE: Continuously variable over six decade bands (0.1 to 1 Hz), 1 to 10 Hz, 10 to 100 Hz, 100 Hz to 1 kHz, 1 kHz to 10 kHz, and 10 kHz to 100 kHz). Frequency resolution is determined by a ten-bit (1/1000) Digital-to-Analog Converter (DAC) at each selected band.
- (2) AMPLITUDE: Rear-panel potentiometer allows adjustment of 0 to 5 V rms.
- (3) SECOND-HARMONIC DISTORTION:
 - (a) 10 Hz: 0.5%
 - (b) 1 kHz: 0.3%
 - (c) 100 kHz: 2%
- (4) OUTPUT IMPEDANCE: 600 Ω .

DIGITAL INTERFACE (Models 5205/95 and 5206/95): This option allows the lock-in amplifier

to communicate with a system via both IEEE-488 and RS232C data links.

- (1) INTERFACE FUNCTIONS: Complete source and acceptor handshakes, basic talker with serial poll, complete service request.
- (2) INSTRUMENT FUNCTIONS CONTROLLED: Sensitivity, expand, time-constant, phase, reference mode, internal oscillator frequency, dynamic reserve, frequency-range card, zero offset, autofunctions, display selection, and all other front-panel settings.

BROADBAND PLUG-IN CARD (Models 5205/97 and 5206/97): See Signal Channel FREQUENCY RANGE specifications.

AUDIO FREQUENCY PLUG-IN CARD: See Signal Channel FREQUENCY RANGE specifications.

LOW FREQUENCY PLUG-IN CARD (Models 5205/99 and 5206/99): See Signal Channel FREQUENCY RANGE specifications.

1.6 DESCRIPTION

1.6A INTRODUCTION

The Model 5205/6 is a heterodyning lock-in amplifier. Input signals at the reference frequency are mixed with an internally developed signal derived from the reference signal. The resulting sum and difference frequency signals are applied to a quasi-resonance filter to remove the upper sideband. The difference frequency is then processed as the information signal. This approach allows the use of narrow-band fixed-frequency filters while still allowing operation over a wide frequency range. The functioning of the M5205/6 is discussed in greater detail in the following paragraphs, which are keyed to Figure I-7, a simplified block diagram of the M5206. This figure can be readily adapted to the M5205 by simply deleting those blocks that denote functions provided in the M5206 but not in the M5205.

1.6B SIGNAL CHANNEL

Input signals are first applied to an internal pre-amplifier. This circuit, together with the accompanying gain switching amplifiers and attenuators, buffers the signal and helps set its amplitude at the input to the signal mixer. Next is the low-pass filter. Its purpose is to pass all signals in the passband of the selected frequency range, while very sharply attenuating signals above the passband of the range. As indicated in the figure, the 3 dB down frequency in BROADBAND operation is 400 kHz. In AUDIO operation it is 40 kHz and in LO it is 4 kHz. Not only does this fast-rolloff filter reduce the total noise bandwidth of the instrument and thereby contribute to the improvement in signal-to-noise ratio achieved, but it provides a

very great attenuation of signals at image frequencies, thereby eliminating a significant source of measurement error.

The low-pass filter is followed by some more gain switching circuits. Their output, which includes the signal of interest at the reference frequency, f_r , together with noise and interference, is applied to one input of the Signal Mixer. The output of the Reference Channel is applied to the mixer's other input. This signal is at $f_r + f_i$, where f_r is the reference frequency and f_i is the intermediate frequency (i.f.). The Signal Mixer has the sum $[f_r + (f_r + f_i)] = 2f_r + f_i$ and difference $[f_r - (f_r + f_i)] = f_i$ frequencies as its output. The sum frequency is removed by the following I.F. Amplifier, which, as shown in the figure, has a quasi-resonance response. Below the resonant frequency, the response rolls off steeply to provide a great attenuation of frequencies above f_r . The effect is to further reduce the noise bandwidth, thereby improving the signal-to-noise ratio ahead of the phase-sensitive detectors. Also, in the same manner that the post-preamp low-pass filter eliminated the image frequencies as a source of error, the I.F. Amplifier attenuates the harmonics, removing them as a potential source of measurement error. Note that the intermediate frequency is different for each of the frequency bands. In the BROADBAND mode it is nominally 1 MHz. In AUDIO it is 100 kHz, and in LOW it is 10 kHz. The lower the selected passband, the lower the noise bandwidth is ahead of the phase-sensitive detectors, and the better the performance of the instrument with regard to improvement in signal-to-noise ratio.

Thus the Signal Mixer accepts synchronous input signal at the reference frequency and transposes it to the I.F. frequency, which is 10 kHz, 100 kHz, or 1 MHz, according to the selected F BAND. At the output of the Signal Mixer, noise components will be the same number of cycles above or below the I.F. frequency as they are at the signal channel input. However, due to the effects of the Lo Pass Filter and the I.F. Amplifier, noise components above the intermediate frequency will be greatly attenuated. The Lo Pass Filter suppresses image frequency input components and the I.F. Amplifier suppresses harmonics. Together they reduce measurement errors from these sources.

1.6C REFERENCE CHANNEL

The actual reference channel circuitry, even at the block diagram level, is far more complex than depicted in Figure I-7 and described here. Nevertheless, this description should aid the reader in getting a "feel" for how the reference channel function is achieved.

Referring to Figure I-7, note that the applied reference signal is buffered and then applied to a Phase Detector. Also applied to the Phase Detector is the output of a Low-Pass Filter, which, in

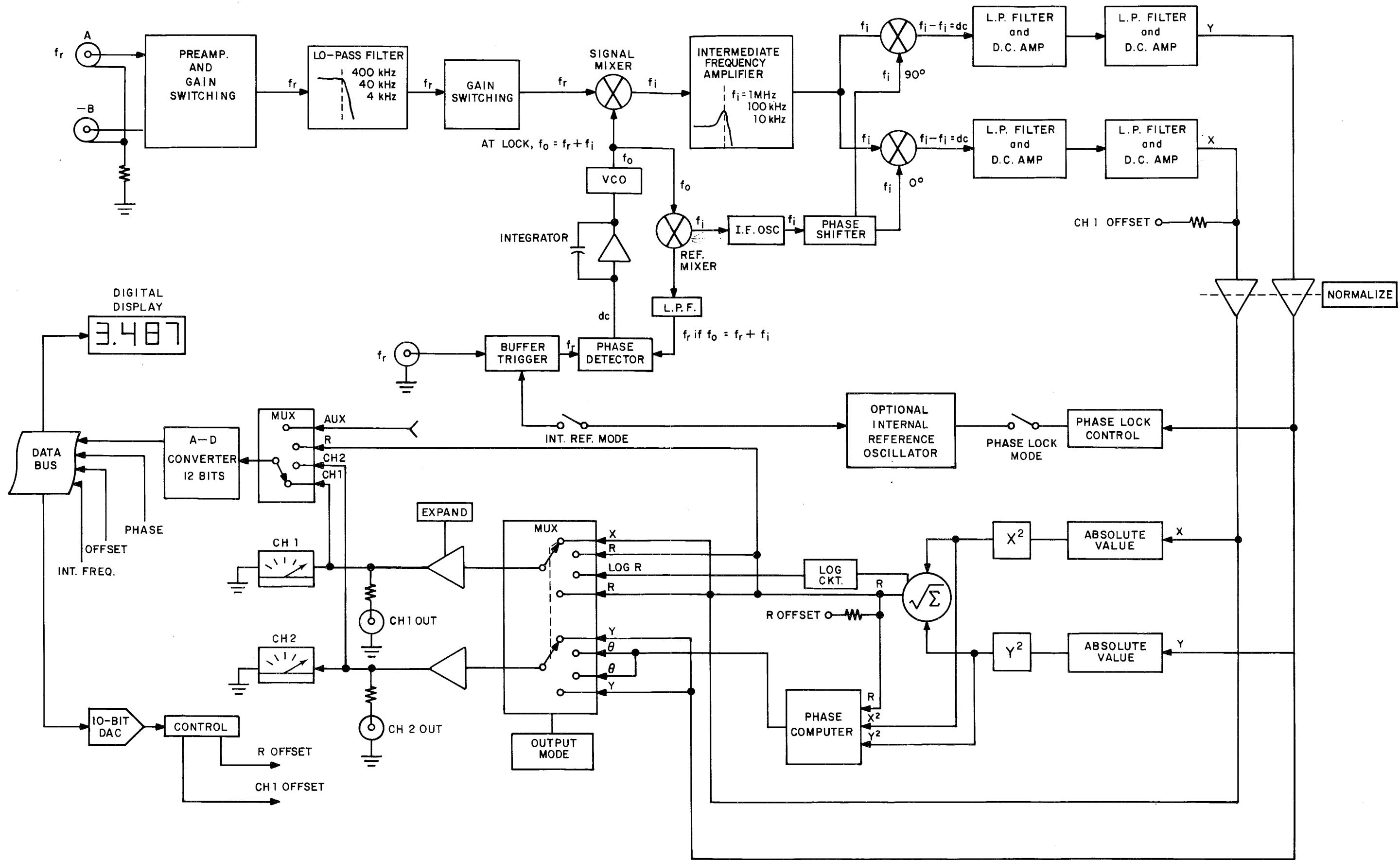


Figure I-7. SIMPLIFIED BLOCK DIAGRAM

turn, is driven by the Reference Mixer. If the output of the Low-Pass Filter is a signal at f_r , the case when frequency-phase lock is established, there will be no output from the Phase Detector. If the output of the Low-Pass Filter is not at f_r , there will be a net dc output from the Phase Detector. The Phase Detector output is applied to an integrator, which controls a Voltage Controlled Oscillator (VCO). When there is zero Phase Detector Output, the output of the VCO is constant. If there is a net Phase Detector Output, the output of the VCO will be driven in the direction necessary to restore reference lock.

Note that the VCO output drives the Signal Mixer. It is additionally applied to one input of the Reference Mixer, which has as its other input the output of the I.F. Oscillator. The I.F. Oscillator generates a signal at the I.F. Frequency, 1 MHz, 100 kHz, or 10 kHz. This signal is mixed with f_o , the output of the VCO, providing sum and difference frequencies. The sum frequency is removed by the Low-Pass Filter. At reference lock, f_o equals $f_r + f_i$. When this is the case, the frequency at the output of the Low-Pass Filter will simply be the difference frequency, f_r . The loop will always operate to establish and maintain this condition. As a result, the Signal Mixer will have applied to it the signal of interest at f_r and the reference signal at $f_r + f_i$. The difference frequency out of the Signal Mixer will be at f_i . This frequency is passed by the I.F. Amplifier and applied to the Demodulators. The Demodulators are driven at f_i by the I.F. Oscillator. A Quadrature Phase Shift circuit is interposed between the I.F. Oscillator and the Demodulators. The Phase Fine Adjust circuit, not shown, operates on the f_o drive to the Signal Mixer.

1.6D OUTPUT CHANNEL

The signal out of the I.F. Amplifier is applied to the Phase Sensitive Detectors. These detectors are driven by a signal at the I.F. frequency produced in the Reference Channel as previously described. The two drives are in quadrature, that is, they are always at 90° with respect to each other. Thus, while one detector demodulates at 0° , the other demodulates at 90° . The phase of the drive signals can be shifted in increments of 90° (Coarse Phase Adjustments). The Fine Phase Adjustment works on the drive to the earlier described Signal Mixer. The coarse and fine phase adjustments are used to establish the desired phase relationships at the two Phase Sensitive Detectors. Usually, the phase is set so that the signal input to these detectors will be in phase with the drive to one of them and 90° out of phase with the drive to the other.

Like the previously described mixers, the Phase Sensitive Detectors have sum and difference frequencies at their output. Since the signal and drive inputs to these detectors are at the same frequency, the difference output is at 0 Hz, that is,

dc. The magnitude of the dc varies directly with the magnitude of the applied signal frequency and with the cosine of the angle between the signal and drive frequency. Thus, the output will be maximum when the signal is at 0° with respect to the drive, and zero when the signal is at 90° with respect to the drive. The sum component at twice the I.F. frequency will also be present. This component, together with asynchronous noise and interference, is removed by the low-pass filters that follow. There are two filters in each channel. If 6 dB/octave is selected, one filter is "in". If 12 dB/octave is selected, both are "in". The passband is set by the user-selected time constant. The larger the time constant, the greater the noise suppression. Most of the improvement in signal-to-noise ratio achieved by the instrument is provided by these filters. When the phase adjustments have been properly made, the filter output in Ch 1 will be a dc voltage proportional to the rms amplitude of the fundamental frequency component of the synchronous input signal. The filter output of Ch 2 will be zero because of the cosine response of the phase sensitive detector. If the phase relationships at the phase sensitive detectors are other than 0° and 90° , both channels will have non-zero output levels.

The filter outputs are applied to normalizing amplifiers. If the NORMALIZE capability has not been activated, the gain of these amplifiers is fixed so as to provide correct output levels with respect to the selected full-scale sensitivity. On the other hand, if NORMALIZE has been activated, the gain of these amplifiers will be automatically servoed to the value required to give full-scale output ("R" OUT in M5206) for the given input level. Note that the Ch 1 Offset voltage is applied to the Ch 1 Normalizing Amplifier.

These amplifiers are followed by the circuits that develop the various output functions. The magnitude function, R, is developed by taking the square root of the sum of the squares of the individual X and Y output levels. "R" then serves as the input to a Log Converter to generate the LOG R function. A Phase Computer develops a voltage proportional to θ , the angle between the signal applied to the "In-Phase" Phase Sensitive Detector and the reference drive to that detector.

As shown in Figure I-7, these different functions are applied to the Output Mode Multiplexer, which determines which functions will be displayed on the analog meters and provided at the OUTPUT connectors. The Ch 1 and Ch 2 output functions are made available to another Multiplexer, together with "R" and the AUX input line. This multiplexer selects which analog function is to be routed to the input of an A/D Converter. The output of the A/D Converter is placed on the Data Bus. Other inputs to the bus include the Phase setting, the set value of Offset, and the set fre-

quency of the optional Internal Oscillator. The parameter selected with the Display key is routed to the Digital Panel Meter for display. Note that the data bus also drives a ten-bit digital-to-analog converter. This converter receives the digital Offset information and develops from it proportional

analog voltages. The Ch 1 Buffer amplifier that follows the Output Mode Multiplexer provides the Expand function. The R Offset voltage is summed with the R input on the appropriate input line of the Output Mode Multiplexer.

SECTION II INITIAL CHECKS

2.1 INTRODUCTION

The following procedure checks the performance of the M5205/6. In general, this procedure should be performed after inspecting the instrument for obvious shipping damage (any noted to be reported to the carrier and to EG&G PARC; take care to save the shipping container for inspection by the carrier). Note that the procedures that follow are not intended to demonstrate that the instrument "meets specs", but rather to simply demonstrate that it has arrived in good working order. Each instrument receives a careful checkout before leaving the factory, and ordinarily, if no shipping damage has occurred, will perform within the limits of the specifications. If any problems are encountered in carrying out these checks, contact the factory or the authorized factory representative in your area for aid.

2.2 EQUIPMENT REQUIRED

- (1) Sine Wave Oscillator to provide 1 V rms sine wave at 1 kHz.
- (2) Suitable cables for connecting the oscillator output to the signal and reference inputs of the lock-in amplifier.

2.3 PROCEDURE

2.3A LINE VOLTAGE

- (1) Check the position of the rear-panel Voltage Selection switch. For operation from a line voltage of nominally 115 V, "115" should show in the switch "window". For operation from a line voltage of nominally 230 V, "230" should show.
- (2) Plug the line cord into an appropriate source of power.

2.3B TEST CONNECTIONS

- (1) Set the M5205/6 Input switch to the "A" position.
- (2) Turn on the external oscillator and adjust it for a 1 V rms output signal at 1 kHz.
- (3) Connect the oscillator output to both the REFERENCE and "A" inputs of the lock-in amplifier.

2.3C TURN ON SEQUENCE

- (1) Set the POWER ON switch to ON.
- (2) Observe the digital display. It should remain dark for about a second after the power switch is set to ON. Then the model number,

5205 or 5206, should appear for a second or two. After the model number extinguishes, the display indication will be indeterminate because the "turn on" control settings are those in effect at the time the instrument was last operated.

2.3D TEST CONTROL SETTINGS

- (1) Press the AUTOFUNCTION SELECT key and, while it is held in, press the SENSITIVITY key, thereby selecting the default values for the front-panel controlled parameters. (This operation is referred to as doing a DEVICE CLEAR. **NOTE:** If the unit is NOT equipped with the AUDIO FBAND card, ERR1 will be briefly displayed. FBAND card selection takes place in step 4.)
- (2) Press the MODES key as necessary to light the RESERVE LED.
- (3) Press the MODES key as necessary to light the FBAND LED.
- (4) Press the SET up-arrow or SET down-arrow key as necessary to light the BROAD BAND LED, if the unit is equipped with the broad-band circuit card. If the unit is not equipped with the broad-band circuit card, advance the lighted position to AUDIO or LOW, whichever applies. If the unit is equipped with both the audio and the low-frequency cards (but not with the broad-band card), select AUDIO.
- (5) Press the TIME CONSTANT key as necessary to light the SET LED.
- (6) Press the SET down-arrow key as necessary to light the "30" and "ms" LED's.
- (7) Press the SENSITIVITY key as necessary to light the SET LED.
- (8) Press the SET down-arrow key as necessary to light the "1" and "V" LED's.

2.3E PHASE

- (1) Press the PHASE key as necessary to light the 90° LED.
- (2) Press the SET up-arrow or SET down-arrow key as necessary to light the 270°-360° LED.
- (3) Press the PHASE key again to light the FINE LED.
- (4) Observe the analog meter indication (Channel 1 meter in the M5206) and, while so doing, tap the SET up-arrow or down-arrow key as neces-

sary to get a meter indication of "0". Should you overshoot the optimum point, use the "other" SET arrow key to reverse direction.

- (5) Press the PHASE key, thereby lighting the 90° LED.
- (6) Press the SET up-arrow one time. The meter indication should go to positive full scale, indicating an input signal level of 1 V rms. Similarly, the digital display should indicate 1.000 V. Note that the sensitivity tolerance of the lock-in amplifier as well as the output tolerance of the external oscillator could cause the actual indication to vary some from the ideal 1 V level.
- (7) Press the DISPLAY key as necessary to light the PHASE LED. The digital panel meter should display the phase shift introduced to bring the input and reference signals into phase at the input of the phase-sensitive detector. Since the same signal was applied to both inputs, the requisite phase shift should be approximately 0° or 360° (depending on the direction of the residual error) and the display should indicate this value. Some phase difference between the reference and signal channels will be present, and the actual phase shift required to bring the two signals into phase will be other than 0° (360°). If the instrument being checked is a Model 5205, press the DISPLAY key as required to light the OUTPUT LED and go to Subsection 2.3F. If a Model 5206, go to step 8.
- (8) Press the OUTPUT MODE key as necessary to light the R, θ LED. The CHANNEL 1 meter should indicate full scale (plus or minus the signal level and sensitivity tolerances) and the CHANNEL 2 meter should indicate the *difference* angle at the input of the Phase Sensitive Detector. That angle will be approximately 0° if the phase adjustments were properly made. This angle can also be displayed with greater sensitivity on the digital panel meter by pressing the DISPLAY key as necessary to light the CH 2 LED. If desired, the user may touch up the phase setting (PHASE FINE LED must be lighted; press the SET up-arrow or down-arrow key to adjust the

phase as required). When satisfied with the phase indication, leave the CH 1 and X,Y LED's lighted. **NOTE:** In an actual measurement, a more accurate phase setting will result if the fine phase adjustment is made for exactly zero Y output, rather than for zero θ .

- (9) Press DISPLAY until OUTPUT (M5205) or CH 1 (M5206) is lighted.

2.3F OFFSET AND EXPAND

- (1) Disconnect the input signal from the "A" connector. The meter indications should zero.
- (2) Press the OFFSET key (CH 1 OFFSET in the M5206) as required to light the POLARITY LED. Then press the SET up-arrow key as required to light the "+" LED. Next press the OFFSET key again to light the SET LED. Then press the SET up-arrow key as required to obtain a digital panel meter indication of +0.100. The analog meter (CH 1 meter in the M5206) should indicate positive 10% of full scale.
- (3) Press the EXPAND key (CH 1 EXPAND in the M5206). The $\times 10$ EXPAND LED should light, indicating that an additional factor of ten gain has been introduced. The digital panel meter should still indicate ≈ 0.100 and the analog meter (CH 1 analog meter in the M5206) should deflect full scale to the right.
- (4) Press the EXPAND key again, thereby extinguishing the $\times 10$ EXPAND LED. Then press the OFFSET key (CH 1 OFFSET in the M5206) as required to extinguish SET and light POLARITY. Next, press the SET up-arrow or down-arrow key as required to extinguish the "+" LED. Be sure the "-" LED is off as well (when both polarity indicators are extinguished, the Offset Function is turned OFF).

This completes the Initial Checks. If the indicated behavior was observed, the user can be reasonably sure that the unit incurred no "hidden" shipping damage and is in good working order. Users are not advised to make more detailed evaluations of the instrument's performance without first reading Section IV, OPERATING INSTRUCTIONS.

SECTION III CONDENSED OPERATING INSTRUCTIONS

3.1 INTRODUCTION

The instructions contained in this section are provided as an operator convenience. Their principal utility is as an aid to someone who already has an operating knowledge of the instrument, but who may feel the need for a quick review before going ahead. This section is not intended to meet the requirements of the first-time operator. Many considerations of critical importance in particular applications are bypassed for the sake of brevity, making it essential that the user read Section IV to be assured of optimum measurement results. Note that these condensed operating instructions are confined to control via the front-panel keys. Computer controlled operation is too complex for the level of discussion in this section.

3.2 INSTALLATION

The Model 5205/6 can be operated in most laboratory environments. The power requirements and temperature range are stated in the specifications.

3.3 USE

The Models 5205 and 5206 are lock-in amplifiers, best described as high sensitivity, high performance ac voltmeters. They respond to the rms amplitude of the fundamental frequency component of the input signal, and read out in rms units. Through the use of phase-sensitive detection and averaging, these instruments are able to accurately measure the amplitude of minute signals masked with noise. The phase-sensitive detection process requires that a second signal, referred to as the reference signal, be applied as well as the signal to be measured. The reference signal must be synchronous with the signal to be measured, must be "clean", and must be at a fixed phase with respect to it.

3.4 DEFAULTS

At power up, the Model 5205/6 does not "default" to factory-determined values for each operating parameter. Instead, it "remembers" the values in effect the last time it was operated. Nevertheless, default values are available. Once the unit is powered up, they can be established by simply pressing the SELECT key, and, while it is held in, momentarily pressing the SENSITIVITY key (DEVICE CLEAR function). The defaults are:

FRONT-PANEL PARAMETERS	DEFAULT
DISPLAY (M5205).....	OUTPUT
DISPLAY (M5206).....	CH 1
OFFSET (M5205).....	ZERO and OFF

CH 1 OFFSET (M5206).....	ZERO and OFF
RESERVE.....	HIGH STAB
F BAND.....	AUDIO*
REFERENCE.....	EXT. F
OSCILLATOR (option).....	40 kHz
PHASE.....	0°
TIME CONSTANT.....	100 ms
dB/OCTAVE.....	6
SENSITIVITY.....	.5 V
AUTO-FUNCTIONS.....	all OFF
OUTPUT MODE (M5206).....	X,Y
EXPAND (M5205).....	OFF
CH 1 EXPAND (M5206).....	OFF

INTERFACE PARAMETERS

SRQ MASK.....	0
PROMPT.....	ON
ACKNOWLEDGMENT.....	OFF
DELIMITER.....	comma

When the M5205/6 is powered up, the front-panel LED's indicate the "remembered" parameter selections. They may or may not be suited to the intended measurement. If they are "closer" to the desired settings than the default values, don't do a DEVICE CLEAR. If the default values are closer, do a DEVICE CLEAR (press SELECT and SENSITIVITY).

Since these Condensed Instructions apply to LOCAL operation only, if the REMOTE LED is lighted, do a DEVICE CLEAR before proceeding. If SRQ is lighted, it means that the M5205/6 was requesting a service request when it was last turned off, and that the service request simply continued when the instrument was turned back on. The fact that there is a service request will not interfere with LOCAL operation. However, if the instrument is connected to a computer, it might be advisable to do a DEVICE CLEAR, terminating the service request, and reducing the possibility of interference by the computer.

3.5 CONNECTIONS

The reference signal should be connected to the REFERENCE INPUT connector. This signal must be at the frequency of the signal to be measured and at a fixed (but not necessarily the same) phase with respect to it. A 1 V rms sine wave or square wave is optimum. However, reference signals as small as 140 mV pk-pk can be used. The signal to be measured is applied to the connector(s) at the right of the front panel. For a single ended measurement, set the Input Selector switch to "A" and connect the signal to the "A" Input. For differential measurements, set the Input Selector switch to "A - B", and connect the signal differentially to the "A" and "B" Inputs.

*If the AUDIO card is not present, ERR1 will be displayed briefly. The user will have to select BROADBAND or LOW, as appropriate.

3.6 OPERATION

The parameters are set by means of the front-panel keys. For most parameters, the SET up-arrow and down-arrow keys are used in conjunction with the Parameter Selection key to make the user's selection or set an operating value. Since the underlying assumption of these condensed operating instructions is that the user has some operating familiarity with the instrument, the specific details of how these keys are used and interact are not provided here. Detailed information on the use of all keys is provided in Section IV. The following text suggests a general approach to making the required selections.

- (1) DISPLAY: Usually, the best approach is to begin by monitoring the output. This is done by selecting OUTPUT (M5205) or CH 1 OUTPUT (M5206).
- (2) EXPAND: Begin with the EXPAND OFF. It can be activated at any time, if necessary.
- (3) OUTPUT MODE (M5206 only): Begin with X,Y selected. Other viewing modes can be selected later, if required.
- (4) OFFSET (CH 1 OFFSET in M5206): Begin with the OFFSET OFF, that is, neither Offset "+" nor Offset "-" should be lighted.
- (5) MODES: This key is used in specifying the frequency range and dynamic reserve capabilities of the instrument. The F BAND selected must correspond with the F BAND circuit card in the unit. Every unit will have at least one. Some may have two or all three. In units having one card only, the card is most probably the BROAD BAND card, which works well in most applications. The initial reserve selection should be made on the basis of the amount of noise accompanying the signal. If the signal is essentially noise free, select HIGH STAB. If the signal is moderately noisy, select NORMAL. If the signal is very noisy, select HIGH RESERVE. Note that each reserve setting works over a range of Sensitivity settings as opposed to working with all Sensitivity settings. Sensitivity dominates. If the user tries to select a reserve setting that is incompatible with the Sensitivity setting, that attempt will be unsuccessful and a compatible reserve value will remain selected. The user will have to change the selected sensitivity to use the desired reserve range. If the sensitivity is later changed to one that is incompatible with the selected reserve, the reserve will be changed automatically to an acceptable setting.
- (6) REFERENCE: For most measurements the user will want to select the EXT F mode. The EXT F/2 mode is used for second harmonic measurements. In the INT mode, the lock-in amplifier is the source of the reference signal. To use this mode, the instrument must be equipped with the Internal Oscillator option. Internal reference mode operation is outside the scope of these condensed operating instructions.
- (7) PHASE: The phase adjustments are used to bring the input signal and the reference signal into phase at the input of the phase sensitive detector. When they are in phase, the output is maximized (CH 1 Output in the M5206). Phase and Sensitivity are usually adjusted alternately. First the Sensitivity is adjusted for an output indication. Then the Phase setting is roughly adjusted for a peak. The Sensitivity can then easily be changed to optimize the output indication, if necessary, after which the Phase adjustment can be brought "right on". In the case of the Model 5206, better Phase setting sensitivity and accuracy is obtained by adjusting for "0" on the CH 2 meter instead of for maximum on the CH 1 meter. This technique can also be used with a Model 5205. The user simply adjusts for "0" with the Phase controls (first adjust for a rough peak to be sure the Sensitivity setting is reasonable), followed by incrementing the phase by 90° in one step to establish the final peak reading.
- (8) TIME CONSTANT: The higher the time constant, the greater the noise reduction the instrument achieves, but at the expense of increased response time. A time constant of 30 ms is generally a good value to use at the start. It's long enough to give good noise reduction, but not so long as to unduly degrade the response time. As for the rolloff rate, try 6 dB/octave initially. If the noise at the output is still too high, the time constant can be increased and/or the rolloff rate increased to 12 dB/octave.
- (9) SENSITIVITY: The optimum sensitivity setting is the one which yields the highest on-scale reading consistent with preventing input overload from noise accompanying the signal. Should overload occur, a higher reserve setting can be selected. If the overload persists, a lower sensitivity can be selected. The resulting loss in output can sometimes be compensated for by use of the EXPAND capability.
- (10) AUTOFUNCTIONS: The AUTORANGE and AUTOSSET auto-functions can greatly simplify the measurement taking process. The AUTORANGE function automatically adjusts the Sensitivity every six time constants (6 dB/octave) or every 12 time constants (12 dB/octave).

octave). The maximum setting rate is once every 1.2 s (6 dB/octave) or 2.4 s (12 dB/octave). The maximum sensitivity to which the instrument can range, if desired, can be set via the SENSITIVITY AUTO LIMIT function. The AUTOSSET function is more powerful than the AUTORANGE function in that it automatically adjusts the phase as well as the sensitivity. However, unlike the AUTORANGE function, which repeats automatically, the SET function cycles once only each time it is activated. One convenient way of taking measurements is to manually set all parameters except PHASE and SENSITIVITY. Then simply activate AUTO-SET, wait for the auto-set cycle to go to completion, and take the reading. AUTO-OFFSET introduces exactly the amount of offset necessary to reduce the output indication to zero, useful for tracking changes in output level about some previously established level. AUTO-NORMALIZE automatically adjusts the sensitivity as required to give full-scale output with an arbitrary

input level. It will only do this if the applied signal is between 40% and 110% of full scale. This function is useful for evaluating a series of measurements against some "standard" measurement which has been normalized to full scale. Note that only one auto-capability can be active at a time.

- (11) REMOTE INTERFACE: As far as these condensed operating instructions are concerned, the only point to be made is that the REMOTE indicator be extinguished. The instrument must be under LOCAL control. If REMOTE or SRQ is lighted, do a DEVICE CLEAR.

This completes the condensed operating instructions. Again, it must be emphasized that these condensed instructions are intended primarily as a quick review for someone who already has operating experience. They should not be used as a substitute for SECTION IV, OPERATING INSTRUCTIONS.

SECTION IV OPERATING INSTRUCTIONS

4.1 INTRODUCTION

Although operation of the Models 5205 and 5206 is straightforward, there are a number of factors to consider to be assured of optimum performance in every application. This section of the manual treats those factors in some detail. Topics covered include the operating controls, dynamic range, harmonic sensitivity, noise improvement, and operation with a computer.

ting diode) indicators are provided on the front panel so that the desired operating parameters can be established quickly and easily. Moreover, these LED indicators allow the operator to determine the instrument's status at a glance when the measurement is underway. This is as true for computer-controlled operation as for direct operator controlled operation. The digital panel meter allows the operator to directly read any of several critical parameters at any time.

4.2 FRONT-PANEL CONTROLS, SWITCHES, AND INDICATORS

4.2A INTRODUCTION

The Models 5205 and 5206 Lock-In Amplifiers are well designed from a human engineering point of view. A combination of keys and LED (light-emit-

Users will find the human engineering features incorporated into the front-panel design make operation of these instruments largely self-teaching. Nevertheless, users are advised to carefully read through the following descriptions of the front-panel features before using the instrument in an actual measurement situation.

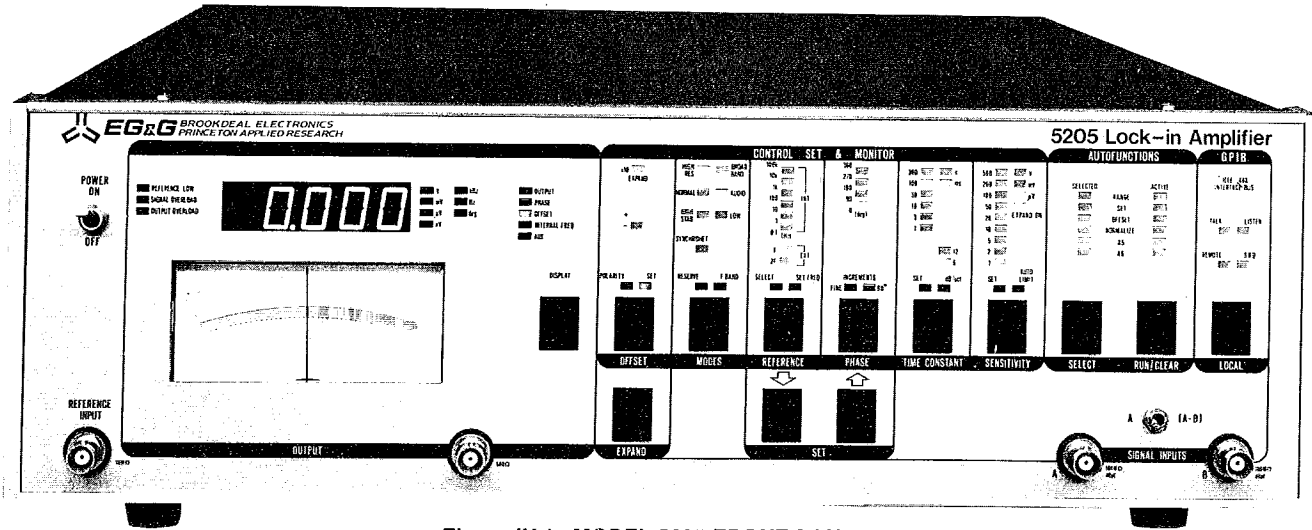


Figure IV-1. MODEL 5205 FRONT PANEL

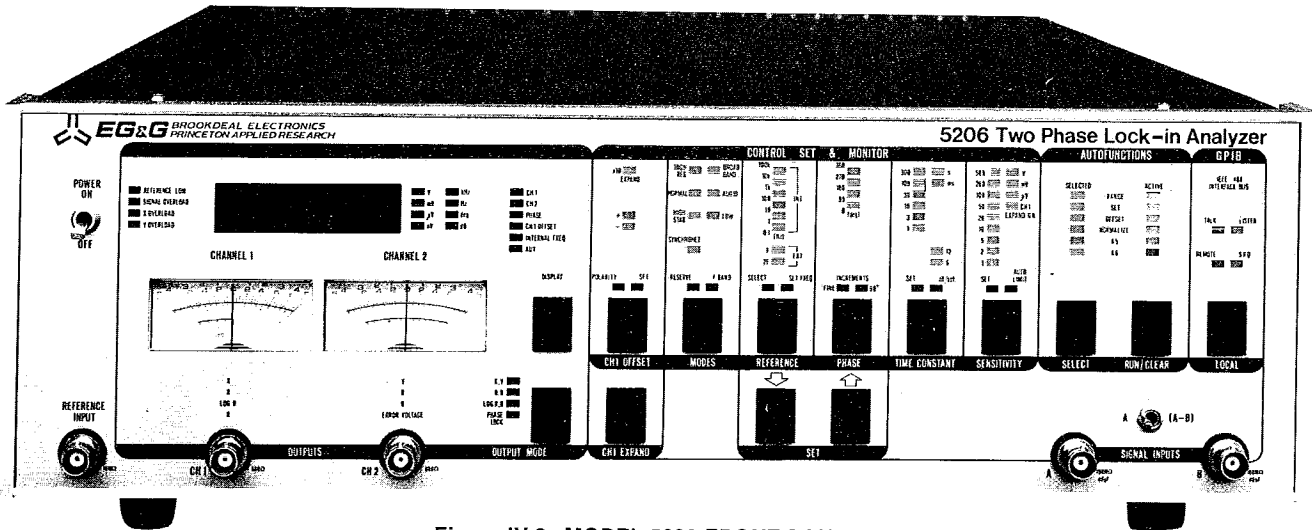


Figure IV-2. MODEL 5206 FRONT PANEL

4.2B KEYS

Observing the front panel, note that the various features and functions are grouped for operator convenience. The LED's marking the functions controlled by any select key are located in a clearly delineated area near the key. For example, the DISPLAY key sets the function displayed by the digital panel meter. At any time, one LED in the group will be lighted to indicate the displayed function. Each time the DISPLAY key is pressed, the lighted position shifts. By holding down the key, the user can quickly advance through the available display functions to reach the one wanted. The other select keys work in similar fashion, although in some cases, the complexity of the select/set operation requires a slightly more complex procedure. For example, note that the CONTROL SET & MONITOR select keys, OFFSET, MODES, REFERENCE, PHASE, TIME CONSTANT, and SENSITIVITY, are all part of a single grouping. All of these keys are operated in conjunction with the SET keys (there are two, UP and DOWN) to achieve the desired function. When any of these six select keys is pressed, the associated function "controls" become active as indicated by one of the two LED's directly above the key. For each function, there are two possible selections. The user alternates between the two by pressing the select key. Once the desired selection has been made, the UP/DOWN keys are used to refine the selection or set the parameter values. Although this system of interacting key controls may initially seem to be complex, in practice it is simple and convenient. Specific information regarding each key and function is provided in the following paragraphs.

(1) CONTROL SET AND MONITOR KEYS

SET: This pair of keys is located just to the right of center and near the bottom of the panel. The key to the left is called DOWN, symbolized by a downward pointing arrow directly above the key. That to the right is called UP, symbolized by an upward pointing arrow above the key. As indicated by the front-panel symbolization, these keys interact with the OFFSET (CH1 OFFSET in the Model 5206), MODES, REFERENCE, PHASE, TIME CONSTANT, and SENSITIVITY keys to determine the corresponding functions and parameters as follows.

- (a) **OFFSET (CH1 OFFSET in the M5206):** This key, used in conjunction with the UP/DOWN keys, controls the dc offset. In the case of the Model 5206, offset is introduced into Channel 1 only.

The operator can turn the offset on or off, and, when the offset is on, set its magnitude and polarity. Pressing the OFFSET key transfers the lighted position from

POLARITY to SET, or vice versa.

When POLARITY is the lighted position, the UP/DOWN keys set the offset. UP selects POSITIVE ("+" indicator lights) and DOWN selects negative ("- " indicator lights). If UP is pressed when the offset is positive ("+" indicator lighted), the offset will turn off. Pressing DOWN when the offset is negative ("- " indicator lighted) will also turn off the offset. When the offset is off, both the "+" and "-" indicators are extinguished. Note that the offset capability must be on, either "+" or "-" illuminated, before the offset magnitude can be set.

When SET is the lighted position, the UP/DOWN keys are used to set the offset magnitude. The UP arrow increases the magnitude. The DOWN arrow decreases it. When either of these keys is pressed, the offset changes in increments of 0.1% of full scale. The rate is slow enough to allow the user to easily advance the offset one 0.1% increment at a time. If the key is pressed down long enough for ten incremental advances to occur, the size of the steps increases to 1% of full scale. This two-speed advance system allows users to increment rapidly to the desired offset, while still maintaining sufficient resolution to set the offset to exactly the desired value. To observe the selected offset, simply press DISPLAY as many times as necessary to light the OFFSET (CH1 OFFSET in the M5206) indicator. As long as this indicator is lighted, the offset polarity and magnitude will be displayed on the digital panel meter. Should the offset capability be off, (both "+" and "-" extinguished), the digital panel meter will display the word OFF if the user attempts to display the OFFSET potential.

In the case of the Model 5206, the offset function is even further refined. It can be used to shift the "X" output level, or the "R" output level according to the OUTPUT MODE selected at the time the offset is specified. If the OUTPUT MODE is either "X" or PHASE LOCK when the offset is specified using the CH 1 OFFSET and UP/DOWN keys, the offset appears at the "X" output only. If the OUTPUT MODE is either "R" or LOG R when the offset is specified, the offset appears at the "R" output only. Note that offsetting "X" affects "R", but not vice versa.

- (b) **EXPAND (CH1 EXPAND in M5206):** This key works directly to turn the $\times 10$ output expand feature on or off. When the ex-

pand is "on", the corresponding LED lights to inform the user of the expansion status. The Expand indicator is near the OFFSET "controls" because the offset is affected by the expansion. In the case of the Model 5206, note that the expansion affects Channel 1 only.

- (c) **MODES:** This key, in conjunction with the UP/DOWN keys, is used to select the DYNAMIC RESERVE and FREQUENCY BAND modes. When the MODES key is pressed, either RESERVE (Dynamic Reserve) or F BAND (Frequency Band) will light. To set the Dynamic Reserve, RESERVE must be lighted. To set the Frequency Band, F BAND must be lighted. When RESERVE is lighted, the UP/DOWN keys are used to choose the desired Dynamic Reserve, HIGH RES (60 dB), NORMAL (40 dB), and HIGH STAB (20 dB). The corresponding output drift specifications are 1000, 100, and 20 ppm/°C respectively.

Users should note that there is an interaction between RESERVE and SENSITIVITY, as follows:

RESERVE	SENSITIVITY RANGE
HIGH STAB.....	100 μ V through 5 V
NORMAL.....	10 μ V through 50 mV
HIGH RES.....	1 μ V to 5 mV

Should the user attempt to select a reserve setting inconsistent with the sensitivity, the reserve won't change. Instead, the LED indicating the selected sensitivity will flash to indicate the problem. On the other hand, should the operator set the sensitivity to a value inconsistent with the selected reserve, the reserve will automatically change to a value that will allow the sensitivity setting being made. The reserve LED will flash to indicate that an adjustment is being made.

When F BAND is lighted, the UP/DOWN keys are used to choose the desired signal-channel frequency band, BROAD BAND (2 Hz to 200 kHz), AUDIO (10 Hz to 20 kHz), and LOW (1 Hz to 2 kHz). For a frequency band to be selected, it is first necessary that the corresponding Frequency Determining Card be installed. If the card corresponding to the selected frequency range has not been installed, the digital panel meter will briefly display the message ERR1 when the selection is attempted. (If there are no FBAND cards in the unit when it is turned on, ERR1 will be displayed continuously.)

- (d) **REFERENCE:** This key, together with the UP/DOWN keys, is used to select the reference mode and, if the INTERNAL reference mode is selected, to set the frequency. When REFERENCE is pressed, either SELECT or SET FREQ will light. SELECT has two functions. It allows selection of the reference mode, and, if the selected mode is internal, it allows the internal frequency range to be specified. The lighted position advances through the six internal range positions and then through the two external mode positions. When any of the six internal range indicators are lighted, the instrument is operating in the Internal Reference mode, and the specific range over which the frequency can be adjusted is given by the labels immediately above and below the LED's. For example, if the range were 10 kHz to 100 kHz, the LED between "10k" and "100k" would be lighted. Note that internal reference mode operation is only possible if the Internal Oscillator card has been installed. If the card is missing and the Internal Reference mode is selected, the digital panel meter will briefly display the "message" ERR1.

There are two External Reference modes, F and 2F. In the "F" mode, the reference channel operates at the frequency of the applied reference signal. In the "2F" mode, it operates at twice the frequency of the applied reference signal.

When SET FREQ is lighted, the UP/DOWN keys can be used to set the internal reference frequency to the specific desired value in the selected range. The increments are 0.1% of full scale (full scale is the upper end of the band as indicated by the symbolization directly above the lighted Internal Reference Mode LED). If the key is pressed in long enough for the frequency to advance through ten increments, the increments increase to 1% of full scale. This system of two-speed incrementing allows the user to rapidly advance to the desired frequency while maintaining sufficient resolution to set the frequency to the desired value. To display the internal reference frequency, simply use the DISPLAY key to advance to the INTERNAL FREQ display mode.

- (e) **PHASE:** This key, together with the UP/DOWN keys, sets the phase shift introduced in the reference channel. When PHASE is pressed, either FINE or 90° lights. If 90° is lighted, the UP/DOWN keys are used to select the phase quadrant. There are four quadrant indicator LED's. The symbolization to the left of the

LED's indicates the quadrant boundaries, although the actual range extends an additional 2.5° in both directions beyond the values symbolized on the front panel. All phase angle indications are in degrees of advance introduced in the reference channel.

When FINE is lighted, the UP/DOWN keys can be used to set the phase precisely within the selected range. Each phase increment is 0.025°. If the UP or DOWN key is held in, the first increment will be 0.025° and the next nine increments will be 0.1°. After that the increments increase to 1°. This system of three different sized phase increments allows the user to advance the phase rapidly, while still maintaining fine resolution for precise phase setting. The amount of phase advance introduced at any time can be read directly from the digital panel meter when it is operating in the PHASE mode as established by the DISPLAY key.

- (f) TIME CONSTANT: Together with the UP/DOWN keys, this key sets the averaging time constants and the rolloff rate of the time-constant filter. When TIME CONSTANT is pressed, either the SET or dB/oct LED lights. When SET is lighted, the UP/DOWN keys are used to select the desired time constant. Values from 1 ms to 100 s* in 1-3-10 sequence are provided. When dB/oct is lighted, the UP/DOWN keys are used to select the filter rolloff rate, either 6 dB/octave or 12 dB/octave.
- (g) SENSITIVITY: This key is used together with the UP/DOWN keys to set the sensitivity of the instrument and, if desired, to set the automatic sensitivity limit in auto-range operation. When SENSITIVITY is pressed, either SET or AUTO LIMIT lights. When SET is lighted, the user selects the desired full-scale sensitivity with the UP/DOWN keys. This is the sensitivity unaided by any optional pre-amplifiers. If the $\times 10$ EXPAND function has been activated, the sensitivity is increased by a factor of ten over that selected. In other words, when EXPAND is "on", the sensitivity range is 100 nV to 500 mV. In the case of the Model 5206, the EXPAND function affects the Channel 1 sensitivity only; the Channel 2 sensitivity range is always 1 μ V to 5 V.

Note that sensitivity and reserve interact. Sensitivities from 100 μ V to 5 V inclusive are available with the reserve set to HIGH

STAB. Sensitivities from 10 μ V to 50 mV inclusive are available with the reserve set to NORMAL. Sensitivities from 1 μ V through 5 mV are available with the reserve set to HIGH RES. Should the operator (or autorange) select a sensitivity inconsistent with the reserve setting, the reserve setting will automatically change to a value consistent with the sensitivity being set and the reserve LED will flash to indicate the change. The converse is not true, that is, if the reserve is set to a value inconsistent with the set sensitivity, the sensitivity does not change. However, the LED indicating the selected sensitivity flashes to indicate the problem. Sensitivity is the dominant parameter.

When AUTO LIMIT is lighted, the UP/DOWN keys are used to set the maximum sensitivity to which the unit will auto range. The AUTO LIMIT setting has no effect on the sensitivity when it is being controlled by the operator; it affects autorange operation only. As an example, assume an experiment in which the sensitivity is to be autoranged. Although the signal amplitude is expected to vary over a wide range, the user decides to limit the maximum sensitivity to 10 μ V. To do so he has only to press SENSITIVITY to light AUTO LIMIT, followed by using the UP/DOWN keys to light the 10 μ V LED. In the subsequent measurement, the sensitivity will be able to take values in the range of 10 μ V to 5 V as required to track the changing signal amplitude, but no matter how small the signal becomes, the unit will not become more sensitive than 10 μ V.

(2) AUTO FUNCTIONS

- (a) SELECT: The SELECT key determines which of the autofunctions is subject to RUN/CLEAR control. Each time the SELECT key is pressed, the lighted position advances one step. The sequence is OFF (none lighted), followed by RANGE, SET, OFFSET, NORMALIZE, and then back to OFF. Positions A5 and A6 are reserved for possible future developments. In the SELECT OFF state, none of the autofunctions can be activated or deactivated. Their status remains constant. For the status of an autofunction to be changed by the user, it is first necessary that the corresponding SELECT LED be lit. The SELECT key simply provides that function. No advance will occur if the selected function is active, and the LED for the selected function will flash to indicate the problem.

*10 s maximum with HI STAB reserve setting.

- (b) RUN/CLEAR: This key activates or deactivates the various auto functions. Only one at a time can be active. Otherwise stated, the ACTIVE light for a given auto-function cannot be turned on unless all of the autofunction ACTIVE lights are out. Each of the autofunctions is briefly described below.

RANGE: This autofunction allows the sensitivity to be automatically ranged. When AUTORANGE is activated, the magnitude of the "R" output ("X" output in the M5205) is monitored at approximately six time constant intervals (12 TC intervals at 12 dB/octave). The RUN/CLEAR key is used to activate or deactivate the function, as desired. Once activated, it remains active until turned off.

The upper switching threshold is at 110% of full scale. For example, suppose an input signal level of 7 mV. The sensitivity would autorange to 10 mV full scale. If the input signal then increased to 11 mV (110% of full scale), the sensitivity would autorange to 20 mV. In the other direction, the sensitivity autoranges as soon as the signal level crosses the full-scale level of the next higher range. In the example being considered, should the signal drop below 10 mV, the sensitivity will autorange from 20 mV full scale back to 10 mV full scale. Should the signal level continue to drop, the next autorange would occur when the signal level reached 5 mV, the next at 2 mV, and so forth. When operating with the autorange active, it is important to consider the AUTO-LIMIT parameter, which is set by the SENSITIVITY and UP/DOWN keys as previously described. The AUTO LIMIT function sets the maximum sensitivity to which the unit can autorange. Consider the example again. Suppose the AUTO-LIMIT had been set to 1 mV. If the signal dropped below 500 μ V, the expected autorange would not occur because of the limit imposed by the AUTO-LIMIT function.

In the Model 5206, autoranging is always done with respect to the "R" output, independent of the selected Output Mode. In both the Model 5205 and the Model 5206, autoranging occurs no more often than once every six time constants (once every 12 TC if 12 dB/octave). For example, if the time constant were one second, the signal level would be checked every six seconds. The maximum autoranging rate of once every 1.2 s (2.4 s if 12 dB/octave) applies with a time constant of 1, 3, 10, 30, or 100 ms.

Note that the AUTOSSET and AUTORANGE routines are not intended to be run with an offset present. However, they will function with offset unless the values of the offset and signal are such that the resulting magnitude is less than 50% of full scale on one range but greater than 110% of full scale on the next more sensitive range. If this is the case, the autoranging criterion can never be satisfied and the auto-range routine will simply oscillate between one range and the next. This happens because offset is generated as a percentage of full scale; when the range changes, the magnitude of the offset changes too.

Another AUTOSSET/AUTORANGE constraint is that neither will proceed if the applied reference signal is too low in amplitude.

Operation with AUTORANGE active precludes certain user operations. Specifically, one cannot change the offset or manually change the sensitivity. However, offset can be added *before* going to autorange operation, although the use of offset in AUTORANGE (or AUTOSSET) operation is better avoided as previously discussed. Should one attempt to change the offset status or change the sensitivity during autorange, the AUTORANGE ACTIVE light will flash rapidly for about a second to indicate the problem. Since all of the autofunctions are mutually exclusive, one cannot activate any autorange function if another is already active. Should this be attempted, again the appropriate ACTIVE light will flash to indicate the operating error.

SET: A more powerful function than RANGE, SET works on both the sensitivity and the phase. With respect to sensitivity, autoranging is done in the same way as for RANGE except that it cycles only once each time SET is activated. However, in each cycle, the autoset routine will try as many as twenty-one times to get the resultant (Output in the M5205) between 40% and 110% of full scale. In addition to ranging the sensitivity, SET automatically adjusts the phase relationship between the input and reference signals as necessary to obtain maximum output (M5205). In the case of a Model 5206, the phase is adjusted for maximum "X" output and minimum "Y" output. At the same time, the Output Mode is set to "R, θ " so that the routine will have access to the phase information.

The Model 5205 uses a different algorithm for computing the phase information. This routine proceeds in steps that are approximately six time constants apart (12 time constants apart if 12 dB/octave is selected). The routine proceeds as follows.

(i) First the Output level is read. If it is greater than 110% of full scale, the sensitivity is decreased. If it is less than 110% of full scale, the phase is shifted by one quadrant and the routine proceeds to the following step.

(ii) The Output level is read again. If it is greater than 110% of full scale, the sensitivity is decreased. If it is less than 110% of full scale, the microprocessor computes the "proper phase" from the two measured values for the Channel 1 Output. The Phase Shifter is then set to the computed value and the routine proceeds to the following step.

(iii) The unit reads the Output level a third time. If it is not within proper bounds, the sensitivity is adjusted in the proper direction and the routine returns to step (i). If the output is within the allowable range, the routine is finished.

The proper bounds for the routine are defined as 110% of the current range and 50% of the next higher range. For example, if the sensitivity is 5 mV, the allowable range would be 1 mV to 5.5 mV. Note that the time between steps is doubled if 12 dB/octave is selected.

One particularly useful feature of the SET function is that, when it is running, other non-conflicting functions can be invoked. This is specially useful if the user wants to go to a shorter time constant while the autoset routine is running, thereby speeding up the autosest operation.

SET differs from RANGE in that it remains active only long enough to make a single sensitivity and phase adjustment. (An autosest operation in progress can be aborted with the RUN/CLEAR key, if desired.) As soon as an autosest operation is completed, SET is automatically deactivated. Should the user wish to autorange the sensitivity and phase again, it will be necessary to reactivate the SET function with the RUN/CLEAR key. The restrictions that apply to RANGE with respect to changing the OFFSET status, manually changing the SENSITIVITY, and activating another autofunction apply to SET as well. However, since SET is generally ac-

tive only for a short time (the actual time can vary considerably depending on the specific operating conditions), they are less likely to be noticed by the operator.

OFFSET: This autofunction automatically introduces dc offset that neutralizes the signal at the output. This action occurs each time OFFSET is activated, and takes less than a second. In the Model 5206, either the "X" or "R" output is neutralized, according to the OUTPUT MODE status at the time auto-offset is activated. If the output mode is either "X" or PHASE LOCK, the "X" output is offset to zero. If the output mode is either "R" or LOG R, the "R" output is offset to zero.

NORMALIZE: This autofunction controls the lock-in amplifier's gain to achieve full-scale output for any signal in the range of 40% to 110% of full scale. In the Model 5205 the "X" (only) output is normalized. In the Model 5206 the "R" output is normalized. The signal level is read and the gain adjusted once only when AUTONORMALIZE is activated. The "X", "Y", and "R" outputs* are then displayed as percentages of full scale so that changes in signal level relative to that present when the function was activated can be readily tracked. The output levels continue to be displayed as percentages of full scale for as long as NORMALIZE remains active, that is, until deactivated with the RUN/CLEAR key. If the signal level is not between 40% and 110% of full scale, normalization will not occur. The only constraint on NORMALIZED operation is that common to all of the autofunctions, namely, that only one autofunction can be active at a time.

(3) DISPLAY

The DISPLAY key selects the parameter displayed by the digital panel meter. Each time the DISPLAY key is pressed, the displayed function changes, as indicated by the LED's just above and to the left of the DISPLAY key. The displayed function for each is as follows.

(a) **OUTPUT (M5205 only):** The digital panel meter displays the instrument's output level in units of V, mV, or μ V, as indicated by the lighted "units" LED to the right of the display (nV is reserved for future use). In AUTONORMALIZED operation, the output level will be displayed as a percentage of full scale and all of the units LED's will be unlighted.

*OUTPUT in the M5205; "X", "Y", and "R" in the M5206.

- (b) CH1 (M5206 only): The digital panel meter displays the function selected with the OUTPUT MODE key. Either "X", "R", LOG R, or PHASE LOCK can be selected. The significance of each is:

"X": "X" is the amplified and filtered output of the In Phase demodulator. The units are those indicated by the lighted units-LED or in % of full scale (all units-LED's unlighted).

"R": "R" is the signal magnitude, calculated by taking the square root of the sum of the squares of the In-Phase and Quadrature demodulator outputs. The units are indicated to the right of the display. If all of the units-LED's are unlighted, the units are % of full scale. This output remains constant as the phase between the input and reference signal changes.

LOG R: This output is computed by finding the logarithm to the base ten of the magnitude "R". The units are dB below full scale.

PHASE LOCK: The digital display indicates the CH1 magnitude "R" output level once phase lock occurs.

- (c) CH2 (M5206 only): The digital display indicates the level of the function selected with the OUTPUT MODE switch, as follows.

"Y": "Y" is the output of the Quadrature Demodulator. The units are those indicated by the units-LED's. If all of these indicators are unlighted, the units are % of full scale.

θ : θ is the phase of the input signal (with respect to the reference signal) minus the phase offset introduced with the Phase controls. In other words, θ indicates the phase angle between the signal and reference inputs to the In-Phase Phase Sensitive Detector. The units are in degrees. Note that θ is selected for two OUTPUT MODE positions.

PHASE LOCK: The digital panel meter displays the phase-lock "error voltage".

- (d) PHASE: The digital display indicates the amount of phase shift introduced in the reference channel in degrees. Because the display is limited to four places, phase changes smaller than the least significant place units are not displayed. This "truncation" may be noticed by the user. For example, suppose the phase to be

100.050°. Only the first four places will be displayed, giving a displayed phase of "100.0°". Two phase increments would be required to change the indication. The first would advance the phase to 100.075° where the "75" would be lost by truncation. The second would advance the phase to 100.100°, giving a display indication of "100.1°".

- (e) OFFSET (CH1 OFFSET in M5206): The digital display indicates the amount of offset introduced as a percentage of full scale. There is no distinction made between manual offset and that introduced by the AUTO-OFFSET function.

- (f) INTERNAL FREQ: The digital panel meter displays the frequency of the internal oscillator in either Hz or kHz. This is true even if the M5205/6 is operating in the EXT. Reference mode. If the M5205/6 isn't equipped with the Internal Oscillator Option, a meaningless frequency reading will be displayed.

- (g) AUX: The digital panel meter displays the output of one of the rear-panel plug-in modules, if present. The units are % of full scale (10 V).

(4) LOCAL

This key does not implement the Remote/Local function of the GPIB as defined by the IEEE 488 standard. With respect to the standard, the M5205/6 is classified as having no remote/local function capability.

The LOCAL key determines whether the instrument is subject to control from the front panel. When LOCAL is pressed, the REMOTE LED lights, indicating that the instrument can be controlled via the GPIB or RS232 interface and that it will not respond to the front-panel controls. Note that the GPIB and RS232 interfaces are only present in units equipped with the Digital Interface Option (M5205/95 or M5206/95). To return to local (front-panel) operation, it is only necessary to press the LOCAL key again. Note that the REMOTE indicator also lights under other circumstances as explained in the discussion of the GPIB indicators, which follows.

(5) GPIB INDICATORS

There are four, TALK, LISTEN, REMOTE, and SRQ. Their purpose is to facilitate the development of computer control programs. Although the front-panel heading is "GPIB", users should bear in mind that these indicators are also germane to operation with

RS232C data links. The specific function of each indicator is:

- (a) REMOTE: When the lock-in amplifier senses the arrival of the first character of a command, this indicator lights. It remains lighted until the command has been executed. The REMOTE light is also controlled by the LOCAL key as previously described.
- (b) LISTEN: This indicator lights when the lock-in amplifier senses the first character of a command. It remains lighted until the terminator is sensed. This indication does not mean that the host computer has transmitted the LISTEN message. Rather, it means that the M5205/6 is expecting more input before the current command is complete.
- (c) TALK: This indicator does not mean that the host computer has transmitted the TALK message. Rather, it lights when the lock-in amplifier has output ready to be sent. It goes out when the lock-in amplifier has finished sending. When lighted, it indicates that the M5205/6 has more output to dump before the command is completed.
- (d) SRQ: This indicator lights when an event occurs that caused the lock-in amplifier to assert SRQ (make a service request). It remains lighted until the controller has completed a serial poll on the lock-in amplifier. See the discussions of the Digital Interface Option functions for additional information,

(6) OUTPUT MODE (M5206 only)

This key determines which functions are available for display on the digital panel meter. There are two parameters for each selection. The one on the left is displayed in Channel 1. The one on the right is displayed in Channel 2. The significance of each selection is:

- (a) X,Y: The output of the In Phase ("X") demodulator is the Channel 1 output. The output of the Quadrature ("Y") demodulator is the Channel 2 output.
- (b) R,θ : The magnitude (square root of the sum of the squares of the In Phase and Quadrature Demodulators) is the Channel 1 output. The phase angle between the signal and reference inputs to the In-Phase PSD is the Channel 2 output.
- (c) LOG R,θ : The log of the magnitude is the

Channel 1 output. The angle between the signal and reference inputs to the In-Phase PSD is the Channel 2 output.

- (d) PHASE LOCK: This position establishes phase-lock operation. This is a special operating mode that only applies in units having the internal oscillator option and operated in the Internal Reference Mode. In this mode, the internal oscillator "locks" to the input signal in frequency and phase, allowing measurements to be made without the need for an external reference signal. The feature is best used with relatively "clean" input signals. To establish phase lock, the frequency is manually adjusted (REFERENCE and UP/DOWN keys) until the frequency is within one percent of full scale of the signal frequency. As the oscillator frequency comes closer and closer to the signal frequency, the panel-meter indications will change more and more slowly until lock-on occurs. At that point the readings will stabilize.

In Phase Lock operation, the normal X and Y output levels are applied to the analog meters. If the phase lock is perfect, the X indication will be maximum and the Y output will be zero. Since X and R are equal when the phase is locked, the Ch 1 panel meter indication is called "R" on the front panel. Similarly, any Ch 2 (Y) analog meter indication gives the error in the phase lock; a "perfect" lock/phase will give zero Ch 2 output. The utility of the ERROR output is simply to give a sensitive indication of phase lock. If the indication, even if non-zero, is stable, "lock" has occurred. If the ERROR output is fluctuating, the phase has not locked.

(7) DOUBLE KEY FUNCTIONS

A number of special functions are provided that require the operation of two keys for activation. With but one exception, the function is activated by pressing the RUN/CLEAR key, and, while it is pressed, momentarily pressing another key as explained below. It is strongly advised that NO autofunction be selected (all LED's above SELECT key should be extinguished) before activating a double-key function. The reason is simply that, if an autofunction is selected, that function will be activated when the RUN/CLEAR key is pressed. The result will be more things going on at once than the operator intended, with confusion a distinct possibility.

- (a) GPIB ADDRESS: Briefly pressing REFERENCE while RUN/CLEAR is pressed

causes the GPIB address currently selected by the GPIB address switches, located on the Digital Interface card, to be displayed (hex code) for about three seconds. The displayed quantity are switch settings only. TO ACTUALLY CHANGE THE ADDRESS, IT IS NECESSARY TO DO A POWER UP INITIALIZATION (turn the power off, wait a few seconds, change the switch settings, and turn the power back on).

- (b) RS232 PARAMETER SELECTIONS: Briefly pressing PHASE while RUN/CLEAR is pressed causes the RS232 DIP switches, located on the Digital Interface card, to be displayed (hex code) for about three seconds.
- (c) FIRMWARE REVISION LEVEL: Briefly pressing the TIME CONSTANT key while RUN/CLEAR is pressed causes the firmware revision level number to be displayed (hex code) for about three seconds. This information should be noted so that it can be reported to the factory in any subsequent discussions of operating or service problems.
- (d) PANEL LIGHTS OFF: Briefly pressing the SENSITIVITY key while RUN/CLEAR is pressed causes all of the front-panel LED's to be extinguished. Repeating this operation restores them to their normal mode.
- (e) POWER-ON INITIALIZATION: Briefly pressing the OFFSET (CH1 OFFSET in the M5206) key while RUN/CLEAR is pressed causes the power-on initialization sequence to be executed.
- (f) DEVICE CLEAR: Briefly pressing the SENSITIVITY key while the SELECT key is pressed causes the instrument parameters to assume the default state, as follows:

FRONT-PANEL PARAMETERS	DEFAULT SETTING
DISPLAY (M5205).....	OUTPUT
DISPLAY (M5206).....	CH 1
OFFSET (M5205).....	ZERO and OFF
CH 1 OFFSET (M5206).....	ZERO and OFF
RESERVE.....	HIGH STAB
FBAND.....	AUDIO*
REFERENCE.....	EXT. F
OSCILLATOR.....	40 kHz
PHASE.....	0° in Quadrant 0° to 90°
TIME CONSTANT.....	100 ms
dB/OCTAVE.....	6
SENSITIVITY.....	.5 V
AUTOFUNCTIONS.....	all OFF
OUTPUT MODE (M5206).....	X, Y
EXPAND.....	OFF

*If an Audio Band Card is not installed, ERR1 will be displayed briefly. This is normal and indicates that the user must set the FBAND manually.

INTERFACE PARAMETERS

SRQ MASK.....	ZERO
PROMPT.....	ON
ACKNOWLEDGMENT.....	OFF
DELIMITER.....	comma (hex 2C)
LOCAL/REMOTE.....	LOCAL

4.2C ERROR INDICATORS

There are two ways of indicating errors, first by means of the three (four in the M5206) Error LED's at the left of the digital panel meter, second, by displaying messages on the digital panel meter. A brief discussion of each follows.

(1) LED ERROR INDICATORS

- (a) REFERENCE LOW: This indicator lights if the applied reference signal is too small in amplitude to assure proper reference-channel operation. The reference signal range is 140 mV to 2 V pk-pk.
- (b) SIGNAL OVERLOAD: This indicator lights if a stage ahead of the mixer is overdriven. Should this happen, the recommended action is to increase the pre-mixer reserve range. If operating with HIGH STAB selected, try either NORMAL or HIGH RES. If operating with NORMAL, try HIGH RES. If the unit is already operating with HIGH RES selected, there is no alternative but to reduce the sensitivity.
- (c) OUTPUT OVERLOAD: This indicator lights if the output exceeds full scale. Such an indication could be caused by excessive noise at the output (try increasing the time constant), by operating with the sensitivity set too high for the signal level (decrease the sensitivity), or by introducing OFFSET sufficient to cause the output to exceed full scale (turn the offset off or reduce it). Another possibility is that the instrument is operating with x 10 expansion when the pre-expand output signal level is too large to permit it.

- (d) X OVERLOAD and Y OVERLOAD (Model 5206 only): These indicators work exactly the same as the OUTPUT OVERLOAD described in the preceding paragraph, the only difference being that, in the Model 5206, there are two output channels to consider. Note that the expansion and offset functions affect Channel 1 only.

(2) DISPLAY ERROR INDICATIONS

- (a) ERR1: This message indicates that the option card has not been installed for the option function selected. It is active for functions relating to the FREQUENCY BAND and INTERNAL OSCILLATOR cards. If the unit is turned on with no

FBAND card installed, ERR1 will be displayed continuously. If a DEVICE CLEAR is executed in a unit not having an AUDIO card, ERR1 will be displayed briefly, and there is no FBAND selection until made by the operator.

- (b) ERR2: This message indicates that an invalid command has been received by the digital interface.
- (c) ERR3: This message indicates that an invalid parameter has been received by the digital interface.
- (d) ERR4: COMMAND OVERRUN; indicates that a character has been received from the interface while the lock-in amplifier is busy processing the previous command. This COMMAND OVERRUN error alerts users to the need for pacing commands in an orderly manner by using the serial poll via the GPIB or by using the prompt character via RS232. When this error occurs, ERR4 is flashed when the initial command is finished, and the TALK and LISTEN LED's turn on to indicate the overrun condition. These LED's stay on until the next command is received.

4.2D DIGITAL DISPLAY AND METER(S)

Both the Model 5205 and the Model 5206 use the same four-digit (plus sign) digital display. The parameter displayed is determined by the DISPLAY key and, in the Model 5206, by the OUTPUT MODE key as well. LED indicators to the right of the display indicate the units of the displayed parameter. If all of the units-LED's are extinguished, the parameter is displayed as a percentage of full scale. In the Model 5205 there is a single analog panel meter directly below the digital display. In the Model 5206 there are two analog meters, located side by side below the digital display. The parameter displayed on the analog meter(s) depends on the model of the lock-in amplifier, as follows.

- (1) MODEL 5205: The analog meter displays the amplified and filtered mixer output. Assuming the phase is adjusted correctly, the meter directly indicates the amplitude of the input signal. The meter has a center-zero, three-inch scale and is accurate to $\pm 2\%$ of full scale.
- (2) MODEL 5206: The analog meters display the quantities selected with the OUTPUT MODE key (previously described). The Channel 1 (left) meter can indicate the "X" output, the "R" output, the log of the "R" output, or the "R" output in Phase Lock Mode operation. The Channel 2 (right) meter can indicate the

"Y" output, the phase angle between the input and reference signals at the mixer, or the "error" output in Phase Lock Mode operation. These meters have center-zero scales and are accurate to $\pm 2\%$ of full scale.

4.2E OUTPUTS

In the Model 5205 there is an output BNC connector located below and to the right of the analog panel meter. The output at this connector tracks the analog meter indication. Full-scale is ± 10 V and the source resistance is 600 Ω . The Model 5206 has two front-panel output connectors, one for each channel. The output at the connector beneath the Channel 1 analog panel meter tracks the Channel 1 meter indication. The output at the connector beneath the Channel 2 analog panel meter tracks the Channel 2 meter indication. The source resistance at both output connectors is 600 Ω .

4.2F INPUTS

There are three input connectors, one for the reference input, the other two for the signal input.

- (1) REFERENCE INPUT: This input is located at the lower left-hand corner of the front panel. The lock-in amplifier can operate in the external reference mode only if a suitable signal is applied to this connector (input impedance 10 M Ω). Symmetrical signals with amplitude in the range of 140 mV to 2 V pk-pk are acceptable.
- (2) SIGNAL INPUT CONNECTORS: There are two, located at the lower right-hand corner of the front panel. An associated toggle switch determines whether the input is single-ended or differential. For single-ended operation, the switch is set to "A" and the signal is applied to the left-hand "A" connector. For differential operation, the switch is set to "A - B" and the signal is applied differentially to the two connectors. The input impedance at both connectors is 100 M Ω . The shell of both connectors "floats" off ground by 10 Ω .

4.2G SWITCHES

There are two switches (other than the keys, described already). The first is the POWER switch, located in the upper left-hand corner. This switch controls the line power to the instrument. In the OFF (down) position, it interrupts both sides of the ac power to the primary of the power transformer. The second switch is the Input Configuration switch, located above and midway between the input connectors. This switch determines whether the input is single ended or differential. In the "A" position, the input is single ended. In the "A - B" position, the input is differential.

4.3 REAR PANEL

4.3A INTRODUCTION

The rear panel of both models is the same. As can be seen in Figure IV-3, there are a number of connectors and switches located at the rear panel. Several of these will only be present if the instrument is equipped with certain options. A discussion of each rear-panel feature follows.

4.3B OUTPUT BNC CONNECTORS

In the case of a Model 5206, two connectors are provided, one for Channel 1, the other for Channel 2. The functions available at these connectors exactly parallel those of the front-panel Channel 1 and Channel 2 Output connectors, and the descriptions of those connectors apply equally to the rear-panel outputs. Only one connector, Channel 1, is provided in the Model 5205. It parallels the front-panel output connector in every respect.

Users of early units will notice "X ZERO" and "Y ZERO" adjustment ports adjacent to these outputs. There are no user adjustments behind these ports. Under no circumstances should users remove the covers over these ports.

4.3C IEEE 488 INTERFACE CONNECTOR

If the instrument is equipped with the Digital Interface Option, an IEEE 488 interface connector is provided at the rear panel in the IEEE 488 INTERFACE area. In the case of early units, there is a space to the right of the connector for an address switch. However, design and space constraints have made it necessary to locate this switch inside the unit on the Digital Interface Card.

A detailed treatment of the IEEE 488 Interface capabilities is provided in the discussion of the Digital Interface Option.

4.3D OSCILLATOR OUTPUT

In units equipped with the Internal Oscillator Option, a BNC connector and level adjustment are provided in the OSCILLATOR OUTPUT area of the rear panel. The oscillator output is provided at this connector at an impedance of 600 Ω . The amplitude can be varied from 0 to 5 V rms with the associated adjustment.

4.3E PREAMP POWER

Any of several different optional preamplifiers can be purchased for use with the Model 5205 or Model 5206. These preamplifiers are powered via a cable that extends between the power connector on the front panel of the preamplifier and the PREAMP POWER connector on the rear panel of the lock-in amplifier.

4.3F AC POWER

The ac line-voltage selector switch, line fuse, and power input connector are all located at the lower right corner of the rear panel. Power and safety considerations for these lock-in amplifiers are discussed in Subsection 1.1.

4.3G ACCESSORY INSTALLATION OPENINGS

There are two openings for mounting accessories on the rear panel. Each opening is furnished with a cover secured by a screw. To gain access to the opening so that an accessory can be installed, it is only necessary to loosen the screw that secures the cover*.

If the unit is not equipped with the Digital Interface Option, two options can be installed. If the unit is equipped with the Digital Interface Option, the RS232 Interface connector is mounted on the

*The installation of rear-panel accessories should only be performed by an experienced electronics technician, and then only with the lock-in amplifier disconnected from all sources of power.

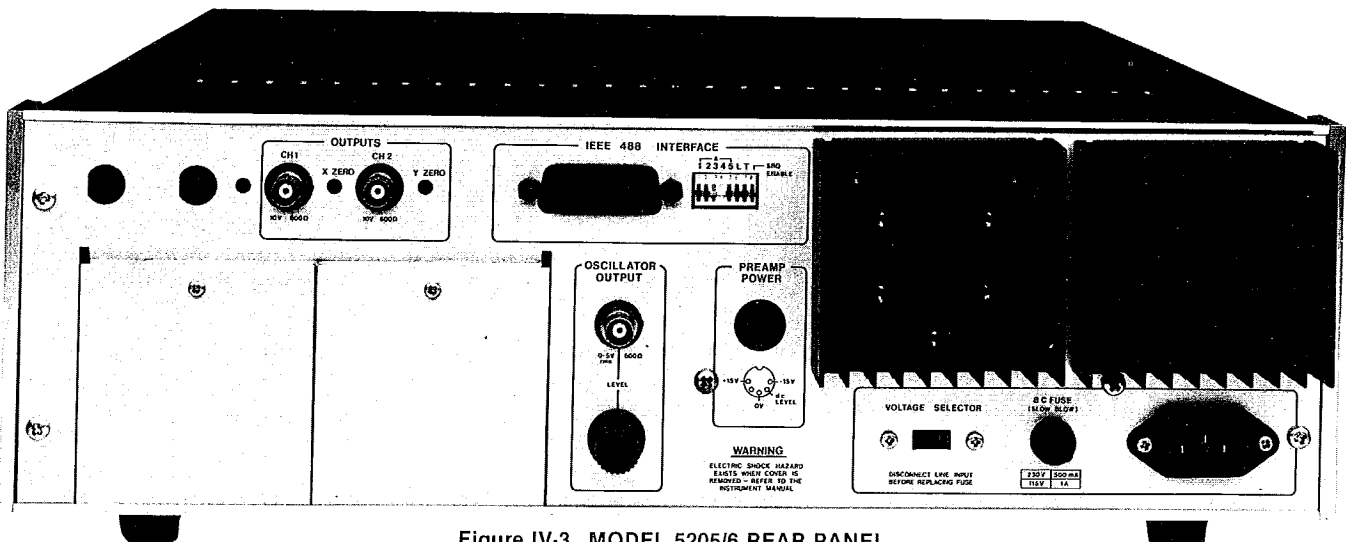


Figure IV-3. MODEL 5205/6 REAR PANEL

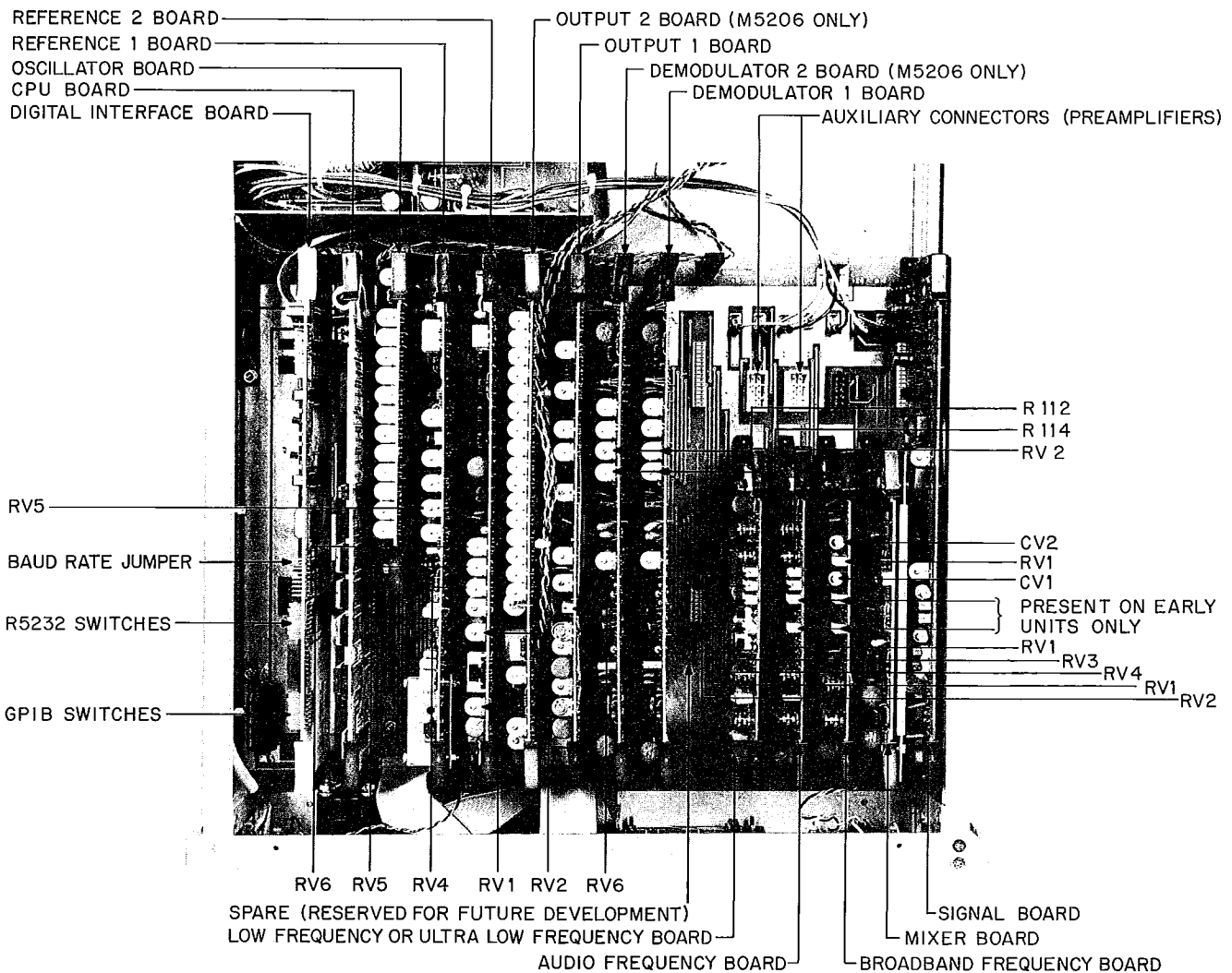


Figure IV-4. BOARDS, SWITCHES, JUMPERS, CONNECTORS, AND FIELD-CALIBRATION ADJUSTMENTS

right-hand option-opening cover, with the result that only one rear-panel option can be installed. Another Digital Interface configuration that allows operation with two rear-panel options in addition to RS232C is available. Contact the factory for information. Figure IV-4 shows the location of the various internal switches and connectors.

4.4 DIGITAL INTERFACE CONSIDERATIONS

4.4A INTRODUCTION

The Digital Interface Option (M5205/95 and M5206/95) allows the lock-in amplifier to be interfaced via either a GPIB (IEEE 488) or RS232 data link. The Digital Interface Option makes provision for complete control of the lock-in amplifier from an external source. The SENSITIVITY, EXPAND, TIME CONSTANT, PHASE, REFERENCE MODE, INTERNAL OSCILLATOR, FREQUENCY, DYNAMIC RESERVE, FREQUENCY RANGE CARD, ZERO OFFSET, AUTOFUNCTIONS, DISPLAY, and all other front-panel operating capabilities can be controlled externally via the digital interface.

4.4B RS232, AN OVERLOOK

INTRODUCTION

Users need not understand the material in Subsection 4.4B to make use of the Digital Interface Option's RS232 capability. This information is provided for background convenience only. Users may find it helpful in the sense that any background information can aid in giving insights that could be useful in solving specific problems. The source of this information is the excellent article by Steve Leibson, THE UNSTANDARD INTERFACE, SERIAL I/O, that appeared in the NOV/DEC 79 issue of the Hewlett Packard publication, KEYBOARD. Specific information for using the RS232 capability is provided in Subsection 4.4C.

RS232, ITS HISTORY AND PROBLEMS

Serial data transmission is not new. Beginning with Morse Code and its use in telegraphy, the technology of serial data transmission has improved steadily to where today there is widespread reliable electronic data communications via serial coding. With the development of com-

puters, the efficacy of serial data transmission in communications between humans and computers was quickly recognized. Serial data communications in computer applications were widely adopted. Initially, teletypewriters were almost exclusively used as combination terminal/display devices in communications between men and computers. With time, terminals and display devices advanced far beyond the teletypewriters used initially, but the serial I/O data handling characteristics of teletypewriters was maintained.

These communications reached a critical point when the distances involved became long. Clearly it was impractical to string wires between widely separated devices if it could be avoided. The ready solution was to make use of the existing telephone line system. Unfortunately, the telephone system was not designed with serial data transmission in mind, but rather voice communications with telephones serving as the I/O devices. The situation was additionally complicated by the inclusion in the telephone system of non-wire "connections" such as microwave data links. The probable chaos of allowing direct connections between the various serial I/O devices and telephone lines was not acceptable, and some sort of standard had to be established. RS232C is that standard. It defines signal and mechanical standards for communications between a piece of Data Terminal Equipment (DTE) and a piece of Data Communications Equipment (DCE). This standard has served well and is the basis for almost all long-distance data transmission. However, its very success has led to its adoption in applications for which it was not intended. Today there are countless communications links that use the RS232C standard, even though the standard is not intended to apply to them. Computers, printers, terminals, measuring instruments, etc., all are provided with serial data links claimed to be "RS232C". However, since many of these devices are neither terminals nor modems, they cannot, by definition, comply strictly with RS232C. Although users may expect that two pieces of equipment having RS232C ports should successfully communicate as soon as they are connected, it almost always happens that they do not. There are several possible reasons why successful communications may be thwarted.

The first stems from the direction of the data flow as a function of the assigned interconnecting wire. The standard specifies that data transmitted from a terminal to a modem be routed via pin 2 of the terminal connector, and that received from the modem enter the terminal via pin 3 of its interface connector. Where the device in question is neither a terminal nor a modem, the manufacturer has to arbitrarily select which pin is used to output data and which to receive data. As a result, it sometimes happens that users have to cross-wire from

pin 2 to pin 3 for two pieces of "RS232C Standard" equipment to communicate.

Handshake compatibility is another problem, sometimes a serious one. RS232C has limited handshake requirements. The standard is concerned solely with terminal-modem communications, and the Request-to-Send and Clear-to-Send lines (pins 4 and 5 respectively) fill that requirement. They do not necessarily satisfy the handshake requirements for other equipment. According to the standard, the DTE is supposed to assert Request-to-Send when it has data to send. Having asserted Request-to-Send, it is then supposed to wait for Clear-to-Send to be asserted by the DCE. Thus far no problems. Once data transfer begins, however, the DCE is not allowed to drop Clear-to-Send until the DTE drops Request-to-Send. Clearly there is a potential for the DCE being asked to take a longer drink than it can handle. If the Clear-to-Send line is arbitrarily used as a spigot to turn the data flow on and off (definitely NOT according to the standard), there is the question of determining just when it should switch. If it changes states when its buffer is full, it might stop in the middle of a character and garble the data. If it waits, the buffer will overflow and data will be lost. The problem is simply that RS232C was not designed for the job it is often asked to do, even though it can generally be "made" to work well.

Another problem has its origin in the RS232C voltage levels. Because RS232C was around long before TTL, its voltage levels differ from those of TTL. Negative true logic is used for data communications; positive true logic is used for commands. The levels are +3 V to +25 V for the positive logic level, and -3 V to -25 V for the negative logic level. The region between ± 3 V is undefined. As a result, TTL levels cannot be used in implementing "RS232C" communications.

Users also must take care to ascertain that both pieces of equipment operate at the same data-transmission rate (baud rate), agree on parity, have the same number of stop bits, and use the same character code (usually ASCII). A mismatch in any one of these parameters will cause data to be garbled or lost.

Between data transmissions, the data line idles at the negative voltage level. Each transmission begins with a start bit, the leading edge of which is defined by the data line going positive (logic 0). The start bit lasts for one bit time (the duration of each bit is set by the baud rate), and acts as a signal to the receiving device to begin sampling the level on the line at the center of each bit time interval in the sequence. Clearly, both devices must agree as to the number of bits to follow if they are to communicate successfully. The start bit is followed by the data bits, seven for ASCII,

that define the character transmitted. Next is the parity bit. The user has the option of having even parity, odd parity, or no parity (no parity-bit time interval included in the sequence). However, both instruments have to be set the same with respect to the parity bit. The parity bit is then followed by either one or two stop bits. The line comes back to the negative logic level for the duration of the stop bits and continues idling at the negative level until another start bit is transmitted, marking the beginning of the subsequent communication. Most RS232-compatible devices have provision for user selection and control of the parity bit, the number of stop bits, and the baud rate. Most use the ASCII code. Sometimes eight bits are used instead of seven, convenient for byte-oriented I/O. Successful communications can usually be established. It's just not so straightforward as users may expect.

Serial interfacing is popular and reliable. However, when two pieces of equipment are to communicate serially, the communications link must be established with care and attention to detail, even though both devices have serial ports implemented "in accordance with the RS232C Standard". Users who wish to have more detailed information about the RS232C standard can purchase a copy of it from:

Electronic Industries Association
 Engineering Department
 2001 I Street, N.W.
 Washington, D.C.

4.4C RS232C, AS IMPLEMENTED IN THE M5205/6

INTRODUCTION

Before the Serial Interface can be used, several factors have to be considered. Included are the details of the pinout, construction of the interconnecting cable, the handshake, and several user-controlled serial interface parameters. The RS232C pinout is indicated in Table IV-1.

RS232C SWITCH ASSEMBLY

One of the two internal switch assemblies located on the Digital Interface board (Figure IV-5) sets the RS232 parameters (the other sets GPIB addresses). For successful serial interface communications, the switches that affect RS232 communications must be correctly set. Table IV-2 indicates the functions controlled by switches 3, 4, and 5. Switches 1, 2, 7, and 6 are not used. Switch 8 provides an ECHO function. When switch 8 is in the ON position, there is no echo. When it is in the OFF position, each character received by the M5205/6 is echoed back to the computer, allowing it to ascertain that the character received was, in fact, the character sent.

A SWITCH IS ON WHEN THE END WITH THE SWITCH NUMBER IS PRESSED DOWN.

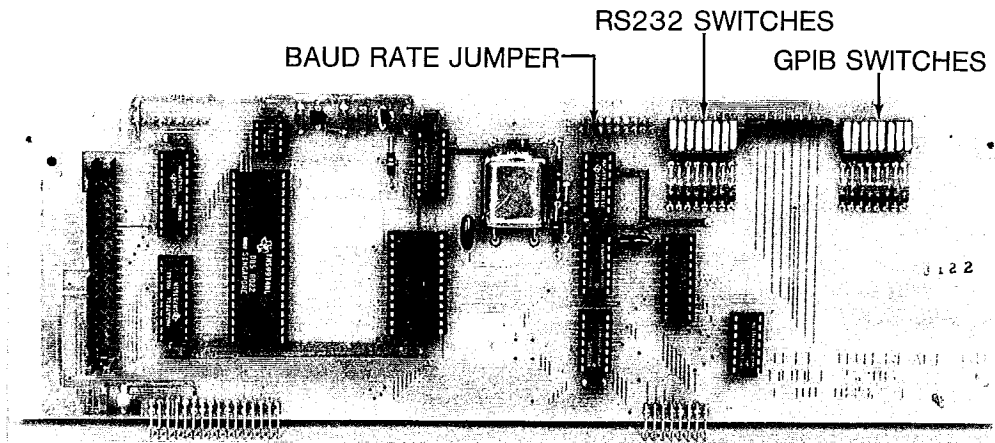
PIN	FUNCTION	COMMENT
1	Earth Ground	Ties the chassis of the M5205/6 to that of the Computer.
2	Transmit Data	The M5205/6 transmits on this line. It must connect to the computer connector pin that receives serial data.
3	Receive Data	The M5205/6 receives data on this line. It must connect to the computer connector pin that transmits serial data.
4	Request to Send	This line is permanently asserted in the M5205/6, that is, it is always at a positive voltage level (+10 V). In other words, the computer continuously receives the message that the M5205/6 is ready to receive a character.
5	Clear to Send	The computer can control the M5205/6 via this line. To enable the M5205/6 to transmit, the line is placed at the positive voltage level (+3 V to +12 V). To hold off transmission by the M5205/6, the line must be at the negative voltage level (-3 V to -12 V). Once this line goes positive, data transfer, if initiated by an appropriate command, will take place. The computer must be able to accept all of the data that can be transferred, or pull this line negative at the proper moments to prevent overflow. NOTE: If the user doesn't wish to use CLEAR TO SEND, simply leave pin 5 unconnected. It will "float" to about +12 V, continuously enabling the M5205/6 to transmit.
6	unused	
7	Logic Ground	Data signal levels should be with reference to logic ground. The logic ground line of the M5205/6 should interconnect with the logic ground line in the computer.
8, 9, 10, 11	unused	
12, 22	unused	
24, 25	unused	

Table IV-1. M5205/6 SERIAL INTERFACE PINOUT

Switch Setting			Selected Parameters	# of Time Slots
SW 5	SW 4	SW 3		
OFF	OFF	OFF	7 BITS, EVEN PARITY, 2 STOP BITS	11
OFF	OFF	ON	7 BITS, ODD PARITY, 2 STOP BITS	11
OFF	ON	OFF	7 BITS, EVEN PARITY, 1 STOP BIT	10
OFF	ON	ON	7 BITS, ODD PARITY, 1 STOP BIT	10
ON	OFF	OFF	8 BITS, NO PARITY, 2 STOP BITS	11
ON	OFF	ON	8 BITS, NO PARITY, 1 STOP BIT	10
ON	ON	OFF	8 BITS, EVEN PARITY, 1 STOP BIT	11
ON	ON	ON	8 BITS, ODD PARITY, 1 STOP BIT	11

NOTE: The combination of 8 BITS, NO PARITY, and 2 STOP BITS is recommended for operation above 9600 baud. The use of two stop bits increases the reliability by reducing the possibility of the receiver and transmitter getting out of synchronization.

Table IV-2. PARAMETER COMBINATIONS SELECTED BY SWITCHES 3, 4, AND 5



NOTE: A SWITCH IS ON WHEN THE END WITH THE SWITCH NUMBER IS PRESSED DOWN.

Figure IV-5. GPIB SWITCH, RS232 SWITCH, AND BAUD-RATE JUMPER LOCATION

WORD CONSTRUCTION

Between transmissions, the transmit data line rests at the low logic state. Each transmission begins with a START bit, the leading edge of which is marked by the transmit line going to the positive logic level. The START bit is then followed by the seven data bits that define the character being transmitted. Bit 8, if transmitted, is a logic 0. The ASCII Character code is used and the most significant bit is sent first. If the user has elected to include a parity bit, it directly follows the bits that define the character. Parity maintenance involves keeping the total number of "1's" in the data (start and stop bits don't count) either even or odd, as desired. If odd parity is selected, the parity bit will be a "1" when that is necessary to have the total number of data bits, including the parity bit, odd. For example, if the data word in question is 0010010, the parity bit would be "1" so that there would be three "1's" in all. If the number of "1's" in the word is already odd, such as in the word 0010110, the parity bit would be a "0". Even parity is similar except that the parity bit is made "1" or "0" as necessary to keep the total number of "1's", including the parity bit, even. The utility of parity maintenance is that it provides a direct way of detecting garbled data if the computer is programmed to only accept words having the selected parity. If a word having incorrect parity is read, it is a message to the computer that data loss is occurring. Although the M5205/6 generates the parity bit, if selected, it does not itself check the incoming parity information.

The parity bit is followed by either one or two stop bits, as selected. The stop bits are at the negative logic level, returning the line to the quiescent state. If the user has elected "no parity", the parity bit time slot will be deleted, and the time slot immediately following the last data bit will be allocated to a stop bit.

BAUD RATE

The user sets the M5205/6 baud rate. The rate selected must be compatible with the rate at which the computer can accept and process the data. Nine different rates are available as selected by means of an internal jumper*. To check and/or change the baud rate, proceed as follows.

- (1) With the cover removed (always unplug the line cord before removing the cover), note that there is an assembly of nine pairs of Berg pins just to the left of the RS232 switch assembly (Figure IV-5). A small removable jumper is mounted on one of the nine pairs of pins. The location of this jumper determines the baud rate; the baud rate is that corresponding to the pair of pins that are jumpered together. The lowest baud rate is on the right and the highest is on the left. The actual rates available are: 150, 300, 600, 1.2 k, 2.4 k, 4.8 k, 9.6 k, 19.2 k, and 38.4 k bits per second.
- (2) If the jumper is not on the pair of pins corresponding to the desired rate, simply pull it off to free it, and transfer it to the pair of pins corresponding to the desired rate.

CONCLUDING STATEMENTS

The preceding paragraphs contain all of the information a user needs to know about the Serial Interface *per se*. To actually use the interface, the user will have to understand and implement the appropriate user commands according to the Model 5205/6 Interface Communications Protocol. The protocol is discussed in Subsection 4.4G. The commands are discussed in Subsection 4.4H.

*This operation should only be performed by an experienced electronics technician, and then only with the unit disconnected from all sources of power.

4.4D GPIB (IEEE 488, 1978), AN OVERLOOK

INTRODUCTION

It is not necessary to understand the material in this subsection to make use of the GPIB interface capability. This information is provided for background only. Users may find it helpful in the sense that any background information can aid in giving insights potentially useful in solving problems. Detailed information regarding use of the GPIB data link as implemented in the Model 5205/6 is provided in Subsection 4.4E.

DESCRIPTION

The IEEE 488-1978 Instrument Bus Standard defines a bit-parallel, byte-serial bus structure designed to allow communications between intelligent instruments. Using this standard, many instruments may be interconnected and remotely controlled or programmed. Data can be taken from, sent to, or transferred between instruments via one connector or port. The standard defines all voltage and current levels, pinouts, connector specifications, timing, and handshake requirements. As a result, it should be possible to take two or more devices equipped with a GPIB port, remove them from their shipping cartons, connect them to the bus, and expect that they will be able to communicate on the bus. However, the standard cannot guarantee that they will necessarily understand one another.

OPERATING STATES

With respect to operating on the bus, there are only three operating states, controller, talker, and listener. The controller (computer) coordinates communications on the bus by commanding the other devices connected to it. Talkers can put information on the bus. Listeners accept messages that have been placed on the bus. Clearly, any given device may be able to support more than one of these states. The controller generally both talks and listens. Individual instruments or peripherals connected to the bus may have one or either capability. For example, the Model 5205/6 can act as both a talker and listener, as commanded by the controller. Systems could exist where a voltmeter connected to the bus would function as a talker only. A printer on the same bus, by way of contrast, might function as a listener only, providing a permanent record of the voltage readings when commanded to do so by the controller. Although a system could contain more than one controller, only one can be active at a time. Similarly, only one talker at a time can be active. Since listening is a passive activity, more than one device is allowed to listen. Devices are assigned addresses for identification. The controller activates each device at the proper time by placing its address on the bus. Once the instrument has been "alerted" in this manner, the appropriate command can be transmitted to it. There is provision for commands that will be recognized by all

devices, or by only those designated via the addressing technique.

NUMBER AND KINDS OF LINES

The bus operates with sixteen signal lines. Of these, eight are data lines. The data lines are bi-directional and carry both data and commands. Together, they constitute the data bus. Of the remaining eight lines, three are designated the byte transfer control group. Their function is to implement the handshake required to transmit a data byte or command. Last is the general interface management group of five lines. These are for single-line commands and status messages. They function independent of the handshake requirement. TTL levels with negative true logic are used throughout.

THE HANDSHAKE

As mentioned in the preceding paragraph, the handshake is implemented on the three byte-transfer control lines, designated \overline{DAV} (data valid), \overline{NRFD} (not ready for data), and \overline{NDAC} (no data accepted). The following sequence occurs each time a data word or command is transferred. Figure IV-6 illustrates a data transfer.

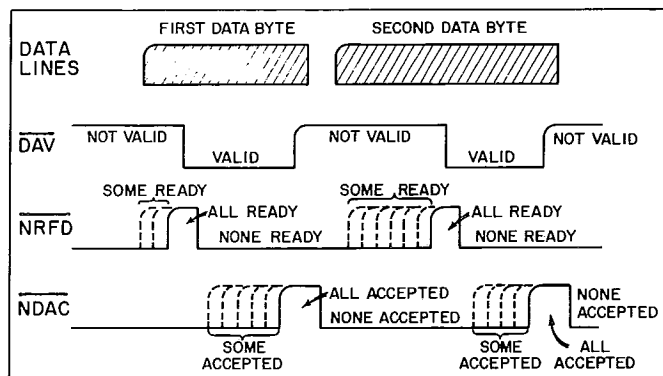


Figure IV-6. GPIB DATA TRANSFER

- (1) Quiescently, the talker may or may not have meaningful data on the bus. As far as the upcoming transfer is concerned, it doesn't matter.
- (2) The talker continuously monitors the \overline{NRFD} line. This line is controlled by all active listeners in such a way that it can change state (low to high) only if every active listener is ready to accept data. As long as any active listener is not ready to accept data, \overline{NRFD} will be low. Once all active listeners are ready, \overline{NRFD} goes high, initiating the transfer.
- (3) On sensing that \overline{NRFD} has gone high, the talker is free to put data on the bus and pull \overline{DAV} down. If the data is already on the bus (it may have been there for some time), \overline{DAV} goes low immediately. If there is no data on

the bus, the byte to be transmitted is placed on the bus first. Then, at least two microseconds later, \overline{DAV} is pulled down, signaling the active listeners that they can read the data byte.

- (4) On sensing that \overline{DAV} is low, the active listeners know that there is a valid data word on the bus and that they are to read it. In so doing, they become "busy" and \overline{NRFD} returns to the low state, where it remains until every active listener is ready to receive data again.
- (5) The active listeners also control the \overline{NDAC} line. It is held low during the quiescent state and while the data is being accepted. The active talker monitors the \overline{NDAC} line. Only when every listener has accepted the data byte does this line go high, notifying the talker that the data byte has been transmitted.
- (6) On sensing the positive transition of \overline{NDAC} , the talker releases \overline{DAV} , allowing it to return to the high state. The listeners sense this and respond by again pulling down on \overline{NDAC} , thereby restoring the quiescent conditions in preparation for the next data transfer.

This sequence repeats with the transmission of every data or command byte.

THE GENERAL INTERFACE MANAGEMENT GROUP

- (1) \overline{ATN} (Attention): This is a critically important line. When asserted (low), it causes the active talker to relinquish control of the \overline{DAV} line. The controller takes the place of the active talker, and both talkers and listeners alike accept the information transmitted when \overline{ATN} is asserted. Specific control information is transmitted when \overline{ATN} is asserted.

It is important to understand that some of the codes transmitted when \overline{ATN} is asserted will have different but equally valid meanings if transmitted when \overline{ATN} is not asserted. The commands that can be transmitted when \overline{ATN} is asserted, Remote Message Commands, are defined by the standard. \overline{ATN} is also asserted when transmitting an address. Commands transmitted when \overline{ATN} is not asserted are user defined. Note that it is not necessary that each device connected to the bus understand all of the standard commands. Individual device manufacturers can select those commands their device will recognize. Should the others appear on the bus, they will simply be ignored. Besides transmitting a command when \overline{ATN} is asserted, the controller could also transmit an address (listen or talk). A device becomes an active talker when its talk address is placed on the bus. It becomes an active listener when its listen ad-

dress is placed on the bus.

- (2) \overline{IFC} (Interface Clear): This line is asserted (pulled low) to override all bus activity and return the bus to a known "clear" state. Ordinarily, it is asserted by the system controller, when it powers up. Otherwise, \overline{IFC} is not used, but is reserved for situations where something has gone wrong. Any data on the bus may be lost when \overline{IFC} is asserted.
- (3) \overline{REN} (Remote Enable): This line is asserted to transfer devices on the bus from local to remote control.
- (4) \overline{EOI} (End or Identify): This line has two functions. First, it may be asserted by the talker to designate the last byte of a multi-byte message. Second, it can be used as part of the parallel polling process described in the following step.
- (5) \overline{SRQ} (Service Request): All devices on the bus share this line. Any device on the bus can assert the line, indicating to the controller that some device requires attention. For example, a voltmeter might assert \overline{SRQ} after it has taken a reading to indicate to the controller that it is ready to place the reading on the bus for transfer and further processing. All service requests look alike. The controller must use either serial polling or parallel polling to identify the devices requiring service.

In serial polling, every device on the bus is successively queried as to its status by the controller. In each case, the device answers with an eight-bit status byte that carries the necessary information. The controller then transmits a serial poll disable command to return the device to the data mode. By the time the controller has queried each device, it will "know" which one required the service, and will act accordingly.

In parallel polling, the controller asserts \overline{ATN} and \overline{EOI} simultaneously, thereby requesting a parallel poll. As many as eight devices can respond simultaneously, each on a different previously-assigned data line. The data line corresponding to the device requiring service will be low, allowing it to be recognized by the controller.

ADDRESSING

Addressing is an essential GPIB concept. Each device on the bus is assigned a listen address and a talk address (assuming both are relevant to the device in question). These addresses are set by switches or jumpers at the device. When the controller wishes to communicate with a specific device on the bus, it uses the address of the device in question. Only the device having the cor-

responding address will respond to the subsequent message.

There are thirty-one listen addresses, from 0100000 to 0111110 (all listen addresses begin with 01). The last code in the listen group, 0111111, is the unlisten command, which causes all devices to go to the listener idle state as opposed to the listener active state. Similarly, if the controller wants a device to talk, it sends the talk address of the device in question, followed by the specific command. The talk addresses range from 1000000 to 1011110 (all talk addresses begin with 10). The last address in the talk group, 1011111, is the untalk command. Since there can be but one talker on the bus at a time, transmitting the untalk command will result in there being no active talker on the bus.

FINAL COMMENTS

The preceding discussion of how the GPIB functions is by no means complete. A great deal of additional detail has to be considered by device designers. The utility of the standard is that users do not have to understand or know any of this. What is required of the user is the controller program that coordinates all the bus activity necessary to accomplish the task at hand. For more detailed information concerning IEEE 488 1978, the reader is advised to purchase a copy of the standard from:

IEEE
345 East 47th Street
New York, New York 10017

4.4E GPIB BUS OPERATING CONSIDERATIONS FOR THE MODEL 5205/6

INTRODUCTION

Although conformance to IEEE 488 assures freedom from the uncertainties that plague RS232C data links, there are, nevertheless, a number of factors that have to be considered, independent of programming, for successful operation on the bus. These are discussed in the following paragraphs.

ADDRESS (INTERNAL GPIB SWITCH ASSEMBLY)

When the controller wishes to communicate with one device on the bus, it begins by placing the address of that device on the bus with ATN asserted. Naturally, each device must "know" its own talk and listen address. In the case of the M5205/6, these addresses are set by switches 1 through 5 of the internal GPIB switch assembly. A switch is ON when the side of the rocker having the number is pressed down. Setting a switch to ON selects a "1". Setting it to OFF selects a "0". Switch 1 sets the least significant bit. Switch 5 sets the most significant bit of the five that can be set with these switches. Each address is seven bits in length. Every listen address begins with 01, and every talk address with 10. Thus the five address

switches at any time define not one address, but two. For example, suppose the switches were set as follows.

SWITCH	SETTING
1.....	0
2.....	1
3.....	1
4.....	0
5.....	1

Since switch 1 defines the least significant bit, the selected address would be 10110. Recalling that every listen address begins with 01, and every talk address with 10, the two addresses defined by this set of switch settings would be:

LISTEN.....0110110
TALK.....1010110

If the controller wished to designate the device an active listener, it would place the address 0110110 on the bus. If it wished to designate the device an active talker, it would place the address 1010110 on the bus.

Table IV-3 lists all possible combinations for GPIB address switches 1 through 5, together with the decimal equivalent in each case. Also indicated are the hex and ASCII equivalents of the complete seven-bit talk and listen addresses.

Switch Bit Sequence	Decimal Equiv.	Hex Talk Address (1st digits 10)	Hex Listen Address (1st digits 01)
00000	0	40	20
00001	1	41	21
00010	2	42	22
00011	3	43	23
00100	4	44	24
00101	5	45	25
00110	6	46	26
00111	7	47	27
01000	8	48	28
01001	9	49	29
01010	10	4A	2A
01011	11	4B	2B
01100	12	4C	2C
01101	13	4D	2D
01110	14	4E	2E
01111	15	4F	2F
10000	16	50	30
10001	17	51	31
10010	18	52	32
10011	19	53	33
10100	20	54	34
10101	21	55	35
10110	22	56	36
10111	23	57	37
11000	24	58	38
11001	25	59	39
11010	26	5A	3A
11011	27	5B	3B
11100	28	5C	3C
11101	29	5D	3D
11110	30	5E	3E
11111	Not an Address	Untalk Command	Unlisten Command

NOTE: Switch 1 sets least significant bit. ON selects "1". OFF selects logic "0".

Table IV-3. ADDRESS SWITCH CODING

OTHER GPIB SWITCH ASSEMBLY CONSIDERATIONS

There are eight switches in the GPIB switch assembly. Five of them set the address as previously described. A special GPIB TEST ECHO operating state, involving switch 8, can be established in which all characters sent or received via the GPIB data link are echoed to the RS232 port. This feature is useful in solving GPIB interface problems. To select this state, switch 8 should be OFF, with switches 1 through 5 set to any combination except all ON. In normal operation, switch 8 is left in the ON position.

Switch 7 defines the terminator. In the OFF position the terminator is a LINE FEED. In the ON position it is a CARRIAGE RETURN. Switch 6 is reserved for future use.

GENERAL INTERFACE MANAGEMENT LINES

There are five general interface lines. Their function is defined by the standard and briefly discussed in Subsection 4.4D. Some additional comment is appropriate for them as they apply to the M5205/6. First, the instrument recognizes ATN and IFC as defined in the standard. It does not recognize REN (Remote Enable). The Model 5205/6 accepts EOI as a delimiter for a multi-byte message. The instrument does respond to SRQ. That response is discussed in detail in Subsection 4.4H.

REMOTE MESSAGE COMMANDS

IEEE 488 defines a large number of commands which the controller can place on the bus when ATN is asserted. Of these, the M5205/6 recognizes DEVICE CLEAR only (code 0010100 with ATN asserted). On receiving the DEVICE CLEAR (DCL) command, the default parameters are established as follows.

FRONT-PANEL PARAMETERS	DEFAULT SETTING
DISPLAY (M5205).....	OUTPUT
DISPLAY (M5206).....	CH 1
OFFSET (M5205).....	ZERO and OFF
CH 1 OFFSET (M5206).....	ZERO and OFF
RESERVE.....	HIGH STAB
FBAND.....	AUDIO*
REFERENCE.....	EXT. F
OSCILLATOR.....	40 kHz
PHASE.....	0° in Quadrant 0° to 90°
TIME CONSTANT.....	100 ms
dB/OCTAVE.....	6
SENSITIVITY.....	5 V
AUTOFUNCTIONS.....	all OFF
OUTPUT MODE (M5206).....	X, Y
EXPAND.....	OFF

INTERFACE PARAMETERS

SRQ MASK.....	ZERO
PROMPT.....	ON
ACKNOWLEDGMENT.....	OFF
DELIMITER.....	comma (hex 2C)
LOCAL/REMOTE.....	LOCAL

*If an Audio Band Card is not installed, ERR1 will be displayed briefly. This is normal and indicates that the user must set the FBAND manually.

4.4F COMMUNICATIONS PROTOCOL

A transmission to the M5205/6 consists of a command followed by a space, arguments if necessary, and a terminator. If a command is followed by one or more parameters, it is taken to be a request to set the associated function according to the parameters. If the command is NOT followed by one or more parameters, it is taken to be a request to read the associated setting. For example, "S 9" is a command to set the sensitivity to setting "9". but "S" is a request to know what the sensitivity setting is. If a command has parameters associated with it, a space MUST separate the command from the parameters. Parameters of a command will be integer numbers separated by a delimiter. The default delimiter is a comma. (For examples, see commands O, J, P, & T in Table IV-4.) Should the comma delimiter be unacceptable to the computer, another delimiter can be specified. The terminator that follows each command message can be either a LINE FEED or a CARRIAGE RETURN, as set by switch 7 of the GPIB switch assembly. At the GPIB port, the M5205/6 accepts EOI asserted as a terminator, and will itself assert EOI with the last character in each message.

Several commands can be sent in one line by using a semicolon to separate the commands*. For example:

```
S 9
T 0,1
X 0
D 0
```

could be transmitted all at once as:

```
S 9;T 0,1;X 0;D 0
```

However, if an error is detected at any point in the line, the rest of the command is ignored. The size of the M5205/6's input buffer is 80 characters. Commands longer than 80 characters will be truncated at 80 characters. Similarly, the size of the M5205/6's output buffer is 80 characters. Any compound command that generates more than 80 characters of output will cause data to be lost.

At the RS232 port, the user has the option of having the interface echo all characters received. This function is controlled by switch 8 of the RS232 Switch Assembly, as previously described (ON position gives no echo; OFF position gives echo).

Numbers are transmitted as ASCII decimal with the most significant digit transmitted first. No more than five leading blanks are permitted.

*Placing multiple commands on one line is faster. Also, it saves paper during a printout. Disadvantages are: (1) additional opportunities for errors are introduced, and (2) some computers have no provision for structuring command sequences in this way.

COMMANDS CANNOT BE TRANSMITTED TO THE M5205/6 WHILE IT IS BUSY EXECUTING A PREVIOUSLY RECEIVED COMMAND. SHOULD A COMMAND BE SENT WHEN THE LOCK-IN AMPLIFIER IS BUSY, IT WILL BE IGNORED, AND AN ERR 4 MESSAGE DISPLAYED.

If the ACKNOWLEDGE function has been activated by sending the appropriate command, the lock-in amplifier responds to each command with either an OK or a question mark. OK signifies that the command has been understood. A question mark means that it has not been understood. These responses precede any response required by the command itself.

Each command consists of one upper case letter. In some cases the letter will be followed by a digit between 0 and 9, if required. Each command letter suggests the associated function. Where there is a conflict, one of the command letters has been selected arbitrarily. For example, the letter "R" is appropriate for both reserve and reference. As it turns out, "R" has been assigned as the reserve function and "J" to the reference function. In the case of ON/OFF functions, "1" is used to denote ON and "0" to denote OFF.

When interfacing a computer to the M5205/6, it is important to keep the structure of the interface simple, clear, and correct. In keeping with this goal, it is advisable that:

- (1) There be only one subroutine to send a command.
- (2) There be only one subroutine to receive a command.
- (3) Provisions be made to assure that no command is sent until the M5205/6 has completed processing initiated by the previous command.
- (4) Any response by the instrument to the command must be read by the computer.

The COMMAND COMPLETE and OUTPUT READY bits of the STATUS byte are well suited to aiding the user in meeting these requirements. These bits can be used to control the program flow. One benefit of the illustrated control scheme is that the programmer need not specify the number of response numbers expected for each command. It will work correctly independent of the execution timing of the commands.

4.4G RS232 AND GPIB DEVICE DEPENDENT COMMANDS

INTRODUCTION

Independent of the choice of data link (serial or GPIB), most messages from the controller to the

M5205/6 will be device dependent commands. These commands are listed in Table IV-4 and discussed in the paragraphs that follow the table. Many of these commands must be accompanied by operands that are either addresses or integer values. All commands should be terminated by CR

M5205/6 COMMANDS	FUNCTION	PARAMETER RANGE
D N*	Selects what data digital panel meter will display.	(0-to-5)
M N	Selects data indicated by panel meter(s).	(0-to-3)
X N	Sets EXPAND on or off.	(0 or 1)
O N1,N2	Sets OFFSET N1 is offset. N2 is the polarity.	(0-to-1000) (0 or 1)
R N	Selects RESERVE.	(0-to-2)
F N	Selects FREQUENCY BAND.	(0-to-2)
J N1,N2	Selects Frequency of Oscillator and Reference N1 is the numerical frequency. N2 is the band.	(100-to-1000) (0-to-7)
P N1,N2	Selects PHASE SHIFT N1 is the Quadrant. N2 is the numerical value. (100 gives a phase shift of -2.5°.) (3900 gives a phase shift of 92.5°.)	(0-to-3) (100-to-3900)
T N1,N2	Selects TIME CONSTANT and dB/OCTAVE N1 selects the TC. N2 selects the dB/octave.	(0-to-10) (0 or 1)
S N	Selects the SENSITIVITY.	(0-to-20)
L N	Selects the sensitivity LIMIT.	(0-to-20)
A1 N	Selects the AUTORANGE on or off.	(0 or 1)
A2 N	Sets AUTOSET on or off.	(0 or 1)
A3	Causes the AUTO-OFFSET routine to run.	
A4 N	Selects AUTONORMALIZE on or off.	(0 or 1)
A5	Reserved for future use.	
A6	Reserved for future use.	
A7	Causes the AUTOPHASE routine to run.	
Q1	Causes integer value of CH1 to be sent.	
Q2	Causes integer value of CH2 to be sent.	
Q3	Causes integer value of AUX to be sent.	
G N	Sets "X" and "Y" Channel gain.	(0-to-4095)
H N	Selects mode of front-panel LED's.	(0-to-2)
K N	Causes the routine associated with the specified key to run exactly as if the key had been pressed at the front panel.	(0-to-13)
Y N	Turns ACKNOWLEDGMENT function on or off.	(0 or 1)
U N	Turns RS232 PROMPT function on or off.	(0 or 1)
V	Causes firmware version number to be sent.	
E	Causes error number of previous command to be sent.	
Z	Causes STATUS byte to be sent.	
B N	Specifies SRQ MASK byte.	(0-to-255)
C N	Specifies delimiter between numbers in all commands.	(any ASCII character)
W N	Duplicates function of front-panel LOCAL key.	(0 or 1)
N	Allows status of the three overload indicators to be read via the interface.	

*"N" represents any number in the indicated range for the parameter.

Table IV-4. M5205/6 DEVICE-DEPENDENT COMMANDS

(carriage return) or by LF (line feed) characters, as set by switch 7 of the GPIB switch assembly (ON for CR, OFF for LF). The M5205/6 uses integer numbers only.

Many commands can be sent with or without an operand. Where such a command is followed by an operand (N), it is taken to be a request to set the associated function according to the operand value. If the command is NOT followed by an operand, it is taken to be a request to read the associated setting. Some commands, such as "V", "E", and "Z" are always commands to send information, and never take an operand. A few commands are used solely to initiate routines, specify control parameters, or turn functions on or off. Included in this group are "A3", "A4 N", "K N", "Y N", "U N", "B N", and "C N".

DETAILED DESCRIPTION OF COMMANDS

(1) D N: When followed by N, the D command sets the parameter displayed by the digital panel meter. If N is not included, the command is a request for the display parameter currently selected. The selections as a function of "N" are:

N	M5205	M5206
0	OUTPUT	CH 1
1	PHASE	CH 2
2	PHASE	PHASE
3	OFFSET	CH 1 OFFSET
4	INT. FREQ	INT. FREQ
5	AUX	AUX

(2) M N: When followed by N, the M command selects the parameter to be displayed by the analog panel meters in the Model 5206. If N is not included, the command is a request for the current "meter selection". The command has no validity for the Model 5205. The selections as a function of "N" are:

N	CH 1 METER	CH 2 METER
0	X	Y
1	R	0
2	LOG R	0
3	X (Phase Lock)	Y (Phase Lock)

(3) X N: When followed by N, the X command switches the EXPAND on or off. If N is not included, the command is a request for the current EXPAND status. An "N" of "1" switches the EXPAND ON. An "N" of "0" switches it OFF.

(4) O N1,N2: When followed by N1 and N2, the O (this is upper case OH, not zero) command controls the offset. If N1 and N2 are not included, the command is a request for the current OFFSET status. The magnitude is set by N1, where N1 can range from 0-to-1000. The units are tenths of one percent of full scale. N2 switches the offset on or off and sets the

polarity. An N2 of "0" turns the offset OFF. An N2 of "1" turns the offset ON with the polarity POSITIVE. An N2 of "2" turns the offset ON with the polarity NEGATIVE.

(5) R N: When followed by N, the R command controls the dynamic reserve. If N is not included, the command is a request for the RESERVE status. The reserve as a function of "N" is:

N	RESERVE
0	HIGH RES
1	NORMAL
2	HIGH STAB

(6) F N: When followed by N, the F command selects the FREQUENCY BAND. If N is not included, the command is a request for the selected F BAND. The selected mode as a function of "N" is:

N	BAND
0	BROAD BAND
1	AUDIO
2	LOW

(7) J N1,N2: When followed by N1 and N2, the J command selects the reference mode and controls the Internal Oscillator Option. If N1 and N2 are not included, the command is a request for the REFERENCE status. If an Internal Reference Band is selected, N1 sets the frequency within the selected band as a percentage of full scale (full scale is the upper limit of the band). The range is 100-to-1000, with each increment being 0.1% of full scale. N2 selects the reference mode, EXT F, EXT 2F, or, via any of the Internal Frequency bands, INT, as follows:

N1	N2	BAND
100-1000	0	10 kHz-to-100 kHz
100-1000	1	1 kHz-to-10 kHz
100-1000	2	100 Hz-to-1 kHz
100-1000	3	10 Hz-to-100 Hz
100-1000	4	1 Hz-to-10 Hz
100-1000	5	.1 Hz-to-1 Hz
100*	6	EXT. F
100*	7	EXT. 2F

*N1 value must be entered, even if selecting External Mode operation. "100" is a suitable value.

(8) P N1,N2: When followed by N1 and N2, the P command sets the Phase Shift. If N1 and N2 are omitted, the command is a request for the current PHASE setting. "N1" selects the quadrant, 0 (0°-to-90°), 1 (90°-to-180°), 2 (180°-to-270°), or 3 (270°-to-360°). "N2" specifies the phase shift within the quadrant in increments of 0.025 degrees. The range of "N2" is 100-to-3900. The phase shift contributed by N2 equals .025 times (N2 - 200). For example, if N2 is 100, the phase shift contributed by N2 will be - 2.5°. If N2 is 3900, the

phase shift contributed by N2 will be 92.5°. The formula relating total phase shift to N1 and N2 is:

$$\text{Total Phase Shift in degrees equals } (N1 \times 90) + [0.025(N2 - 200)]$$

If you know the desired phase shift and want to find N1 and N2, use:

$$N1 = \text{INT}(P/90)$$

$$N2 = (40 * P) - (3600 * N1) + 200$$

Two convenient reference points are 0° (N = 200) and 90° (N = 3800).

- (9) T N1,N2: When followed by N1 and N2, the T command selects the Time Constant and the dB/octave rolloff rate. If N1 and N2 are omitted, the command is a request for these parameter settings. "N1" selects the time constant, as follows:

N1	TIME CONSTANT
0.....	100 s
1.....	30 s
2.....	10 s
3.....	3 s
4.....	1 s
5.....	300 ms
6.....	100 ms
7.....	30 ms
8.....	10 ms
9.....	1 ms
10.....	1 ms

"N2" selects the dB/octave rolloff rate. If N2 is 0, the rate is 12 dB/octave. If N2 is 1, the rolloff rate is 6 dB/octave.

- (10) S N: When followed by N, the S command selects the sensitivity. If the N is omitted, the command is a request for sensitivity. The range for "N" extends from "0" to "20", corresponding to a Sensitivity Range of 5 V-to-1 μV rms full scale in 5-2-1 sequence.
- (11) L N: When followed by N, the L command sets the auto-range sensitivity limit. If the N is omitted, the command is a request for the limit. The range for N is 0-to-20, corresponding to a sensitivity range of 5 V-to-1 μV in 5-2-1 sequence.

Expressed as a "BASIC" formula:

$$N = \text{INT}(\text{ABS}(3.0 * \text{LOG}(V) - 2.4))$$

where N = M5205/6 code and S = sensitivity in volts.

The formula for finding S, given N, is:

$$S = 10 \Delta - (\text{INT}(N/3)) * N1$$

The following BASIC program uses this formula to find S, given N:

```
10 N1 = N - (INT(N/3)*3) + 1
20 IF N1 = 1 THEN N1 = 5
30 IF N1 = 3 THEN N1 = 1
40 S = 10Δ - (INT(N/3))*N1
```

- (12) A1 N: If followed by N, the A1 command turns the AUTORANGE function on and off. If the N is omitted, it is a request to the AUTORANGE status. N = 0 turns the function OFF. N = 1 turns the function ON.
- (13) A2 N: If followed by N, the A2 command turns the AUTOSSET function on and off. If the N is omitted, it is a request for the AUTOSSET status. N = 0 turns the function OFF. N = 1 turns the function ON.
- (14) A3: This command causes the AUTO-OFFSET routine to run. [The sequence O 0 0 (that's OH ZERO ZERO) turns the AUTO-OFFSET function off.]
- (15) A4 N: If followed by N, the A4 command controls the AUTONORMALIZE routine. If the N is omitted, it is a request for the AUTONORMALIZE status. N = 1 turns the function ON. N = 0 turns it OFF.
- (16) A5 and A6: These commands are reserved for future use.
- (17) A7; AUTO-PHASE: In the Model 5206, the A7 command invokes a single iteration of the AUTO-RANGE routine and then an AUTO-PHASE routine. In the case of the M5205, each time an A7 command is received, one of the three steps required to complete an AUTO-PHASE routine is invoked. As a result, A7 is not generally a useful command in an actual experiment with a M5205. The AUTO-SET command (A2) is preferred.
- (18) Q1, Q2, and Q3: These commands cause the Channel 1 Output, the Channel 2 Output (M5206 only), or the Auxiliary Output value respectively to be transmitted via the interface. The number sent is an integer where -2000 = -f.s. and +2000 = +f.s. Readings may be up to 20% greater than full scale before data loss occurs. In the case of the Model 5205, the output (analog meter reading or AUX potential) is the actual parameter transmitted. In the case of a Model 5206, the quantity transmitted can be any of several parameters according to the selected OUTPUT MODE. Either voltage (CH 1, CH 2, or AUX), log of voltage, or phase angle (θ) can be selected (front-panel OUTPUT MODE key or "M N" command).

The instrument can execute a Q1 command

once in approximately 40 ms. If Q1 and Q2 commands are interleaved, one reading can be taken every 80 ms, and both channels can be read in approximately 160 ms. These intervals do not account for any time required by the host computer to receive the results of one command and transmit the next.

Here are some examples of Q1 commands not interleaved with Q2 commands:

```

Q1 (CR)
Q1 (CR)
or
Q1;Q1;Q1;Q1

```

Here are some examples of interleaved commands:

```

Q1;Q2
or
Q1 (CR)
Q2 (CR)

```

- (19) G N: If followed by N, the G command accesses the Gain DAC's used by the AUTO-NORMALIZE routine to scale the output voltage. If N is omitted, the command is a request for the present GAIN value. The allowable range for "N" is 0-to-4095. The default or "normal" value of "N" is 1638. With this value, a full-scale input signal will result in a full-scale output. The gain factor for other values of "N" is: N/1638. For example, the command G 4095 would increase the gain by a factor of $\times 2.5$. The command G 819 would decrease the gain to 0.5 of its normal level.

- (20) H N: If followed by N, the H command controls the front-panel LED's. If N is omitted, the command is a request for the LED status.

N	OPERATION
0.....	All LED's OFF
1.....	Normal Operation
2.....	All LED's ON (test function)

- (21) K N: If followed by N, the K command has exactly the same effect as pressing one of the front-panel keys. If N is omitted, the command is invalid. The key selected as a function of "N" is:

N	SELECTED KEY
0.....	DISPLAY
1.....	CH 1 OFFSET (OFFSET in M5205)
2.....	MODES
3.....	REFERENCE
4.....	PHASE
5.....	TIME CONSTANT
6.....	SENSITIVITY
7.....	SELECT
8.....	RUN/CLEAR
9.....	LOCAL
10.....	OUTPUT MODE (M5206 only)
11.....	CH 1 EXPAND (EXPAND in M5205)
12.....	SET (arrow down)
13.....	SET (arrow up)

There is an ambiguity problem that has to be taken into consideration in using a "K N" command. It is possible that the computer, not knowing which parameter is already addressed at the front panel, will select the parameter that is already addressed. The result will be a different selection than would have occurred if any other parameter were the one addressed prior to issuing the command. For example, assume the computer wanted to "press" the MODES key. If any parameter other than MODES-RESERVE were the one addressed when the "K 2" command was sent, MODES-RESERVE would be selected. However, if MODES-RESERVE were the one already addressed when the "K 2" command was sent, MODES-F BAND would be selected. The action exactly parallels that prevailing when pressing the keys manually. This ambiguity can be averted by always issuing "K" commands in pairs, where the first "K" command "presses" a key other than the one "wanted", and the second duplicates the action of the key of interest. Applied to the example, this would assure that MODES-RESERVE would be selected.

- (22) Y N: When followed by N, the Y command controls the acknowledgment function. If N is omitted, the command requests the acknowledgment status. The default condition is no acknowledgment. The command "Y 1" turns the function ON. "Y 0" turns it OFF. When the function is ON, the lock-in amplifier will respond with an OK (command recognized) or question mark (command not recognized) whenever it receives a command. The effect of the "Y N" command begins with the subsequent command. This is primarily useful during development of programs that use the RS232 Interface; the RS232 Interface cannot detect any invalid command via the Serial Poll. Once the program is developed, there is no need for the acknowledgment.

- (23) U: The U command controls the PROMPT function and applies to the RS232 Interface only. It is a write-only command and cannot be used without the parameter. When the PROMPT function is ON (U 1), on completing the execution of any command, the lock-in amplifier sends the asterisk to the host computer to advise it that the lock-in amplifier is ready for the next command. A PROMPT is also sent after the POWER-UP sequence to advise the computer that it is ready for the first command. A "U 0" command turns the PROMPT function OFF. The default state is ON.

- (24) V: This command causes the version number of the firmware in the lock-in amplifier to be sent. This number is provided to facilitate

communications between the factory and the user regarding firmware, operating, and service questions about the particular lock-in amplifier.

- (25) E: A read-only command, E causes the ERROR status of the previous interface command to be sent. Its purpose is to allow the host computer to verify that the previous command and its parameters were valid before proceeding to the next command. E is most useful during program development via the RS232 Interface. The error codes are:

ERROR CODE	MEANING
0.....	NO ERROR
1.....	OPTION NOT INSTALLED
2.....	INVALID COMMAND VIA THE INTERFACE
3.....	INVALID PARAMETER VIA THE INTERFACE
4.....	COMMAND OVERRUN—LOCK-IN STILL EXECUTING PREVIOUS COMMAND

- (26) Z: This command causes the STATUS byte to be sent by the lock-in amplifier. The STATUS byte contains information which is used to control the generation of service requests on the GPIB Interface. Each bit in the STATUS byte has an assigned meaning as follows:

BIT	MEANING
0	COMMAND COMPLETE: Signifies that the lock-in amplifier is ready for the next command. This bit is set to "1" at power-up and when the lock-in amplifier is ready for the next command. It is always cleared when the "Z" command is invoked.
1	INVALID COMMAND: This bit is set if the previous command was invalid. The principal utility of this bit would be in program development.
2	PARAMETER ERROR: This bit is set if the previous parameter was invalid. The principal utility of this bit would be in program development.
3	REFERENCE LOW: This bit is set if the reference signal is too low. If this happens, the user should check the applied reference signal and increase its amplitude as required.
4	OVERLOAD: This bit is set if there is an overload in the lock-in amplifier. If this occurs, the user should adjust the Sensitivity as required to end the overload. The OFFSET and EXPAND functions can also cause overload if used improperly.
5	SETTLED: This bit is set when the autoranging process has settled on a sensitivity. More specifically, it is set six time constants after the last change of range in an autoranging or autophase sequence. It is also set at power up and whenever the autoranging is turned off. It is cleared when autoranging is started, and is updated every six time constants when autoranging is active. NOTE: If 12 dB/octave is selected, it is set or updated after twelve time constants. With time constant values of 1 μ s through 100 ms, it is set or updated after 1.2 s (2.4 s with 12 dB/octave).
6	SRQ ASSERTED: This bit is set if a Service Request is currently being generated in the lock-in amplifier.

- 7 OUTPUT READY: This bit is set when the Lock-In Amplifier has output to send to the host computer. It is cleared whenever Z is invoked.

- (27) B N: A write-only command, "B" specifies the SERVICE REQUEST MASK BYTE (N is the decimal value of the byte). It, together with the STATUS BYTE (Z), determines whether the lock-in amplifier will generate a SERVICE REQUEST (SRQ). After a DEVICE CLEAR operation, the value of the byte is zero. At power-up, the value is that prevailing prior to the previous power-down. The SRQ MASK BYTE allows the user to specify which status conditions will cause an SRQ to be generated. The meaning of each bit in the SRQ MASK BYTE is the same as the corresponding bit in the STATUS BYTE. The logic state ("1" or "0") of each bit in the SRQ MASK BYTE is specified by the user. The logic state of the bits in the STATUS BYTE is determined by conditions in the lock-in amplifier. When a "1" in the STATUS BYTE matches a "1" in the corresponding bit of the SRQ MASK BYTE, the lock-in amplifier asserts the SRQ line. If a "1" in the STATUS BYTE matches a "0" in the corresponding bit of the SRQ MASK BYTE, SRQ is not asserted.

REF LOW and OVERLOAD are special cases. If one of these bits is unmasked (bit 3 or 4 in STATUS BYTE at logic "1" with logic "1" in corresponding MASK bits), the SRQ will be generated and the corresponding bit in the SRQ MASK will be cleared. The host computer must then try to correct the fault condition so that valid measurements can be taken. When the fault condition has been corrected, the host computer should re-arm the appropriate bit of the SRQ MASK. By correcting the fault and re-arming the bit, a low-reference or overload condition cannot cause an endless stream of SRQ's to be generated.

- (28) C N: A write-only command, when followed by N, the C command specifies the ASCII character to be sent by the lock-in amplifier as the delimiter between two numbers. The default or power-up delimiter is the comma. Any other ASCII character can be specified by the "N" byte, if desired. N is the decimal equivalent of an ASCII non-numeric character, viz., N = 44 for a comma, N = 59 for a semicolon. Note that this command governs only the delimiter for transmitted commands. The M5205/6 will accept any non-numeric character as a delimiter.
- (29) W N: A write-only command, when followed by N, the W command allows the function of the front-panel LOCAL key to be implemented via the interface. If N = 1, the front panel is locked out. If N = 0, the front panel is active.

- (30) N: This command allows the status of the three overload indicators to be read via the interface. On receiving "N", the lock-in amplifier responds with a binary coded decimal number from one to seven. A "1" in bit 0, bit 1, or bit 2 signifies an overload indication as follows:

BIT	M5206	M5205
0	CH 2 OVERLOAD	-----
1	CH 1 OVERLOAD	OUTPUT OVERLOAD
2	SIGNAL OVERLOAD	SIGNAL OVERLOAD

4.5 PRELIMINARY OPERATING CONSIDERATIONS

4.5A POWER REQUIREMENTS

The Model 5205/6 requires 95–130 V or 190–260 V, 50–60 Hz and has a power consumption of nominally 60 watts. A rear-panel switch selects the operating line-voltage range as discussed in Subsection 1.1D.

4.5B LINE FUSE

The Model 5205/6 is protected by a single fuse located at the rear panel. For operation from a nominal line voltage of 115 V, use a slow-blow fuse rated at 1 A. For operation from a nominal line voltage of 230 V, use a slow-blow fuse rated at 500 mA. See Subsection 1.1D for additional information regarding the line fuses.

4.5C WARM-UP

For most applications, five minutes should be sufficient. However, where it is necessary to achieve the best possible gain and phase stability, allow an hour.

4.5D OPERATING FREQUENCY

Although one can, in principle, make equally accurate measurements at any frequency within the operating range of the instrument, operation is simplest and least subject to error over a range having as its lower limit, perhaps a few hundred Hz, and as its upper limit, perhaps 10 kHz. At low frequencies, 1/f noise, including both that which develops in the Model 5205/6 and that which originates in the experiment itself, degrades the signal-to-noise ratio. In addition, increased response and settling time could be a significant problem at very low frequencies. At high frequencies, radiation and associated pickup tend to be bothersome. Another high frequency problem is that of signal attenuation as a result of the input cable capacitance. This can be particularly noticeable when working from a high source resistance. Other frequencies to avoid are the power frequency and its lower order harmonics. By avoiding them, the likelihood of the output being influenced by power frequency pickup, either internal or external, will be minimized.

4.5E GROUNDING

In any system processing low-level signals, proper grounding to minimize the effects of ground loop currents, usually at the power frequency, is an important consideration. In the case of the M5205/6, special design techniques have been employed to give a high-degree of ground-loop signal rejection in single-ended measurements. The outer shells of both the "A" and "B" signal input connectors are tied together and returned to ground through a 10 Ω resistor. This 10 Ω resistor attenuates ground loop currents by the ratio of the 10 Ω to the braid resistance of the input cables. Moreover, this ground-loop current reduction is achieved without adversely affecting the signal to be measured in any way. Figures IV–7 and IV–8 illustrate two ways of measuring single-ended signals. Referring to Figure IV–7, note that the signal source is located inside a grounded enclosure to which signal source common is attached at one point.

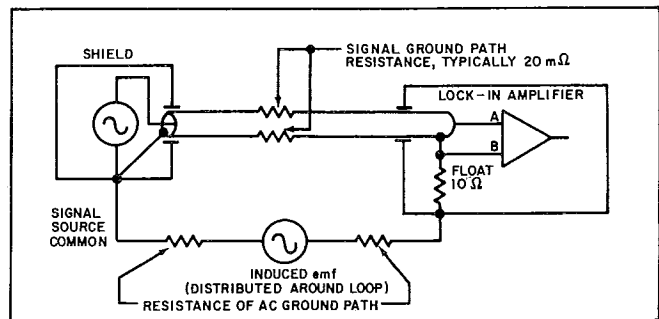


Figure IV-7. GROUND LOOP SUPPRESSION BY 10 Ω INPUT GROUND

The braid of the signal is grounded directly to signal source common as well, thereby assuring that no signal currents or ground-loop currents will flow through the shield (desirable for optimum shielding). The Model 5205/6 Input switch is set to "A" ("A" connector only is active with the switch in this position) and the shell of the input connector is returned to ground through an internal 10 Ω resistor. A ground-loop generator is indicated as being connected between the chassis of the M5205/6 and signal source common. This path would ordinarily consist of the line cord "third wire" (ground) paralleled by the braids of other cables connecting the system components. The ground loop generator causes currents at the power frequency to flow through the braid of the signal cable, through the 10 Ω resistor, and back through the ac ground path to complete the loop. The 10 Ω resistor reduces the magnitude of the ground-loop currents. More importantly, most of the ground loop signal is dropped across the 10 Ω resistor and little across the braid of the signal cable, the ratio being the 10 Ω of the resistor to the 10–20 milliohms (typical) of the braid resistance. As far as the M5205/6 is concerned, the ground loop signal is reduced by this ratio, and the ground loop interference is thus perhaps a factor of a thousand less than it would have been had the

input connector shell been returned directly to ground. This operating input configuration should give excellent results in most applications involving the measurement of single-ended signals.

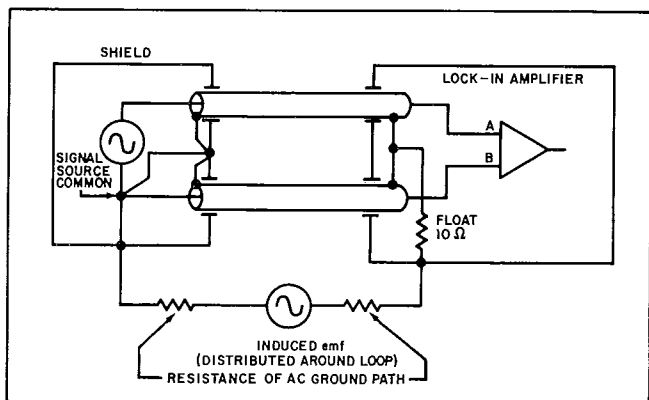


Figure IV-8. DIFFERENTIAL MEASUREMENT OF SINGLE-ENDED SIGNAL

Conceivably, there might be applications where input ground-loop signal would still be a source of significant interference. Figure IV-8 shows how "A-B" operation using both inputs can be used to obtain an even greater rejection of ground-loop interference. Two input cables are used, one connected to the signal source and the other to signal source common. At the source end, the braid of both cables is returned to signal source common. At the lock-in amplifier end, the $10\ \Omega$ ground serves to attenuate the ground-loop currents and minimize the ground loop signal drop across the cable braids, the same as in the single-input measurement. However, the major reduction in ground-loop interference comes not from the $10\ \Omega$ ground return, but rather from the use of the differential measurement technique. In the example illustrated in Figure IV-7, the amplifier "looked" at the potential difference between the center conductor of the cable and the braid. In the differential measurement (Figure IV-8), the amplifier "looks" at the potential difference between the "A" Input and "B" Input. The ground-loop current in the signal braid is of no consequence. The common mode rejection of the amplifier prevents the braid signal from interfering. In operating differentially, it is important to assure that all common-mode interference arising in ground loops is just that, that is, without a significant differential component. This should not prove a problem as long as both signal cables are the same length and follow the same path.

Figure IV-9 shows the M5205/6 operated differentially to measure an "off ground" signal. The most important consideration in using this measurement configuration is to be sure the common mode signal component is not so large as to exceed the common-mode input limit of the M5205/6 (see specifications).

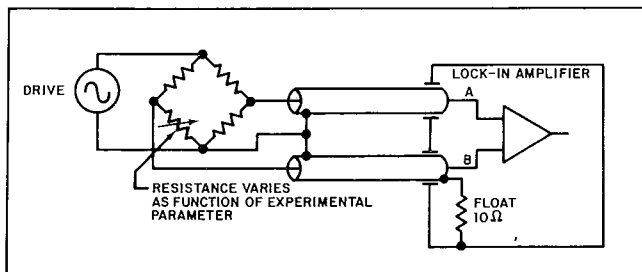


Figure IV-9. DIFFERENTIAL MEASUREMENT OF "OFF GROUND" SIGNAL

The reduction of power frequency interference is not the only benefit to be derived from proper grounding and differential operation. A much more serious source of interference is coherent interference at the signal frequency, such as is produced when reference current is present in the signal cable braid. Figure IV-10 shows a measurement in which care has been taken to avoid coherent interference. All of the reference drive signal current is returned directly to the drive signal source except for the very small component (reference channel input resistance of the M5205/6 is $10\ \text{M}\Omega$) applied to the M5205/6 by way of the Reference Input. No current, whether drive current, reference current, or signal current, is permitted in the experiment shield; the shield contacts ground at one point only. The only coherent signal in the parallel path of the signal cable braid is a small portion of that allowed by the $10\ \text{M}\Omega$ Reference Input resistance. Furthermore, by measuring differentially, the influence of that small component is reduced to a negligibly small level. By using the illustrated techniques, one could operate with very large drive currents without concern that they will contaminate the signal of interest. If electro-static coupling of the drive signal to the detector is a problem, mounting a conducting material around the signal detector should prove helpful. The electrostatic shield should be connected to the system at but one point, signal source common.

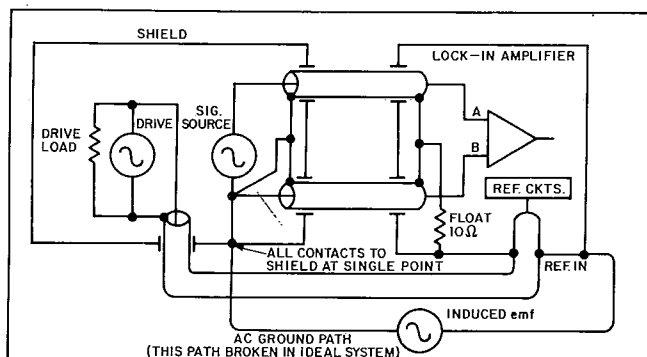


Figure IV-10. COHERENT INTERFERENCE MINIMIZED

4.5F NOISE

Any electronic signal processing system adds noise to that already accompanying the signal to be measured, and the M5205/6 is no exception. Even though the method of signal processing used allows very large improvements in signal-to-noise ratio to be achieved, the amount of noise contributed by the instrument itself affects its performance and limits the achievable improvement. The following discussion of noise figure is potentially important if the M520 is to be used with a preamplifier for which noise figure contours are available. If this is not the case, this noise discussion will mainly be of academic interest only.

One convenient way of specifying the noise performance of an amplifier is to speak of its noise figure, which specifies the amount of noise the amplifier adds to the source thermal noise. Source thermal noise is used as the basis for comparison because it is completely predictable, always present, and is the least amount of noise that can possibly accompany any signal. Its value, in volts rms, is given by:

$$E_n = (4kTBR_s)^{1/2}$$

where:

E_n = rms noise voltage within the bandwidth of the measurement

k = Boltzmann's constant = 1.38×10^{-23} joules/kelvin

T = absolute temperature in kelvins

R_s = resistance in ohms of the resistive component of the impedance across which the voltage is measured

B = Bandwidth over which the measurement is made.

Mathematically expressed, noise figure can be stated as:

$$NF \text{ (dB)} = 20 \log_{10} \frac{\text{Noise Voltage at Output of Amplifier}}{\text{Portion of Numerator Attributable to Source Thermal Noise}}$$

Noise figure is not constant but varies as a function of the source resistance, frequency, and temperature. When the loci of all points having the same noise figure are plotted as a function of frequency and source resistance (temperature constant), the result is a noise-figure contour. A full set of contours completely specifies the noise characteristics of an amplifier over its working range. Although noise-figure contours are not provided for the M5205/6 *per se*, they are available for most of the preamplifiers that can be used with the M5205/6. When a lock-in amplifier is used with a preamplifier, the noise figure of the measurement system in most situations will simply be that of the preamplifier for all practical purposes. Noise figure contours clearly indicate the best noise performance region in terms of operating

frequency and source resistance. They additionally allow one to directly compute the total noise accompanying the signal (amplifier noise and source thermal noise considered, other noise sources neglected). The relating formula is:

$$E_r = (4kTBR)^{1/2} \times 10^{NF/20}$$

where E_r is the total noise referred to the input in volts rms and all other terms are as defined previously. With a noise figure of 3 dB, the amount of noise contributed by the amplifier is 1.4 times the source thermal noise. At 1.4 times the thermal noise, the amplifier noise just begins to be noticeable. At lower noise figures, the amplifier for all practical purposes may be regarded as noiseless. Generally, if one can operate anywhere inside the 3 dB contour, amplifier noise considerations may be neglected.

As critical as amplifier noise is in certain applications, it is nevertheless possible to over-emphasize its general importance. For example, if the signal amplitude is significantly higher than the amplifier noise, the subject becomes purely academic. Also, as previously mentioned, if a preamplifier is used ahead of the lock-in amplifier, the noise figure of the system is generally that of the preamplifier. The principal consideration in such a case should be to operate inside the 3 dB contour *of the preamplifier*.

Two situations deserve special attention, the first being operation from a source resistance very much lower than optimum, and the second being operation from a source resistance very much higher than optimum. In either case, there may be a temptation to "improve" the noise performance by using an external resistor to obtain a "better" source resistance. In the case of the low source resistance, the user may be tempted to connect a resistor in series with the source. In the case of the high source resistance, the user may be tempted to connect a resistor in parallel with the source. Unfortunately, neither approach to the problem does any good and, in fact, both will result in further degradation of the signal-to-noise ratio ahead of the lock-in amplifier. The series resistor adds its thermal noise to that already accompanying the signal. Although the amplifier shows a "better" noise figure than before, it is only because the amplifier noise is now less relative to the thermal noise of the combined resistance (source plus series resistor). The signal is no larger (in fact, it may well be attenuated), the noise is greater, and the improved noise performance is illusory. Recall that noise figure only relates amplifier noise to thermal noise, and does not denote the absolute value of amplifier noise.

Connecting a parallel resistor to lower a high source resistance has a similar effect. Even though the thermal noise does go down, the signal amplitude goes down even more. For example, if a source of resistance R were paralleled by another resistor of the same value, the signal amplitude would go down by a factor of two. However, the thermal noise would only be reduced to .707 of its initial value (thermal noise varies directly with the square root of the resistance), with a net degradation in signal-to-noise ratio.

CAUTION

DO NOT CONSTRUE THIS TO MEAN THAT A LOAD RESISTOR ISN'T REQUIRED WHEN WORKING FROM A PHOTOMULTIPLIER. PHOTOMULTIPLIERS ARE DC DEVICES. THE INPUT TO THE LOCK-IN AMLIFIER IS AC COUPLED. IF THE USER DOESN'T PROVIDE A LOAD RESISTOR BETWEEN THE OUTPUT OF THE PHOTOMULTIPLIER AND GROUND, THE PHOTOMULTIPLIER WILL NOT WORK CORRECTLY. THE OPTIMUM VALUE FOR THIS RESISTOR WILL DEPEND ON THE TUBE AND EXPERIMENTAL PARAMETERES. HOWEVER, IN MANY APPLICATIONS, 1 M Ω WILL GIVE GOOD RESULTS.

One can usually improve an amplifier's noise performance dramatically when working from a lower source resistance by using a signal transformer to raise the source resistance seen by the amplifier. The improvement obtained with a transformer is real. The amplitude of both the signal and noise increases by the turns ratio, but the source resistance increases by the square of the turns ratio. By selecting the proper turns ratio, one can operate at a source resistance where the amplifier is essentially noiseless. For example, if one were working from a 10 Ω source into a preamplifier having a very low noise figure at 100 k Ω , one could use a 1:100 step-up transformer so that the preamplifier would see a source resistance of 100 k Ω . At 100 k Ω the preamplifier would add little additional noise. Even though the thermal noise of the transformer adds to that of the source, a very considerable improvement is usually achieved. EG&G PARC manufactures a line of signal transformers that can be used to raise the source resistance of signals. Performance information can be obtained from the factory or one of its representatives.

When working from a high source resistance, one could, in principle, use a transformer in an analogous manner to improve noise performance. Unfortunately, practical transformer design considerations usually prevent one from doing so. As a result, the options available to an experimenter working with a high source resistance are limited. If working with a photomultiplier, the best one can usually do is to make the load resistor as large as possible. The larger the load resistor, the less the

shunting effect it will have, and the better the signal-to-noise ratio will be at the input of the amplifier. This occurs because the signal amplitude varies directly with the load resistance, while the thermal noise varies with the square root of the noise resistance.

Note that the preceding discussion of noise is based on comparing the noise generated by the amplifier with the source thermal noise. In many situations, other types of noise or interference may accompany the signal as well and could even dominate it. Where this is the case, the amplifier can only perform "better" than the noise figure contours indicate because noise figures are based on a comparison of amplifier noise with the minimum possible noise that can accompany any signal, namely, the source thermal noise.

4.6 OPERATING THE M5205/6

4.6A INTRODUCTION

Operation of the M5205/6 is straightforward. In most instances, the user simply connects the reference signal and the signal to be measured, uses the Set and Select keys to establish the operating parameters, and then reads the signal amplitude and/or phase from the digital display or panel meter.

In many situations, achieving a successful measurement will depend not so much on critically adjusting the M5205/6 controls as on taking the proper steps with respect to the constraints discussed in Subsection 4.5. Factors such as proper grounding and operating inside the 3 dB contour of the preamplifier can be important in making low level measurements.

4.6B A TYPICAL MEASUREMENT

Although the details may vary from one situation to another, most measurements involve going through a sequence pretty much like the one that follows.

- (1) Press in the SELECT key and, while it is depressed, press SENSITIVITY, thereby establishing the "default" selections.
- (2) Connect the reference signal (1 V rms sine wave is "ideal"). The time to establish reference lock will vary with the frequency as given in the specifications.
- (3) Connect the signal to be measured. If doing a single-ended measurement, connect the signal to the "A" connector and set the associated toggle switch to "A". If doing a differential measurement (including one of a single-ended source), connect one signal input cable to "A", the other to "B", and set the associated switch to "A-B".

- (4) Press the AUTOSSET key as required to light the AUTO-SET LED.
- (5) Press the RUN/CLEAR pushbutton to initiate the automatic measurement sequence. The AUTO-SET ACTIVE LED will light and remain lighted while the measurement is in progress. During this time, the instrument automatically adjusts the sensitivity and phase as required to make the measurement. When this LED extinguishes, the digital display will indicate the amplitude of the applied signal.

More often than not, simply establishing the default parameters and using the auto-set function in this way will result in a valid, accurate measurement. However, situations may arise where the experimental constraints are such as to preclude the use of this simple procedure. Where this is the case, it will be necessary to have a more detailed understanding of the instrument's operation and capabilities, and to set the various parameters manually to obtain a good measurement. These factors are discussed in the following paragraphs.

4.6C REFERENCE CHANNEL

REFERENCE SIGNAL REQUIREMENTS: The M5205/6 can lock onto and track a wide range of possible signals. Once locked on, the reference channel remains locked, even if the reference input signal changes frequency. The time to achieve reference lock depends on the frequency of the applied signal and on the selected frequency band. There is no direct indication of when frequency lock occurs. At a low frequency, as much as a minute might be required. At high frequencies, frequency lock occurs in a few seconds.

The only requirements of the reference signal are that its amplitude be at least 140 mV pk-pk, that it cross its mean twice each cycle, and that it remain on each side of the mean for at least one microsecond. Sine waves, square waves, triangle waves, and others are all suitable. Perhaps the "ideal" reference signal is a 1 V rms sine wave.

Even though the M5205/6 can accept and track a wide range of possible reference signals, it is nevertheless important that the reference signal used be relatively noise free. Any superimposed noise can cause many small zero crossings to occur in the region of the main waveform zero crossings, with the result that the Reference Channel momentarily "sees" a much higher frequency than what is actually being applied. When this happens, the reference "lock" can be lost. Frequently, moderately noisy signals can be cleaned up sufficiently for satisfactory use by interposing a single-section low-pass filter between the reference signal source and the Reference Input connector.

FREQUENCY SLEWING: One particularly attractive feature of the M5205/6 is that it maintains reference lock as the reference frequency is changed. However, some phase slippage develops while the frequency change is in progress. As soon as the frequency stops changing, the pre-existing phase relationship is re-established. The slippage specification for the M5205/6 is 5° maximum phase shift if the slew rate is no faster than one decade per fifty seconds.

REFERENCE MODES: There are three reference modes, INTERNAL, EXT. f, and EXT. 2f. The modes are accessed with the REFERENCE and SET keys as previously discussed. In making external mode measurements, the reference channel is driven from an externally derived signal applied to the REFERENCE INPUT connector. This signal is usually derived from the experiment drive signal, that is, both it and the signal to be measured can be traced to a common source. Of the two external modes, the EXT.f mode is the one most commonly used. In this mode, the instrument demodulates with respect to the frequency of the applied reference signal. The EXT. 2f mode is used for second-harmonic measurements. The applied reference signal is presumed to be at the frequency of the signal being measured, but demodulation is done at twice that frequency. The output level then varies only with the amplitude of the 2f component of the input signal, and is not influenced by the fundamental.

Operation in the INTERNAL reference mode differs in that the lock-in amplifier acts as the source of the drive signal. An internal oscillator running at the user-programmed frequency generates a signal that drives the demodulator(s). In addition, this signal is provided at the rear-panel OSCILLATOR OUTPUT connector so that it can be routed to the experiment to control the timing there. This mode is well suited to applications in which the experiment does not produce a suitable reference signal, but is capable of being timed by such a signal developed in the lock-in amplifier. INT. reference mode operation can only be established in units equipped with the INTERNAL OSCILLATOR option.

PHASE CONTROLS: The PHASE and SET keys determine the phase of the synchronous detection process. These keys set the phase shift introduced in the reference channel in degrees of advance. The M5205 and M5206 differ primarily in that, where the M5205 has one phase-sensitive detector (demodulator), the M5206 has two. The output of these detectors varies with the cosine of the angle between the reference and signal inputs to them. Thus, a demodulator's output is maximum when the reference and signal, at its inputs, are in phase. If the inputs to a demodulator are in quadrature, the demodulator output will be zero. In the Model 5206, the two demodulators are

driven in quadrature. Therefore, when the phase is adjusted for maximum indication at one output, the other output will be zero. Since the rate of change of the cosine function with phase is much faster at 90° than it is at 0° , the phase adjustment is most sensitive when adjusting for "zero" output. Suitable procedures follow for making the phase adjustments manually. (The Phase adjustments can be made automatically using the AUTO-SET capability as previously described.)

(1) MODEL 5205

- (a) With the reference and input signals applied, adjust the sensitivity for some indication on the panel meter. (Although unlikely, it is at least possible that the reference and signal would already be exactly in quadrature, with the result that there would be no meter indication. Consequently, if the meter does not deflect, try shifting the phase 90° to get the meter to deflect.)
- (b) Shift the phase as necessary to peak the meter indication. This is a rough adjustment only. If the amplitude of the signal warrants, change the sensitivity as necessary to obtain as near full-scale indication as possible. If the meter indication fluctuates due to noise accompanying the signal, try increasing the time constant as required to get a stable reading.
- (c) Increment the phase setting by 90° , placing the reference and signal in quadrature. Then, using the FINE phase shift function, bring the reference and phase exactly into quadrature as indicated by a panel meter reading of exactly zero. If the digital display is monitoring the output, it will also indicate "0". However, if there is any noise at all at the output, it will be easier to set the phase for the desired zero reading while observing the analog meter than while observing the digital display. (The eye readily integrates the analog fluctuations.)
- (d) Having established exact quadrature between the reference and signal, the user has only to increment the phase by 90° to bring the signal and reference at the input to the detector exactly into phase (positive output indication) or 180° out of phase (negative output indication), depending on the direction of the 90° increment. The signal level can then be read from the panel meter or digital display. To determine how much phase shift was introduced in the reference channel to establish the desired phase relationship at

the demodulator, simply use the DISPLAY key to activate the read-phase function.

(2) MODEL 5206

- (a) With the reference and input signals applied, adjust the sensitivity so that at least one of the panel meters deflects (use the X,Y Output Mode).
- (b) Adjust the phase so that one panel meter indicates zero and the other one peak. Usually users adjust for peak on the X meter and zero on the Y meter, although it could as well be reversed. If necessary, change the sensitivity to keep the peak indicating meter on scale. If there are any meter fluctuations due to noise accompanying the signal, try increasing the time constant as required to reduce the noise to an acceptable level.
- (c) Continue the phase-setting process while observing the zero-indicating meter and fine-adjusting the phase for a meter reading of exactly zero. When the meter reads "0", no further improvement in the phase setting can be made. The signal level can be read from the other meter or from the digital display. Note that the digital display can also be used for the phase adjustment. However, when adjusting for zero, if there is any noise at all at the M5206 output, it will be easier to set the phase while observing the analog meter than while observing the digital display. To determine how much phase shift was introduced in the reference channel to establish the desired phase relationship at the demodulator, simply use the DISPLAY key to select the phase-reading function.

Note that the phase is not shifted with respect to that at the Input and Reference input connectors, but rather with respect to the phase relationship prevailing at the reference channel "firing point", which is at nominally ± 100 mV. Given a reference signal that is at 0° with respect to the input signal, the firing point will be very near 0° if the reference signal is large (1 V rms sine wave for example). With lower amplitude sine wave signals, or with waveforms of other shapes, the firing point may not be at 0° . For example, with a sine-wave reference just large enough to trigger the reference channel, there will be a phase delay of nearly 90° . Square waves have the smallest phase delay versus amplitude transfer function. Sawteeth have a larger transfer function than sine waves. Any instability in the amplitude of the reference signal will introduce phase jitter.

4.6D SIGNAL CHANNEL

INTRODUCTION: Configuring the Signal Channel to the experiment consists of making the input connections properly, making the mode selections, and setting the sensitivity. Each of these is discussed below.

INPUT CONNECTIONS: There are two input connectors, one labeled "A", the other "B". Associated with them is a toggle switch that allows the user to select "A" or "A-B". When the switch is set to "A", the "A" Input connector only is active. When the switch is set to "A-B", both inputs are active. The "A only" configuration is used for single-ended measurements. The "A-B" configuration is used for differential measurements. Note that signals from single-ended sources can be processed differentially as previously explained to minimize ground-loop interference. There is a 180° phase difference between the two inputs. If a signal that is in phase with the reference signal is applied to the "A" input, it will arrive at the demodulator (In-Phase Demodulator in the M5206) in phase and develop a positive output. The same signal applied to the "B" input will arrive at the demodulator 180° out of phase and develop a negative output.

MODES: The MODES key provides the means of selecting the desired F BAND and RESERVE modes.

- (1) RESERVE: Reserve is a measure of how large an interfering signal can be without causing overload. There are three Reserve modes, HIGH RESERVE, NORMAL, and HIGH STABILITY. In the HIGH RESERVE mode, non-coherent interfering signals can be 60 dB above full scale without overloading the instrument. In the NORMAL reserve mode, the reserve is 40 dB, and in the HIGH STABILITY mode, it is 20 dB. In terms of voltage, the reserve ratios are 1000:1, 100:1, and 10:1 respectively, with the constraint that interfering signals cannot exceed 14 V pk-pk at the input of the lock-in amplifier. In choosing a reserve setting, the user is making a tradeoff between the amount of interference that can be tolerated and the instrument's output stability. In the HIGH RESERVE mode, the output stability is 1000 ppm/ $^\circ$ C. In NORMAL it is 100 ppm/ $^\circ$ C, and in HIGH STABILITY it is 20 ppm/ $^\circ$ C. For the the output to be as stable as possible, the reserve setting should be no higher than necessary. What this means practically is using the HIGH STABILITY mode when measuring steady signals or signals accompanied by little interference, using the NORMAL mode when measuring moderately noisy signals, and using the HIGH RESERVE mode when the noise level is high enough to

cause overload in the NORMAL mode. Users should additionally note that there are sensitivity restrictions on the three reserve modes as well. HIGH STABILITY measurements can be made with sensitivities of 100 μ V through 5 V, NORMAL measurements can be made with sensitivity settings of 10 μ V through 50 mV, and HIGH RESERVE measurements are restricted to the range of 1 μ V through 5 mV.

The EXPAND function affects dynamic reserve and output stability as well. When activated, it increases the reserve and degrades the output stability by a factor of ten. In the case of the M5206, Channel 1 only is affected.

- (2) F BAND: There are three frequency bands, each supported by a different plug-in circuit card. A given unit may have one, two, or all three cards. If the user attempts to select a frequency band for which the corresponding circuit card has not been installed, an error indication will occur. Users should not take the specified frequency limits for each band as defining the frequency range over which measurements can be made with a given F BAND circuit card, but rather the range over which instrument performance will be optimized by the use of a particular card. Each card will in fact operate a little above and below its specified range. The choice of frequency band affects many parameters, including input low-pass filter response, intermediate frequency response, phase shift, and maximum noise rejection as a function of frequency. These parameters, which differ from one F BAND card to another, can be important in a critical measurement, although users are most unlikely to be concerned about any of these parameters in a typical measurement. Typical curves for these parameters are provided in the specifications.

Summarizing F BAND selection considerations, select the F BAND which "contains" the operating frequency (see Specifications). If the operating frequency falls in the range of more than one of the available F BANDS, excellent results with either (or all three) can be expected. In certain measurements, image rejection or other considerations may make one band preferable over the other (see Specifications for typical curves for each band). If the operating frequency is outside the specified range of the available F BAND circuit cards, try making the measurement anyway. Depending on the characteristics of the signal and/or interference, good measurements may be possible, particularly where the frequency is below the range of the F BAND card available.

SENSITIVITY: The selected sensitivity sets the amount of coherent in-phase signal at the input that results in full-scale output. The sensitivity is manually selected with the SENSITIVITY key (SET lighted), and is directly indicated by the LED's above the SENSITIVITY key. It can also be controlled automatically via AUTORANGE or AUTOSET. Users also have the option of increasing the sensitivity by a factor of ten using the EXPAND function. If activated, the EXPAND ON LED above the SENSITIVITY key will light. Note that the Expand function affects the Dynamic Reserve as well as the sensitivity. When EXPAND is on, the amount of noise (relative to the full-scale input level) that can be tolerated increases by a factor of ten. The tradeoff is that the output stability is degraded by a factor of ten as well. Thus the expand capability can be beneficial when measuring very noisy or very small signals.

When AUTO LIMIT is lighted, the SENSITIVITY key is used to set the maximum sensitivity to which the instrument can range in AUTO RANGE or AUTO SET operation.

Note that Sensitivity and Dynamic Reserve interact. HIGH STAB operation is available for sensitivities from 100 μV to 5V inclusive. NORMAL RESERVE operation is available from 10 μV to 50 mV inclusive, and HIGH RESERVE from 1 μV to 5 mV. If a sensitivity outside the range of the selected reserve is selected, the reserve selection will automatically change to accommodate the new sensitivity. In other words, sensitivity dominates reserve.

To set the sensitivity manually, begin with a low setting (5 V) and step through the available sensitivity settings until the meter deflects. If necessary, adjust the phase to maximize the indication during the Sensitivity setting process. If overload occurs with less than full-scale meter indication, increase the time constant and/or set the reserve to NORMAL or HIGH RESERVE, as required. Bear in mind that each reserve value is available over a specific range of sensitivity settings. The greater the time constant, the greater the output smoothing. However, if the instrument is overloading ahead of the mixer (not enough reserve), increasing the time constant will not prevent overload. With moderately noisy signals, a time constant of 300 ms is generally suitable for the sensitivity and phase-setting processes. (Three hundred milliseconds gives good smoothing without unduely slowing the response time.) Once the optimum sensitivity setting has been determined, the time constant can be increased to further smooth the output indication, if desired. A time constant smaller than 300 ms can, of course, be used if the noise level is small.

Because the EXPAND capability degrades the output stability, it is better reserved for use in situa-

tions where the additional reserve it provides is really required. For example, suppose that, in attempting to set the sensitivity to measure a noisy 30 μV signal, the unit overloads with a sensitivity setting of 500 μV (HIGH RESERVE). By setting the sensitivity to 1 mV, the overload is brought under control, but the resulting meter indication (phase optimized) is only 3% of full scale. The expand can be used to increase the meter indication to 30% of full scale, corresponding to an indicated signal level, taking the expansion into account, of 30 μV .

4.6E OUTPUT CONTROLS

TIME CONSTANT: The coherent signal at the input of the lock-in amplifier is converted to dc by the synchronous detector(s). Input noise that reaches the detector is not converted to dc, but simply shifted in frequency. For example, a noise component that is 100 Hz below the i.f. frequency at the input to the detector will simply be at 100 Hz at the output of the detector; the detector subtracts the i.f. frequency from each input component. Thus, noise reduction after detection is an important consideration in evaluating lock-in amplifier performance. Output noise reduction is implemented by means of low-pass filters controlled by the TIME CONSTANT key. Time constants from 1 ms to 100 s (6 dB/octave or 12 dB/octave) can be selected. In principle, the signal-to-noise ratio can be improved to any arbitrary degree simply by making the filter time constant long enough. Practical considerations, however, generally set a limit on what can be achieved. The improvement in signal-to-noise ratio varies with the square root of the time constant. As a result, the measurement time becomes very long as the time constant is increased to obtain a better signal-to-noise ratio. As a practical guide, the correct time constant is that which reduces the noise to an "acceptable" level.

The equivalent noise bandwidth (ENBW) of a single-section 6 dB/octave filter is 1/4 TC. Its rise time from 10% to 90% of full amplitude is 2.2 TC (0% to 95% is 3 TC). With a 12 dB/octave time constant, the ENBW is 1/8 TC and the 10% to 90% rise time becomes 3.3 TC (0% to 95% is 4.8 TC). Note that the pre-detector passband limiting circuits affect the ENBW as well. Typical response curves for these circuits as a function of the selected reserve mode are provided in the specifications.

ZERO OFFSET: Both manual and automatic offset capabilities are provided. These capabilities facilitate measuring small changes in signal amplitude as a function of time or some other experimental parameter. For example, suppose one had a 70 μV signal. Assuming this signal were measured on the 100 μV sensitivity range with no output expansion, the resulting meter indication

would be 70% of full scale. To examine small variations in this signal using the manual offset capability, one would turn on the function with the OFFSET key (CH 1 OFFSET key in the case of the M5206), taking care to select the negative polarity (negative polarity is used to offset positive output indications; positive polarity is used to offset negative output indications). Then, while noting the output level on either the analog or digital meter, increment the offset until the meter indication is reduced to "0". At that point, full scale would be $\pm 100 \mu\text{V}$ with respect to the $70 \mu\text{V}$ zero indication, allowing amplitude variations to be easily tracked. If the signal level were to increase to $80 \mu\text{V}$, the meter would indicate +10% of full scale. If it were to decrease to $60 \mu\text{V}$, the meter would indicate -10% of full scale. For greater sensitivity, the EXPAND function could be activated, giving a sensitivity of $\pm 10 \mu\text{V}$ full-scale. With the EXPAND activated, zeroing the output indication can be done more precisely and with greater sensitivity than it can with EXPAND off. Bear in mind that, in the case of the Model 5206, the Channel 1 Output only has the offset capability.

Rather than manually adjust the offset, it will usually prove easier to take advantage of the AUTO-OFFSET capability. Each time AUTO-OFFSET is activated, the precise amount of offset required to zero the output is automatically introduced, the process taking about a second. As with manual offset control, EXPAND can be either ON or OFF, as appropriate for the desired sensitivity.

NORMALIZE: The AUTO-NORMALIZE function ideally configures the M5205/6 for measurement against a standard. When this function is activated, the instrument gain is automatically adjusted so that the "standard" input signal yields full-scale output, the only prerequisite being that the standard input signal be between 40% and 110% of full scale. This capability has application wherever a large number of readings are to be compared with a standard. For example, suppose an electronic manufacturing process in which each manufactured component is evaluated by a measurement made with the M5205/6. Further assume that a particular component has been selected as being the standard against which all others are to be compared. With this component in the measurement circuit, the gain of the M5205/6 would be adjusted for an output between 40% and 110% of full scale. Next, AUTO-NORMALIZE would be activated, automatically adjusting the M5205/6's sensitivity for exactly full-scale output. Based on the previous history of the components, one could then select some minimum reading, relative to the standard, that each component must yield to be considered "good". For example, one might determine that those components with readings lower than 70% of standard should be rejected. AUTO-NORMALIZE

assures that this decision point will correspond with measurement readings of 70% of full scale. "Conversion factors" would not have to be applied, the readings could be made easily and quickly, and the possibility of reading errors would be reduced.

Another application for the AUTO-NORMALIZE capability might be in making noise measurements. In this case, the standard component would be the one that yields the maximum acceptable noise. By setting the measurement level for this component to full scale, a convenient standard reading is established. Any component which subsequently yields a reading greater than full scale would be considered unacceptable.

OUTPUT CONNECTORS AND METERS: In the Model 5205 there is a single front-panel OUTPUT connector. In the Model 5206, there are two OUTPUT connectors, one for each channel. For both instruments, these connectors are paralleled by connectors on the rear panel for operator convenience in making system connections. The source resistance at all of these connectors is 600Ω and full scale output is $\pm 10 \text{ V}$. In each case, full-scale connector output corresponds to full-scale deflection on the associated analog panel meter. The analog meter capabilities are a bit different for the two instruments. In the Model 5206, the user can choose to display any of several different parameters on these meters as selected with the OUTPUT MODE switch. In the M5205, the meter is always connected to the output of the phase-sensitive demodulator.

Both models are additionally equipped with a digital panel meter. In the Model 5205, the digital panel meter can display the Output level, the phase, or the offset. If the unit is equipped with the Internal Oscillator Option, the set oscillator frequency can be displayed as well by selecting INTERNAL FREQ. (An oscillator frequency indication will be generated even if the unit is not equipped with the Internal Oscillator Option. Such an indication has no validity.) AUX allows the output of an accessory operating in one of the rear-panel accessory slots to be displayed as a percentage of full scale.

The Model 5206 differs in that the Channel 1 and Channel 2 output levels can be separately displayed on the Digital Panel Meter. Moreover, these levels do not necessarily represent the output of the phase-sensitive detectors. The OUTPUT MODE key gives the user access to several different sets of parameters. If X,Y is selected, the outputs are connected to the demodulators. Except that two demodulators are involved, the situation exactly parallels that in the M5205. If R, θ is selected, the magnitude is provided at the Channel 1 Output, and the difference phase at the Channel 2 Output. Note that this phase indication

is not the same as that displayed on the digital panel meter when PHASE is selected with the DISPLAY key. The following example should help to illustrate the difference. Assume an input signal which is at 30° with respect to the reference. Further assume that the phase shift capability has been used to obtain maximum Channel 1 output (X,Y selected with the OUTPUT MODE key). If the DISPLAY key is then used to select PHASE, the digital panel meter will indicate 30° , the phase shift introduced by the operator to bring the signal and reference into phase at the input of the phase-sensitive detector. If the DISPLAY key is then used to display CH 2, and the OUTPUT MODE key is used to select R,θ , both the Channel 2 analog meter and the digital panel meter should indicate zero, the difference phase at the input of the phase-sensitive detector. LOG R,θ can also be selected. Except that the log of R in dB below full scale is displayed, as opposed to R, this output display function is the same as R,θ . PHASE LOCK is a special measurement mode, functional only in units equipped with the Internal Oscillator Option and operating in the internal reference mode. As previously discussed, this mode can be used to make measurements without the need for a reference signal. However, it is limited to the measurement of "clean signals" at a known stable frequency.

4.7 INTERNAL (CIRCUIT CARD) OPTIONS

4.7A F BAND CARDS

The Model 5205/6 has three operating frequency bands, each determined by the choice of F BAND circuit card installed. One, two, or three circuit cards can be installed. Most often units are purchased with the broad-band card, which yields excellent measurement results over a wide frequency range. However, for optimum results in a specific application, one of the other cards may be preferred. These cards can be installed at the factory or in the field. Users are cautioned that the three cards are similar in appearance. If the cards that come with the unit are removed, carefully label them so that they can be readily distinguished from one another. For proper operation, each card must be plugged into the proper connector. Since the cards look very much alike, and can be physically installed in the wrong slot, it is essential that the user absolutely know which card is which. The location of the three is indicated in Figure IV-4. Installation consists of nothing more than plugging the card in question into the proper slot. Do not touch the adjustments; the boards are prealigned at the factory. **NOTE: FOR PERSONNEL SAFETY, THIS INSTALLATION SHOULD ONLY BE PERFORMED BY A QUALIFIED SERVICE TECHNICIAN AND THEN ONLY WITH THE M5205/6 DISCONNECTED FROM ALL SOURCES OF POWER.**

4.7B INTERNAL OSCILLATOR

Like the F-BAND cards, the Internal Oscillator card can be field installed. However, the installation is a bit more complex since, in addition to the circuit card, it involves a cable, a BNC connector, and a potentiometer. The cable provided with the circuit card has a connector at one end and a potentiometer and BNC connector at the other end. When installed, the circuit card is positioned as shown in Figure IV-4. Note that the cable connector mates with matching pins on the circuit card. From there, the cable is dressed along the rear of the instrument to the panel mounting holes. As shown in Figure IV-12, the BNC connector mounts in the upper opening and the potentiometer in the lower opening. The circuit board adjustments should not be disturbed; the board is prealigned at the factory. The installation is the same for both the M5205 and the M5206. **NOTE: FOR PERSONNEL SAFETY, THE INSTALLATION SHOULD ONLY BE PERFORMED BY A QUALIFIED SERVICE TECHNICIAN, AND THEN ONLY WITH THE INSTRUMENT DISCONNECTED FROM ALL SOURCES OF POWER.**

4.7C INTERFACE OPTION

When installed, the Interface Option gives the Model 5205/6 GPIB and RS232 Interface capabilities. The Interface Card can be installed in the factory or in the field. The installation consists of plugging in the required circuit and installing the cable that interfaces the card to the rear panel. The card simply plugs into the appropriate slot as shown in Figure IV-4. The installation is the same for both the M5205 and the M5206. One end of the cable terminates in a connector that mates with a set of matching pins on the Interface card, as shown in the figure. The other end of the cable terminates in two connectors (GPIB & RS232). The GPIB connector (black) is installed in the IEEE 488 INTERFACE slot. There are two possible but different connectors that may be provided for the RS232 interface. Early units are provided with a "standard" RS232 connector that mounts on the cover of the right-most (viewed from the rear) module opening. Implementation of the RS232 capability using this connector reduces the number of accessory modules that can be installed from two to one. For this reason, an alternative method of implementing RS232, one using a "non-standard" round connector that mounts in a panel opening to the left (viewed from the rear) of the two rear-panel OUTPUT connectors, has been developed. Consult the factory for additional information. The details of Digital Interface operation are discussed in Subsection 4.4. **NOTE: FOR PERSONNEL SAFETY, INSTALLATION OF THE DIGITAL INTERFACE OPTION SHOULD ONLY BE PERFORMED BY A QUALIFIED SERVICE TECHNICIAN, AND THEN ONLY WITH THE INSTRUMENT DISCONNECTED FROM ALL SOURCES OF POWER.**

4.8 INTERFACING THE MODEL 5205/6 TO A HOST COMPUTER

4.8A INTRODUCTION

Successful interface between the Model 5205 or Model 5206 and an external computer requires detailed knowledge of a number of areas, including:

- (1) The response of the instrument to incoming commands.
- (2) The protocol required by the instrument to enable an orderly flow of commands and responses.
- (3) The protocol required by the host computer.
- (4) The capability and requirements of the language in which the host computer is programmed.

Additionally, the user must be aware of interactions between these various factors. In the event that the system does not function as expected, there is ample room for uncertainty as to the cause of the malfunction. By taking a methodical approach, the user can eliminate most of this uncertainty. A suggested approach follows. Additional ancillary information is provided in Subsection 4.4.

4.8B RECOMMENDED STEPS FOR INTERFACING TO A HOST COMPUTER

- (1) **GPIB INTERFACE:** After the instrument is connected to the host computer, try doing a serial poll on the instrument. If this can be done, it confirms that the GPIB address is configured properly and that the host computer and the instrument are able to transmit data back and forth.

RS232C INTERFACE: After the instrument is connected to the host computer, determine whether the computer receives an asterisk from the instrument when it is first turned on. The host computer will not receive an asterisk unless the baud rate, stop bits, and parity bits of the instrument and the computer match, and unless the Transmit Data Output of the M5205/6 is connected to the Receive Data Input of the computer.

- (2) Send the instrument a simple command that will have an easily recognized effect. The A3 command, for example, should cause the front-panel AUTO-OFFSET lamp to turn on momentarily. Doing this will confirm that a command can be sent from the host computer to the instrument.
- (3) Send a command that requires a response from the instrument and thus determine

whether bi-directional data transfer is possible. Sending the S command, for example, requires that the instrument reply with the code for the sensitivity.

If this step is successful, it confirms that the terminator character has been properly specified by the appropriate switch on the Interface board. If it is not successful, the cause may be that the instrument is configured for a <CR> terminator and the host computer expects a <CRLF>. This is a common problem when interfacing to Hewlett-Packard equipment, which generally expects a <CRLF> terminator.

- (4) At this point it is often useful to know whether the host computer can receive a response consisting of more than one number. The command T, for example, should cause the instrument to return the codes for both the time constant and the dB/octave.

NOTE: If the interface passes the test in (3) but fails the test in (4), it is possible that the host computer will not accept the comma as a delimiter between numbers. Determine what delimiter is acceptable to the host computer. Then, if necessary, try changing the delimiter with the CN command, where N is the decimal ASCII code for the new delimiter character. (The sequence C 13, for example, sets the delimiter to <CR>, which is acceptable to many computers that will not accept a comma.)

- (5) A dumb RS232C terminal is especially useful in developing a complex program to control the Model 5205 or Model 5206. By interacting directly with the instrument, the programmer can resolve any ambiguity regarding the instrument's response to specific commands.

An RS232C terminal can be used for developing programs even if the GPIB interface has been selected for connecting the host computer to the instrument. If switch 8 of the GPIB switch bank is turned OFF, the GPIB TEST ECHO mode is enabled, and every character sent or received via the GPIB interface is echoed to the RS232C terminal. Note that the rate of character transfer is determined by the baud rate of the RS232C port. Be careful not to send commands via both the RS232C and GPIB interfaces simultaneously because the instrument will ignore one of them. Turn switch 8 of the GPIB switch bank back to ON after the program development is concluded.

- (6) The host computer must pace the flow of commands so that the instrument completes the previous command before it receives a

new one. For this reason, a single subroutine is recommended for sending all commands to the instrument. A string containing the commands can be passed to this subroutine. In the same vein, it is also recommended that a single subroutine be used to receive responses from the instrument. Figures IV-11 and IV-12 illustrate suitable flowcharts.

To insure that the instrument does not receive a new command before it has processed a previous command, a subroutine for a GPIB interface can check the COMMAND DONE bit in the SERIAL POLL register. For an RS232C interface, it is necessary for the host computer to wait until it receives the prompt character, which indicates that the previous command is done.

(7) A useful exercise at this point is to write a simple program that displays and updates the status of the instrument. The commands Q1 and S, for example, might be embedded in a program that continuously displays the magnitude of the instrument's output in volts on the host computer's video terminal. If the program runs successfully, it can be assumed that it contains the necessary structure for monitoring the instrument's output and pacing the command flow.

(8) A final recommendation is that the controlling program be as modular and structured as possible to permit quick and logical tracing if a problem occurs.

4.8C FLOWCHARTS AND LISTINGS

(1) **SIMPLE STATIC INTERFACE ROUTINE:** This program provides the software necessary to control the Model 5205 or Model 5206 from a host computer. The routine follows the program flow illustrated in Figure IV-11. It has been coded for an Apple II, a Tektronics 4051, an HP85, an HP9825, an HP9845, a MACSYM, and a PET. (**NOTE:** The coding for the HP9845 and MACSYM had not been validated as of the time this manual was written.)

The routine illustrated in Figure IV-11 initially clears the video terminal of the host computer, asks the operator for the instrument's GPIB address, and then issues the prompt ENTER COMMAND:. The program then sends a command string entered from the host computer's keyboard to the instrument. If the instrument generates an output as a result of this string, the host computer's video terminal will display the output and then the prompt, ENTER COMMAND. If there is an invalid command in the command string, the

routine issues the error message COMMAND ERROR before the prompt.

Since the the Simple Static Interface Routine doesn't involve complex interface and control software, programmers can use it to become familiar with the essential features of M5205/6 software control. These include sending commands, receiving responses, and checking the instrument's SERIAL POLL status register.

(2) **THE DEVICE DRIVER SUBROUTINES:** Programmers are advised to use these subroutines (Figure IV-12) to handle basic input and output. With these subroutines, I/O is accomplished by putting a command string into a string variable and calling the appropriate

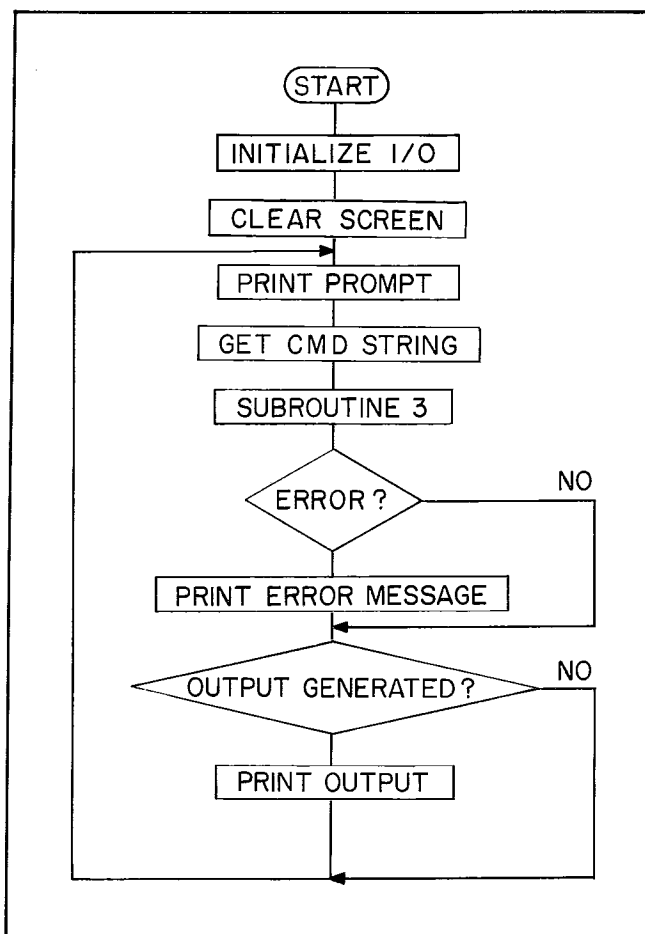


Figure IV-11. SIMPLE STATIC INTERFACE ROUTINE

subroutine. Subroutine 1 sends the command string to the instrument. Subroutine 2 reads the output from the instrument and places the output in the host computer's input array. Subroutine 3 is a concatenation of subroutines 1 and 2.

(3) USER'S ROUTINES: the factory's applications engineers seek additional implementations of the Simple Static Interface Routine for other host computers. Anyone willing to share an implementation of the routine is encouraged to get in touch with the factory.

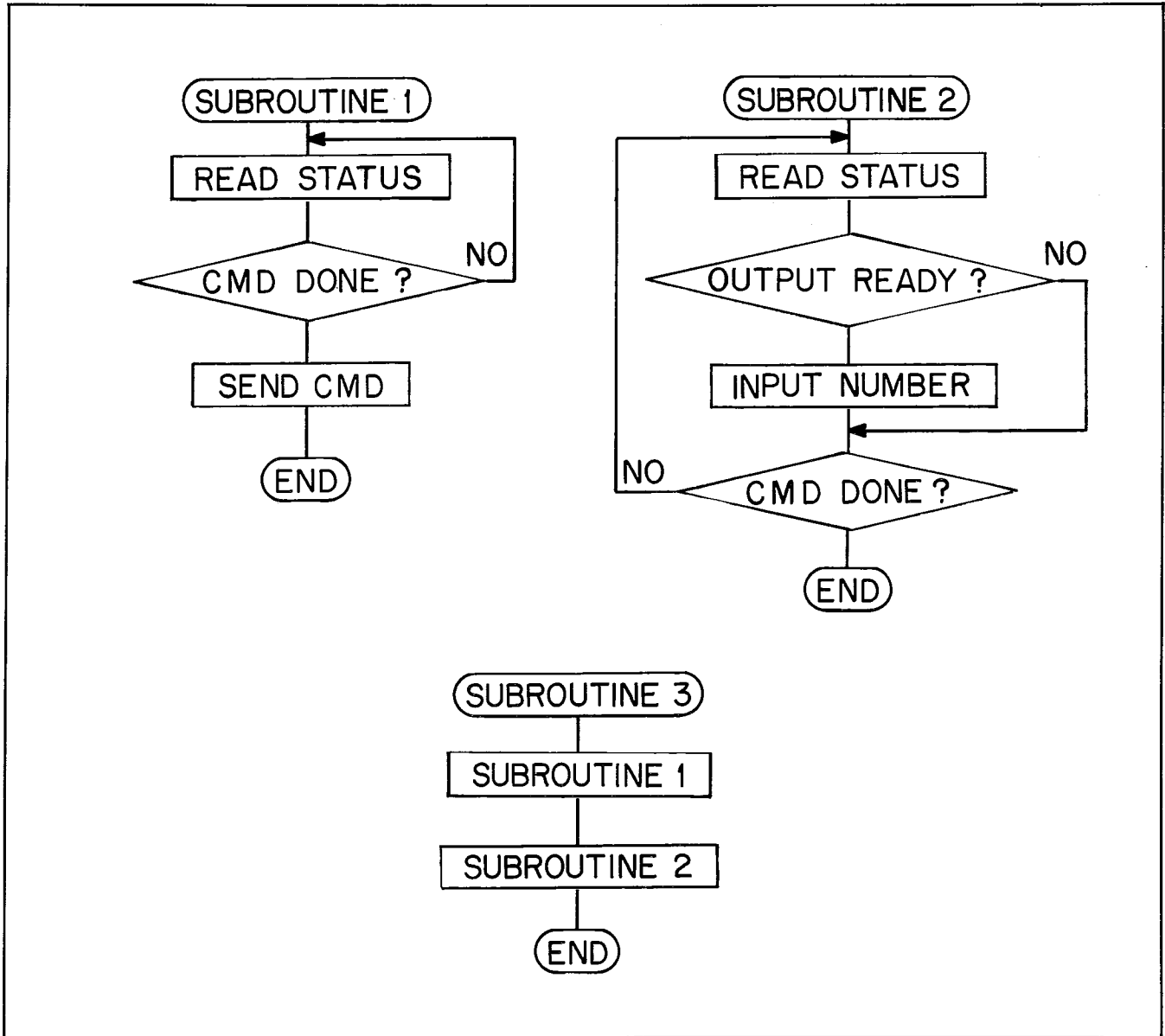


Figure IV-12. DEVICE DRIVER SUBROUTINES

4.8D EXAMPLES OF SIMPLE STATIC INTERFACE PROGRAMS

APPLE II

SIMPLE STATIC INTERFACE PROGRAM FOR APPLE II

```
10 REM APPLE II SIMPLE STATIC INTERFACE
20 D$=CHR$(4)
30 Z$=CHR$(26)
40 DIM A(100) : REM ARRAY OF RESPONSES FROM DEVICE

100 HOME
110 PRINT "DEVICE MUST BE SET FOR"
120 PRINT "CARRIAGE RETURN TERMINATOR"
130 INPUT"ENTER DEVICE GPIB ADDRESS: "; A9
140 INPUT"ENTER SLOT NUMBER OF APPLE GPIB CARD: "; SL
150 PRINT
160 LA$ = "WT" + CHR$(32 + A9) + Z$ : REM GPIB LISTEN COMMAND
170 TA$ = "RD" + CHR$(64 + A9) + Z$ : REM GPIB TALK COMMAND
180 SP$ = "SP" + CHR$(64 + A9) + Z$ : REM GPIB SERIAL POLL COMMAND
190 C$="C 13" : REM DEFINE CR AS DELIMITER
195 PRINT D$;"PR#";SL : PRINT D$;"IN#";SL : PRINT "RA" :
  GOSUB 1000 : PRINT D$;"PR#0" : PRINT D$;"IN#0"

200 REM MAIN LOOP
205 I9=0
210 PRINT : INPUT "ENTER COMMAND: ";C$
220 PRINT D$;"PR#";SL : PRINT D$;"IN#";SL
230 GOSUB 1200 : REM SEND COMMAND AND GET RESPONSES IF ANY
240 PRINT D$;"PR#0" : PRINT D$;"IN#0"
250 S9=INT(S9/2) : REM CHECK FOR ERROR
260 IF S9 <> 2 * INT(S9/2) THEN PRINT "COMMAND ERROR"
300 REM PRINT RESPONSES
310 IF I9 = 0 THEN 350
320 FOR I = 1 TO I9
330 PRINT "RESPONSE#";I;" = ";A(I)
340 NEXT I
350 GOTO 200

1000 REM OUTPUT COMMAND
1010 GOSUB 1400
1020 IF S9 = 2 * INT(S9/2) THEN 1010 : REM WAIT FOR PREVIOUS CMD DONE
1030 PRINT LA$;C$ : REM SEND CMD
1040 RETURN

1100 REM GET RESPONSES
1110 GOSUB 1400
1120 IF S9 < 128 THEN 1140
1130 I9=I9+1 : PRINT TA$; : INPUT A(I9)
1140 IF S9 = 2 * INT(S9/2) THEN 1110
1150 RETURN

1200 REM DEVICE DRIVER
1210 GOSUB 1000
1220 GOSUB 1100
1230 RETURN

1400 REM DO SERIAL POLL
1410 PRINT SP$;
1420 INPUT S$
1430 PRINT "UT" : REM UNTALK DEVICE
1440 REM CONVERT HEX SERIAL POLL STATUS TO A NUMBER
1450 S1 = ASC(RIGHT$(S$,1)) - 48 : IF S1>9 THEN S1 = S1-7
1460 S2 = ASC(LEFT$(S$,1)) - 48 : IF S2>9 THEN S2 = S2-7
1470 S9 = S1 + (16 * S2 )
1480 RETURN
```

TEKTRONICS 4051 SIMPLE STATIC INTERFACE

```

10 REM TEKTRONICS SIMPLE STATIC INTERFACE
20 DIM A(100)
30 REM Maximum number of responses expected is 100

100 PAGE
110 PRINT "Enter device GPIB address: "
120 INPUT A9
130 REM Define carriage return as delimiter
140 C$="C 13"
150 GOSUB 1000

200 REM Main loop
210 PRINT "Enter command: ";
220 INPUT C$
230 GOSUB 1200
240 REM Check for error
250 S9 = INT(S9/2)
260 IF S9 = 2 * INT(S9/2) THEN 300
270 PRINT "COMMAND ERROR"
300 REM Print responses if any
310 IF I9=0 THEN 350
320 FOR I=1 TO I9
330 PRINT "Response#";I;" = ";A(I)
340 NEXT I
350 GO TO 200

1000 REM Output command
1010 REM Wait for previous cmd to finish
1020 GOSUB 1400
1030 IF S9 = 2 * INT(S9/2) THEN 1020
1040 PRINT @A9,32: C$
1045 REM Use of 32 suppresses secondary address
1050 RETURN

1100 REM Get responses
1110 I9=0
1120 GOSUB 1400
1130 IF S9 < 128 THEN 1160
1140 I9=I9+1
1150 INPUT @A9,32:A(I9)
1160 IF S9 = 2 * INT(S9/2) THEN 1120
1170 RETURN

1200 REM Device driver
1210 GOSUB 1000
1220 GOSUB 1100
1230 RETURN

1400 REM Do a serial poll
1410 WBYTE @95,24:
1420 WBYTE @A9+64:
1430 RBYTE S9
1440 WBYTE @95,25:
1450 RETURN

```


SIMPLE STATIC INTERFACE PROGRAM FOR HP85

```

10 ! HP85 SIMPLE STATIC INTERFACE
20 RESET 7
30 SET TIMEOUT 7;5000
40 DIM A(100)

100 CLEAR
110 DISP "ENTER DEVICE GPIB ADDRESS: ";
115 INPUT A9
120 A9=A9+700
130 DISP "DEVICE MUST BE SET FOR"
140 DISP "LINEFEED TERMINATOR"
150 DISP ""
160 C$="C 10" @ GOSUB 1000 ! LINEFEED IS DELIMITER

200 ! MAIN LOOP
210 DISP "ENTER COMMAND: ";
220 INPUT C$
230 GOSUB 1200 ! SEND COMMAND AND GET RESPONSES IF ANY
240 IF BIT(S9,1)=1 THEN DISP "COMMAND ERROR"
250 IF I9=0 THEN 290
260 FOR I=1 TO I9
270 DISP "RESPONSE#";I;" = ";A(I)
280 NEXT I
290 GOTO 200

1000 ! OUTPUT COMMAND
1010 GOSUB 1400 ! DO SERIAL POLL
1020 IF BIT(S9,0)=0 THEN 1010 ! WAIT FOR PREVIOUS CMD DONE
1030 OUTPUT A9 USING "K"; C$
1040 RETURN

1100 REM GET RESPONSES
1110 I9=0
1120 GOSUB 1400 ! CHECK CMD DONE AND OUTPUT READY BITS
1130 IF BIT(S9,7)=0 THEN 1150
1140 I9=I9+1 @ ENTER A9;A(I9)
1150 IF BIT(S9,0)=0 THEN 1120
1160 RETURN

1200 REM DEVICE DRIVER
1210 GOSUB 1000
1220 GOSUB 1100
1230 RETURN

1400 ! DO A SERIAL POLL
1410 S9=SPOLL(A9)
1420 RETURN

```

SIMPLE STATIC INTERFACE PROGRAM FOR HP 9845

```

10 ! HP 9845 SIMPLE STATIC INTERFACE
20 ABORTIO 7 ! INTERFACE CLEAR
30 DIM A(100)

100 PRINT PAGE
110 DISP "ENTER DEVICE GPIB ADDRESS: ";
120 INPUT A9
130 A9=A9+700 ! GPIB INTERFACE IS INTERFACE 7
140 DISP "DEVICE MUST BE SET FOR LINEFEED TERMINATOR"
150 C$="C 10"
160 GOSUB 1000 ! LINEFEED IS DELIMITER

200 ! MAIN LOOP
210 PRINT "ENTER COMMAND: ";
220 INPUT C$
230 GOSUB 1200 ! SEND COMMAND AND GET RESPONSES IF ANY
240 IF ((S9 DIV 2) MOD 2) THEN PRINT "COMMAND ERROR"
250 IF I9=0 THEN 300
260 FOR I=1 TO I9
270 PRINT "RESPONSE#";I;" = ";A(I)
280 NEXT I
290 PRINT
300 GOTO 200

1000 ! OUTPUT COMMAND
1010 GOSUB 1400 ! DO SERIAL POLL
1020 IF (S9 MOD 2) = 0 THEN 1010 ! WAIT FOR PREVIOUS CMD DONE
1030 OUTPUT A9 USING "K"; C$
1040 RETURN

1100 REM GET RESPONSES
1110 I9=0
1120 GOSUB 1400 ! CHECK CMD DONE AND OUTPUT READY BITS
1130 IF ((S9 DIV 128) MOD 2) = 0 THEN 1150
1140 I9=I9+1
1145 ENTER A9;A(I9)
1150 IF (S9 MOD 2) = 0 THEN 1120
1160 RETURN

1200 REM DEVICE DRIVER
1210 GOSUB 1000
1220 GOSUB 1100
1230 RETURN

1400 ! DO A SERIAL POLL
1410 STATUS A9;S9
1420 RETURN

```

MACSYM

MACSYM COMPUTER SIMPLE STATIC INTERFACE

```

10 REM MACSYM SIMPLE STATIC INTERFACE
20 DIM A(10)
30 REM MAXIMUM NUMBER OF RESPONSES EXPECTED IS 10
40 N=1
50 REM N IS CHANNEL NUMBER FOR I/O

100 { CLEAR SCREEN }
110 INPUT "ENTER DEVICE GPIB ADDRESS: "; A9
120 GPIB N,0,A9
130 REM DEFINE CARRIAGE RETURN AS DELIMITER
140 C$="C 13"
150 GOSUB 1000

200 REM MAIN LOOP
210 PRINT "ENTER CMD: "
220 INPUT C$
230 GOSUB 1000
240 GOTO 200

1000 REM DEVICE DRIVER
1010 I9=0
1015 REM I9 IS INDEX FOR INPUT
1020 CONFIGURE 0,A9
1025 REM SEND COMMAND
1030 PRINT C$
1040 CONFIGURE A9,0
1045 REM PREPARE FOR INPUT IF ANY
1050 GOSUB 1200
1060 IF S9 <> 2 * INT(S9/2) THEN 1100      ( DOES IT HAVE BIT TEST? )
1070 IF S9 < 128 THEN 1050
1080 GOSUB 1400
1090 GOTO 1050

1100 REM CMD DONE
1110 CONFIGURE 0,0                          ( ? RETURN I/O TO NORMAL )
1120 S9=INT(S9/2)
1130 IF S9 = 2 * INT(S9/2) THEN 1150
1140 PRINT "COMMAND ERROR"
1150 IF I9=0 THEN 1190
1160 FOR I=1 TO I9
1170 PRINT "RESPONSE#"; I9; " = "; A(I9)
1180 NEXT I
1190 RETURN

1200 REM DO SERIAL POLL
1210 STATUS A9,S9
1220 RETURN

1400 REM GET A RESPONSE
1410 INPUT A(I9)
1420 I9=I9+1
1430 RETURN

```

PET

PET SIMPLE STATIC INTERFACE (CBM 2001 BASIC 2.0)

```
10 REM PET SIMPLE STATIC INTERFACE
20 F1=3 : REM FILE NUMBER
30 DIM A(100)

100 PRINT " " : REM CLEAR SCREEN

110 FOR I = 634 TO 634 + 199
111 READ N : POKE I,N : REM POKE SERIAL POLL ROUTINE
112 NEXT

120 INPUT "ENTER DEVICE GPIB ADDRESS: ";A9
125 POKE 0,A9 : REM PASS ADDRESS TO MACHINE LANGUAGE ROUTINE
130 OPEN F1,A9
140 C$="C 13" : REM DEFINE CARRIAGE RETURN AS DELIMITER
150 GOSUB 1000

200 REM MAIN LOOP
205 I9=0
210 PRINT : PRINT "ENTER COMMAND: ";
220 INPUT C$
230 GOSUB 1200
240 IF (S9 AND 2) THEN PRINT" COMMAND ERROR"
250 IF I9=0 THEN 290
260 FOR I=1 TO I9
270 PRINT "RESPONSE#";I;" = ";A(I)
280 NEXT I
290 GOTO 200

1000 REM OUTPUT COMMAND
1010 GOSUB 1400
1020 IF (S9 AND 1)=0 THEN 1010
1030 PRINT#F1,C$ : REM SEND COMMAND
1040 RETURN

1100 REM GET RESPONSES
1110 GOSUB 1400
1120 IF (S9 AND 128)=0 THEN 1140
1130 I9=I9+1 : INPUT#F1,A(I9)
1140 IF (S9 AND 1)=0 THEN 1110
1150 RETURN

1200 REM DEVICE DRIVER
1210 GOSUB 1000
1220 GOSUB 1100
1230 RETURN

1400 REM DO A SERIAL POLL
1410 SYS(736) : REM CALL MACHINE LANGUAGE ROUTINE
1420 S9=PEEK(2)
1430 RETURN

9000 REM MACHINE CODE FOR SERIAL POLL ROUTINE
9001 DATA 173,64,232,41,64,240,249,165,1
9002 DATA 73,255,141,34,232,169,247,45,35,232
9003 DATA 141,35,232,173,64,232,41,1,240,249
9004 DATA 169,8,13,35,232,141,35,232,169,255
9005 DATA 141,34,232,96

9010 DATA 169,2,13,64,232,141,64,232,173,64,232
9011 DATA 41,128,208,249,173,32,232,73,255
9012 DATA 133,2,169,253,45,64,232,141,64,232
9013 DATA 169,8,13,33,232,141,33,232,173,64,232
9014 DATA 41,128,240,249,169,247,45,33,232
9015 DATA 141,33,232,169,255,141,34,232,96

9020 DATA 169,251,45,64,232,141,64,232,169,24
9021 DATA 133,1,32,122,2,165,0,9,64
9022 DATA 133,1,32,122,2,169,253,45,64,232
9023 DATA 141,64,232,169,247,45,33,232,141,33,232
9024 DATA 169,4,13,64,232,141,64,232,32,165,2
9025 DATA 169,8,13,33,232,141,33,232,169,2,13,64,232,141,64,232
9026 DATA 169,251,45,64,232,141,64,232,169,95
9027 DATA 133,1,32,122,2,169,25,133,1
9028 DATA 32,122,2,169,4,13,64,232,141,64,232,96
```

NOTE: SERIAL POLL ROUTINES ADAPTED FROM "PET AND THE IEEE 488 BUS" BY FISHER AND JENSEN.

4.8E M5205/6 NUMBER CONVERSION FORMULAE

M5205/6 NUMBER CONVERSION FORMULAE

COMMAND

S N $T1 = N - [\text{INT}(N/3) * 3] + 1$ (TO SENSITIVITY)
 IF $T1 = 1$ THEN $T1 = 5$ (IN VOLTS)
 IF $T1 = 3$ THEN $T1 = 1$
 $V = [10 ^{-\text{INT}(N/3)}] * T1$

 $N = \text{INT}[\text{ABS}(3.0 * \text{LOG}(V) - 2.4)]$ (TO INTEGER)

O N1,N2 IF $N2 = 2$ THEN $N2 = -1$ (TO OFFSET INT)
 $O = (N1 * N2) / 10$ (% FULL SCALE)

 $N1 = \text{ABS}(O * 10)$ (TO INTEGER)
 $N2 = 1$
 IF $O < 0$ THEN $N2 = 2$

J N1,N2 $F = N1 * [10 ^{(2 - N2) }]$ (TO FREQUENCY IN HERTZ)

 $N2 = 5 - \text{INT}[\text{LOG}(F) + 1]$ (TO INTEGER)
 IF $N2 < 0$ THEN $N2 = 0$
 $N1 = \text{INT}[F ^{(N2 - 2) }]$

P N1,N2 $P = (N1 * 90) + .025 * (N2 - 200)$ (TO PHASE IN DEGREES)

 $N1 = \text{INT}(P/90)$ (TO INTEGER)
 $N2 = (40 * P) - (3600 * N1) + 200$

T N1,N2 $T = 10 ^{ [2 - \text{INT}(N1/2)] }$ (TO TIME CONSTANT IN SECS)
 IF $N1 <> [\text{INT}(N1/2) * 2]$ THEN $T = T * .3$

 $N1 = 4 - [2 * \text{INT}(\text{LOG}(T))]$ (TO INTEGER)
 IF $\text{LOG}(T) <> \text{INT}[\text{LOG}(T)]$ THEN $N1 = N1 - 1$

 $\text{DB} = 12 - (6 * N2)$ (TO DB/OCTAVE)

 $N2 = 1 - \text{INT}[(\text{DB}/12)]$ (TO INTEGER)

G N $G = N / 1638$ (TO GAIN FACTOR)

 $N = \text{INT}(1638 / G)$ (TO INTEGER)

NOTES:

N AND N1 AND N2 REPRESENT INTEGER PARAMETERS FOR M5205/6 COMMANDS.

T1 IS A TEMPORARY VARIABLE.

LOGS ARE TO THE BASE 10.

4.8F DEFINITIONS

DEVICE	Apparatus (in this case the Model 5205 or Model 5206) configured to receive commands and transmit data via a GPIB interface or RS232C interface.
HOST COMPUTER	A controlling computer programmed to issue commands and receive data from one or more devices.
COMMAND	A string of ASCII characters sent from the host computer to the device.
PARAMETER	A number that must be sent after a command mnemonic to specify what the device must do.
TERMINATOR	The ASCII character or characters designated as the signal that the host computer has sent a complete command to the device.
<CR>	Abbreviation for the carriage return character.
<LF>	Abbreviation for the linefeed character.
<CRLF>	Abbreviation for the carriage return, linefeed sequence.
RESPONSE	Output sent by the device in response to a command from the host computer. Not all commands generate a response. Responses may be single number or multiple numbers.
DELIMITER	An ASCII character sent by the device in a response consisting of more than one number. The default delimiter is the comma. (The host computer can change the delimiter character by issuing the proper command.) A device usually requires a delimiter between parameters of a command. The delimiter required by the device may differ from the delimiter required by the host computer.
MULTIPLE COMMAND	A command created by concatenating two or more commands.

SEPARATOR

An ASCII character sent between commands if several commands are concatenated into one multiple command. Only one terminator is sent at the end of the entire multiple command.

4.8G EXAMPLES

The following examples illustrate some commands and responses. These examples assume that <CR> is an acceptable terminator for the host computer and that the instrument has been properly programmed for a <CR> terminator by setting switch 7 of the GPIB switch assembly (located on the Interface Board) to the ON position. If the host computer requires <CRLF> as the terminator, switch 7 of the GPIB bank must be set to the OFF position. (Power must be OFF for the change to "take"; switch settings are scanned only immediately after the unit is powered).

HOST COMPUTER SENDS	DEVICE RESPONDS	COMMENT
Q1 <CR>	1096 <CR>	A single command issued and followed by a single response.
Q1;Q2 <CR>	1096 <CR> - 312 <CR>	A multiple command issued with a semicolon separator. Each command generates one response.
T <CR>	6, 0	A single command followed by a response consisting of two numbers.
S 13 <CR>		A single command with one parameter.
P 0,0 <CR>		A single command with two parameters and a comma delimiter.

SECTION V SERVICE

5.1 SAFETY

WARNING!

POTENTIALLY LETHAL VOLTAGES ARE PRESENT INSIDE THIS APPARATUS. THESE SERVICE INSTRUCTIONS ARE FOR USE BY QUALIFIED SERVICE PERSONNEL ONLY. TO AVOID ELECTRIC SHOCK, DO NOT PERFORM ANY SERVICING UNLESS YOU ARE QUALIFIED TO DO SO.

Any adjustment, maintenance and repair of the opened apparatus under voltage shall be avoided as far as possible and, if unavoidable, shall only be carried out by a person skilled in the repair of electronic apparatus who is aware of the hazard involved.

When the apparatus is connected to a power source, terminals may be live, and the opening of covers or removal of parts is likely to expose live parts. The apparatus shall be disconnected from all voltage sources before it is opened for any adjustment, replacement, maintenance, or repair.

Note that capacitors inside the apparatus may still be charged even if the apparatus has been disconnected from all voltage sources. For this reason, service personnel are advised to wait several minutes before assuming that all capacitors are discharged.

If a fuse is replaced, make sure that only fuses with the required current and voltage rating, and of the specified type, are used for replacement. The use of makeshift fuses and the short-circuiting of fuse holders are prohibited.

5.2 INTRODUCTION

Servicing an electronic instrument generally comprises aligning it or repairing it. Although these are different activities, they may be linked to the extent that a partial alignment may be necessary after a repair. The Model 5205/6 was not designed with field service in mind. The alignment requires special fixtures and software that are not available for release outside the factory. For this reason, EG&G PARC does not recommend that the M5205/6 be included in routine maintenance/alignment programs. Field troubleshooting, on the other hand, if performed by one skilled in the art, is certainly possible. A skilled troubleshooter familiar with the M5205/6 circuitry should be able to isolate the problem to a circuit board. In some cases, it may be possible to identify and replace the faulty component from supplies on hand. However, since many of the components in these instruments are either not generally available or are selected for optimum performance, immediate

field repair may not be possible, and it may be necessary to ship the unit or the faulty circuit board to the factory for service. Users are advised to always contact the factory for advice on how to proceed. It is particularly important that users not attempt to make field repairs on units still in Warranty, as any damage done on such units in the process of attempting such repairs may invalidate the warranty.

The text in this section of the manual consists for the most part of circuit descriptions. This text complements and expands on the ideas developed in Subsection 1.6. These descriptions should be useful to a person knowledgeable and skilled in troubleshooting electronics instruments. No detailed troubleshooting "procedure" is provided.

5.3 SIGNAL CHANNEL

5.3A PREAMPLIFIER (schematic on page VI-2)

Observing the schematic, note that the input signal is coupled through capacitors C2 and C3 to the differential input stage, Q10. Transistors Q1 through Q6 are used as diodes in an input protection network and are not involved in processing the input signal. The current available to Q10 is supplied by constant-current source, Q11. Q8 and Q9 serve to keep the Q10A potential and current constant. Q12 and Q13 do the same for Q10B. The differential output of the input stage is supplied by Q8 and Q12. This differential current signal is injected into the emitters of Q14 and Q16. Q15 is connected as a diode to compensate the temperature coefficient of Q17, which is connected as a current reflector. The signal current at the common collector of Q14 and Q17 is applied to current-to-voltage converter IC5. The gain will depend on the value of the feedback resistor. As shown, a solid-state switch array controlled by the selected Sensitivity and Dynamic Reserve determines the magnitude of the resistance connected between the output and summing junction of IC5. The preamplifier output is taken from pin 6 of IC5 and leaves the board via pin 13 of the card-edge connector. Note that there is an alternative path. If some sort of "filter" is installed in one of the rear-panel accessory compartments, and provision is made for switching Q18 into conduction, the preamplifier output signal can be brought out via pin 14 of the card-edge connector. This line leads to the input of the accessory.

Either the direct preamplifier output or the accessory output is applied to the input of the LO-PASS filter located on the FBAND circuit board.

5.3B LO-PASS FILTER (pages VI-3 & VI-4)

A given instrument could have one, two, or three FBAND cards, corresponding to the BROADBAND, AUDIO, and LO passband capabilities. There are actually two different kinds of FBAND circuit cards. Except for critical component values, the LO and AUDIO cards (schematic on page VI-4) are identical. The BROADBAND circuit card (schematic on page VI-3 has somewhat different circuitry). In any case, the preamplifier output signal is applied to pin 16 of whatever FBAND cards are present. Observing either schematic, note that the signal is directly applied to an FET switch. Depending on which FBAND is selected, the input switch on one of the cards will be biased on, allowing the signal to be applied to the Lo-Pass Filter circuit that follows. Both the Audio/Lo and Broadband cards use modified Butterworth filters. Three stages of filtering are cascaded, with each providing a 12 dB per octave rolloff for a total of 36 dB/octave. The 3 dB down frequency is either 4 kHz (LO), 40 kHz (AUDIO), or 400 kHz (BROADBAND). The purpose of the filter is to provide a high rejection of components at the image frequency. The output of the last Butterworth stage is routed through an FET switch so that the output of the selected card only is applied to the Mixer. The filtered signal leaves the circuit card via pin 12 of the card-edge connector. From there, the signal is routed to the signal amplifier on the Preamplifier Board.

5.3C SIGNAL AMPLIFIER (page VI-2)

Referring to the schematic, note that the signal re-enters the Signal Channel Board via pin 9 of the card-edge connector. As shown, this signal is applied to source follower Q19. Another section of Q19 acts as a current source to this stage. Q19 drives gain-switching amplifier IC6. The gain of this stage is determined by state of solid-state switch arrays IC7 and IC8, which are controlled via the Sensitivity and Dynamic Reserve selections. The amplified signal exits via pin 7 of the card-edge connector.

5.3D MIXER (schematic on page VI-7)

As shown in the schematic, the signal from the gain-switching stage that follows the Preamplifier is applied to pin 13 of the Mixer Board. From there the signal is routed to the input of U1, a non-inverting amplifier with a gain of nominally three. The output of this stage is capacitively coupled to the input of U2, the input to the actual Mixer. The gain of this amplifier, measured from the output of U1 to pin 6 of U2, is one sixth, as determined by the ratio of R12 or R14 to R4. The feedback path for U2 is not immediately obvious, and takes either of two routes depending on the state of the mixer at any moment. When Q2 and Q5 conduct, the feedback path extends from pin 6 of U2 through R9 to the emitter of Q1, and from there through Q1, through Q2, and through R12 to the summing junction of U2. When Q3 and Q4 con-

duct, the path is similar, except that the involved parts are R18, Q6, Q4, and R14. In any case, the output of U2 is injected into the emitters of Q2 and Q4. The switching is done by Q2, Q3, Q4, and Q5. The square-wave drive applied to their bases switches them on and off. Q2 and Q5 conduct for one half cycle. Q3 and Q4 conduct for the other half cycle. The drive signal is derived from the Reference Channel, which supplies a signal to pin 7 of the Mixer Board. The frequency of this signal is the sum of the reference signal frequency plus the i.f. frequency, where the i.f. frequency is either 10.1 kHz (LO), 101 kHz (AUDIO), or 1.01 MHz (BROADBAND). Since the signal input to the mixer is at the reference frequency, the mixer difference frequency output will be at the i.f. frequency. The signal at pin 7 is "sharpened" by U3 to make the switching transitions as fast as possible. Q15 and U4 simply develop the potentials and level shifts required by U3. The output of U3 is applied to Q2, Q3, Q4, and Q5 to do the switching as previously described. The mixer outputs are combined by the following amplifier to develop the expected double-sideband signal. Mixer input components at the reference frequency will be at the i.f. frequency at the mixer output. Input components some number of cycles above or below the reference frequency will appear at the mixer output the same number of cycles above or below the i.f. frequency.

Looking at the post-mixer amplifier in a bit more detail, note that Q10 and Q11 are current sources for the two halves of the input stage, Q9. Q7 and Q8 keep the potential across Q9 constant. The differential output of the input stage is applied to Q12 and Q13. The amplifier output is taken from the shared collector circuit of Q13 and current-reflector Q14. The signal exits the Mixer board via pin 16 of the card-edge connector, and from there is routed back to the i.f. amplifier on the active FBAND card.

5.3E I.F. AMPLIFIER (pages VI-3 & VI-4)

The I.F. Amplifier circuit differs according to selected FBAND circuit card. The LO and AUDIO cards use the circuit depicted on page VI-4. The BROADBAND card I.F. Amplifier is depicted on page VI-3. For either type FBAND card, the signal is applied via pin 9 of the card-edge connector. From there the signal is routed through an FET switch. Note that there is a pair of FET switches at the output of the I.F. Amplifier, one in the X path, the other in the Y path (This is the first point where the signal path is divided.) The switches routing the signal to and from the I.F. Amplifier are biased "on" for the selected card and off for any other FBAND cards which may be present. These switches effectively isolate the tuning circuits on the unselected cards.

Referring to the schematic of the broadband circuit, note that there are two very similar two-pole

tuning circuits interposed between Q4, the input switch, and Q12 and Q13, the output switches. These two circuits provide a highly peaked amplifier response, as shown in the specifications. Its primary purpose is to eliminate harmonics from the signal. The LO/AUDIO I.F. Amplifier is similar except that it uses integrated-circuit amplifiers instead of discrete transistors. Also, it uses R's and C's only for tuning whereas the broadband circuit uses inductors as well. The signal exits the card via pins 4 and 5 of the card-edge connector.

5.3F DEMODULATOR (pages VI-9, VI-10, & VI-11)

There are two demodulators (one in the M5205), one for the X signal, the other for the Y signal. Recall that the separation takes place in the I.F. Amplifier, and that there is no difference between these signals at the input to the demodulator(s). The difference results from the respective demodulator drives being in quadrature, as described in Subsection 1.6.

Referring to the schematic on page VI-9, note that the signal is applied to FET switches Q1 and Q2. These switches have a complex drive. The drive is at the I.F. frequency, so that the applied signal will be demodulated (synchronously rectified). The drive to Q2 is 180° out of phase with that to Q1. In addition, the drive signal is inverted at a frequency of 1 kHz, that is, at one millisecond intervals, the drive signal undergoes a 180° phase reversal. Q1 and Q2 are followed by another demodulator, U1, driven by the same 1 kHz signal that provides the inversions to the Q1-Q2 drive. The scheme used results in a differential rectified i.f. frequency output proportional to the amplitude of the i.f. signal at the input (pin 17). Any dc offset in Q1 and Q2 is converted to a 1 kHz signal which, on being rectified by U1, is applied equally to U2A and U2B. The result is two equal and opposite voltages (U3 provides an inversion) that cancel when they are added at the junction of R26 and R27. The only net output results from the signal input.

U4A and U4B are "Howland Amplifier" circuits. As a result of their being in the circuit, U2A and U2B see a high impedance looking back to Q1 and Q2, thereby assuring that the gain of U2A and U2B to their own voltage temperature drift is minimized.

Switches Q3 and Q4 are controlled by the choice of FBAND. When BROADBAND is selected, these two switches are ON. When LF or AUDIO are selected, they are OFF. Because the drive effects in Q1 and Q2 are somewhat different at 1 MHz than they are at 100 kHz or 10 kHz, the additional Howland circuit shunting provided by Q4 is required when BROADBAND is selected. Similarly, there is shift in the offset of U3 when BROADBAND is selected. Q3 switches in the compensating voltage.

Q6 and Q7 act as another modulator driven at

1 kHz. They sample the error voltage on the inverting input of U7 (schematic on page VI-10) and convert it to a square wave at 1 kHz. U18A and U18B make the voltage differential. After being coupled through C43 and C44, this error signal is routed to the input of the 1 kHz demodulator, U1, where it is rectified. After being routed through the U2-U3 buffer/adder stages, the voltage arrives at R42 (page VI-10). The circuit values chosen are such that the error voltage at R42 (TP4) is exactly equal to that at pin 2 of U7. As a result, there will be no current through R42 and R43 due to offset in U7. By maintaining zero current due to offset in these resistors, the gain of U7 can be switched without offset-current shifts. Q5 and U9 are gain-switching circuits controlled by the Sensitivity and Dynamic Reserve settings. U9 provides balanced impedances to U7 (R49 paralleled by R50 equals R44 paralleled by R45).

5.4 OUTPUT CHANNEL

5.4A DEMODULATOR BOARD (pages VI-10 and VI-11)

The demodulator output is applied to gain-switching amplifier U7. The gain of this amplifier is controlled by Q5 and U9 as previously described. U7 also provides the first of the two stages of time-constant filtering. When 6 dB/octave is selected, only the first of these stages is "in". When 12 dB/octave is selected, the signal passes through both. The time constant is varied by changing the size of the capacitor connected between the input and output of U7. As can be seen from the schematic, capacitors C16 through C26 can be selected. U5 and U6 are multiplexers that respond to latches (U16 and U17; schematic on page VI-11) controlled by the Time Constant Selection lines.

U8 is a "filler circuit". This circuit is basically a sample-and-hold controlled by complementary switches U9A and U9B. Normally, the switch connected between the output of U7 and the input of U8 is "on", while that connected between the output of U8 and the summing junction of U7 is "off". When the time constant selection is changed, a fill sequence is initiated. The U8 input switch turns off, causing the output of U8 to hold at the voltage on the formerly selected capacitor. The U9 output switch turns "on". If the voltage on the newly selected capacitor is any different from that on the formerly selected capacitor, there will be a net error voltage to U7 developed at the junction of U51 and U52. This voltage will force the output of U7 to the voltage that was on the formerly selected capacitor, in the process rapidly charging the newly selected capacitor to the voltage that was on the one formerly selected. As soon as the fill is completed, the U8 control switches resume their original state.

Q8 and Q9 are limiters to protect U5 and U6.

The second time-constant filter stage is schematically depicted on page VI-11. Note that it is identical to that described above. Also shown on this schematic are the latches that control the time-constant multiplexers.

5.4B OUTPUT BOARD 1 (page VI-12)

The demodulated X and Y signal levels enter Output Board 1 via pins 21 and 22 respectively. The X signal is applied to MDAC (Multiplying Digital to Analog Converter) IC2 and the Y signal to IC3. These devices are incorporated into the feedback paths of amplifiers IC1a and IC1b such as to allow the gain of the amplifiers to be set by the microprocessor via the data bus. This is the way the gain shift required to achieve NORMALIZED operation is accomplished. IC4, IC5, and IC6 are latches that control the MDAC's. The gain-adjusted X level appears at the output of IC1a, and from there exits the board via pin 33. The gain-adjusted Y level appears at the output of IC1b, and from there exits the board via pin 37. These signals are also applied to Multiplexer, IC13, together with the magnitude signal (R), log R, and θ . This multiplexer selects the levels applied to the panel meters. Either X and Y, R and θ , log R and θ , or X and Y (Phase Lock Mode) are selected. The selected pair of signals is applied to amplifiers IC29 and IC31 respectively. Their output in turn is applied to the panel meters, to the corresponding BNC connectors, and to the Multiplexer, IC12, that determines the signal applied to A/D converter, IC27. This device develops the data word to be applied to the digital display. Note that the EXPAND function is accomplished by controlling the gain of IC29. Latch IC9 applies the proper gain-control data word to the gain-setting circuit. The Offset circuits consist of IC11, IC18a, IC18b, IC25a, IC25b, and IC25c, together with their associated components. The programmed offset appears as a word on the data bus. IC8 and IC9 latch the word and apply it to DAC IC11, which develops the dc offset level. Two different offsets are provided by the circuits that follow. The R OFFSET level exits the board via pin 17 and from there is applied to the Phase Computer circuit on Output Board 2. The CHANNEL 1 level is routed back to the "X" Normalizing Amplifier, IC1a. Other signals applied to the IC12 Multiplexer are "R" and AUX. IC19 is a clock for IC27. IC14, 15, 16, 17, and their associated passive components and latches provide the Overload Detect functions. IC24 is a buffer between the detector latches and the data bus. IC7 buffers a number of data lines for placement on the bus.

5.4C OUTPUT BOARD 2 (page VI-13)

MAGNITUDE: The X and Y signals enter Output Board 2 via pins 27 and 31 respectively. The X signal is applied to the X Absolute Value circuit

(IC2a and IC2b), and the Y signal is applied to the Y Absolute Value circuit (IC2c and IC2d). These circuits provide a signal proportional to the absolute value of the X and Y inputs respectively. The absolute value of X is squared by the Q2a-Q2b pair. The absolute value of Y is squared by the Q4a-Q4b pair. The squared signals are summed and their square roots taken at the junction of Q2b and Q4a to provide the magnitude signal. This signal is amplified to the proper level by IC8, the output of which is "R", or MAGNITUDE. Note that the R OFFSET signal developed on Output Board 1 is applied to pin 23 of the Output Board and from there is routed to the input of IC8 where it shifts the R reference level. The polarity of R is sensed by comparator IC10. This information is used by MDAC IC19 in developing the Phase Signal. The R signal exits Output Board 2 via pin 28.

LOG R: IC3a, IC3b, IC3c, and IC3d develop the log R signal. The inputs to the Log R circuits are the magnitude signal applied to the non-inverting input of IC3a, and the +10 V reference, which enters the board via pin 7. The log R signal, which is not used on Output Board 2, exits the board via pin 29.

PHASE COMPUTER: Most of the remaining circuits on the board belong to the Phase Computer, which develops the arc tan Y/X signal. The actual phase computation is performed by IC9c, IC9d, and the two associated sections of IC15.

The X^2 and Y^2 signals are routed through IC9a and IC9b, through pairs Q3a-Q3b and Q6a-Q6b, and then through buffers IC4a and IC4b respectively. These signals are then applied to comparator IC5, as well as to two of the switches in IC11. IC5 senses the polarity relationship of X^2 and Y^2 , and controls IC11 so as to apply either one signal or the other to R68 at the input of one section of IC15.

IC1 is a comparator that senses the polarity of X. Similarly, IC12 is a comparator that senses the polarity of Y. IC10 senses the polarity of R. The output of all three comparators is applied to IC19, which, on the basis of the polarity relationships, selects the correct outputs of the phase computation circuits to bring out to the stage of IC15 that provides the arc tan Y/X signal. Another section of IC15 (pins 1,2,&3) provides the -10 V reference level required by the phase computing circuits.

OTHER: IC7, IC13, IC14, and a section of IC11 help provide the Phase Lock operating mode. IC16 and IC17 are Overload Detectors. The two sections of IC18 provide one of the drives to the Y Channel Demodulator.

5.5 OSCILLATOR BOARD (page VI-5)

Referring to the schematic, note that the oscillator is basically an integrator, IC8, which ramps

linearly upwards or downwards as controlled by Q5. The ramping rate (oscillator frequency) depends on magnitude of the capacitance around the integrator (selected by multiplexers IC6 and IC7) and by the supplied current. The current in turn depends on the resistor selected by multiplexer IC4 and by the voltage applied by IC5a, which buffers the output of MDAC IC3. IC1 and IC2 are latches that read and hold the digital data representing the desired frequency. IC1 and IC2 controls IC3 and the three switches, Q1, Q2, and Q3 that drive the multiplexers. The triangular wave signal at the output of IC8 is applied to comparator IC9, which alternately switches the ramping direction as the thresholds are crossed, and to Q4 and IC5c, which shape the triangular wave into a reasonable sine wave. The signal to the Reference Circuits exits via pin 11. This signal controls the Reference Channel when operating in the Internal Reference Mode. The variable-amplitude signal available at the rear panel is generated from the IC5c direct output signal. This signal is cabled to the rear-panel Oscillator Amplitude potentiometer. The center tap of this potentiometer is applied to the non-inverting input of buffer IC5d, and from there is applied to the OSC. OUT connector.

5.6 REFERENCE BOARDS

5.6A INTRODUCTION

The description of the reference channel in Section I, together with the corresponding portions of the Simplified Block Diagram (Figure I-7) illustrate the "classical" approach to making a frequency-tracking reference channel. It is important to note that the M5205/6 reference channel does not strictly function as described in Section I. In the classical method, f_c and f_r are mixed, producing sum and difference frequencies. A low-pass filter following the mixer removes the sum frequency and the resulting difference frequency is compared with a signal derived from the applied reference signal to generate an "error" voltage. This voltage controls the VCO in such a way as to maintain the VCO output at $f_c + f_r$.

In the M5205/6 there is no Reference Mixer, but rather a "Pulse Nibbler" that accomplishes a similar function digitally. This circuit has as its inputs f_c and a signal derived from the reference input. The two are directly added such that the output is a digital stream of pulses at f_c with an extra pulse added each f_c period. This pulse stream is then processed so as to make each succeeding pulse wider than the one before it, with resetting to the minimum width occurring at f_c intervals. The result is a "digital" sawtooth. As shown in the reference channel block diagram on page VI-31, this pulse stream is applied to the integrator input. Although this signal alone would control the VCO, the sawtooth dithering of the VCO is unde-

sirable. To remedy this problem, an analog sawtooth signal developed from f_c is summed with the digital sawtooth to exactly neutralize the sawtooth value of the cycling pulse stream from the Pulse Nibbler. The result is a smooth control dc voltage applied to the integrator. This dc controls the VCO in much the same manner as in the classical approach. The Signal Mixer is driven at $f_c + f_r$, yielding a signal at f_c that is applied to the demodulator. The drive to the demodulator is at f_c to obtain the dc levels processed by the Output Board circuitry. As explained in the earlier discussion of the Demodulator, the demodulator drive is synchroset (phase reversed at synchroset frequency, 1 kHz in the M5205/6). A separate 1 kHz drive is thus also required by the demodulator to complete the demodulation process.

5.6B REFERENCE BOARD 2 (page VI-15)

INPUT SCHMIDT TRIGGER: This circuit, which comprises IC12 and its associated components, accepts either the applied externally derived reference signal (pin 11) or a signal from the internal oscillator (pin 45), and shapes it for processing by the digital circuits that follow. In the External Reference Mode, the externally derived reference signal is processed. In the Internal Reference Mode, the output of the internal oscillator (optional) is processed.

Transistors Q2 and Q3 are connected as diodes which become forward conducting if the applied signal exceeds plus or minus ten volts respectively. These "diodes" provide overload protection by clamping the input signal to the nominally ten volt level at the emitter of Q4 or Q5, as appropriate.

The reference signal is applied to pair Q6 which acts as an impedance buffer for the Trigger circuit that follows. Note that Q6 is followed by a switch that sets the Trigger reference potential at 0 V, +0.1 V, or -0.1 V. The 0 V position is used for reference signals that extend equally above and below ground. The +0.1 V reference optimizes triggering with positive pulses and the -0.1 V reference optimizes triggering with negative pulses. Note that the switch is arranged so that the Trigger circuit "fires" on the positive-going edge of positive pulses (switch to positive reference position) and on the negative-going edge of negative pulses (switch to negative reference position).

PHASE TRIM ONE-SHOTS: The output of the Trigger circuit is applied, in parallel, to monostables IC15a, IC15b, IC16a, and IC16b. Each of these monostables provides precisely the correct amount of delay to trim the phase accuracy of the high end of each of the operating bands. Multiplexer IC19a selects the output of one of these delays as determined by the state of Latch IC4, which monitors the data bus. Thus the signal at

the output of IC19a is simply a square wave at f_r , the frequency of the applied reference signal.

$f_r/2$ QUADRATURE GENERATOR: The output of IC19a is applied to One-Shot IC20, and to the inputs of D flip-flops IC21a and IC21b. IC20 simply provides short pulses at f_r . IC21a and IC21b are connected as a divide-by-four. They drive D flip-flops IC23a and IC23b in such a way as to provide the four phases (0° , 90° , 180° , and 270°) of a signal at $f_r/4$. These signals are applied to Exclusive OR gates IC27a and IC27b, which act as digital multipliers such that their outputs are complementary square waves at $f_r/2$. These signals, GATE 1 and GATE 2, are applied to NAND gates IC1c and IC1d. They are also brought out at pins 18 and 20 from where they are routed to the Reference 1 board.

Note that IC1c and IC1d are also driven by the pulse output (at f_r) of IC20. As a result of the gating provided by IC1c and IC1d, quadrature-related signals at $f_r/2$ are generated. These signals, RESET 1 and RESET 2, are brought out at pins 16 and 19 from where they are routed to the Reference 1 board.

IC29a and IC29b produce a similar pair of signals, SAMPLE & HOLD 1 and 2, also quadrature related and synchronous with RESET 1 and RESET 2.

The primary function of the reference circuits discussed to this point is to generate the GATE 1, GATE 2, RESET 1, RESET 2, S/H 1 and S/H 2 signals, all of which are used to control the Sawtooth Generators on Reference Board 2. In addition, IC21a and IC21b supply quadrature-related signals at $f_r/4$ to IC24a and IC24b, which are part of the Pulse Nibbler.

OSCILLATOR KEEP ALIVE: The block of circuits consisting of IC34, IC35b, Q7, Q8, Q9, Q10 and their associated components prevent the voltage-controlled oscillator from drifting to a very low frequency when no reference is applied. Observing the schematic, note that S/H 1 and S/H 2 are applied through resistors to the base of Q7. Since these two pulse streams are at $f_r/2$, the net effect is to pulse Q7 at f_r , developing a voltage on C34. The circuit acts as a Ratemeter in the sense that the potential on C34 is proportional to f_r . This voltage is compared with +10 V at the input of IC34. Should the voltage on C34 drop below 10 V, IC34 will act through Q10 to switch the logic level applied to C35b. The change is clocked out by f_r . This output, FAST ACQ, is routed to Reference Board 1. There it locks up the Phase Detector to keep the oscillator running at a high frequency. It additionally establishes a high ramping current at both Sawtooth Generators.

f_r and SYNCHROHET: The i.f. frequency drive has as its source the crystal-controlled oscillator com-

prising IC1a, IC1b, and their associated components. The output of this oscillator, which is at nominally 4 MHz, is applied to a series of cascaded divide-by-ten stages, IC6a, IC6b, IC10a, and IC10b. Note that the available frequencies are a factor of four high with respect to the desired i.f. drive frequencies. The output of each divider is applied to Multiplexer IC14a, which is controlled by Latch IC4. The Multiplexer output ($4f_r$) is applied to the divide-by-four circuit consisting of IC9a and IC9b. The resulting multi-phase output is applied to Multiplexer IC13a, which is controlled by Latch IC3. The control line states correspond to the selected Phase Quadrant such as to cause a correctly-phased signal at f_r to be provided at pin 7 of IC13a. Note that the $4f_r$ signal at the output of IC14a also clocks D flip-flops IC31a and IC31b. In addition, the signal exits the circuit board via pin 26.

The Synchrohet frequency of nominally 1 kHz is generated by Exclusive OR Gate IC27d, Gates IC32c, IC32d, Dividers IC30b, IC33a, IC33b, and Multiplexer IC19b. Observing the circuit, note that the pulse train at f_r is applied to pin 2 of IC27d. The output of this gate is also a pulse train at f_r . However, because of the following dividers and the feedback to pin 1 of the gate, this pulse train reverses phase at a 1 kHz rate. The signal at the output of IC27d is divided by 10, 100, or 1000, according to the selected band. However, the selection is done in reverse sequence with respect to the f_r selection. When f_r is 1 MHz, the synchrohet division factor is 1000. When it is 100 kHz, the synchrohet division factor is 100. When it is 10 kHz, the synchrohet division factor is 10. In other words, the synchrohet division factor, as selected by the multiplexer, is always that which will give 1 kHz at the output of the Multiplexer (pin 7 of IC19b). This signal, which is fed back to pin 1 of IC17d, causes the output of that gate to reverse phase at a 1 kHz rate. This synchrohetted f_r signal is applied to D flip-flop IC31b, which is clocked by a $4f_r$ signal from the output of IC14a. The result is a synchrohetted f_r signal delayed by a quarter cycle. This signal and its complement are brought out at pins 32 and 31, and from there are routed to the Demodulator. Similarly, the 1 kHz synchrohet signal, also required by the demodulator, is brought out at pins 29 and 30. The $4f_r$ signal exits the board via pin 26.

VCO PROCESSING: A signal from the VCO is applied to pin 12 of IC7a. This signal is applied to a chain of Divide-by-Ten circuits, which, in turn, drive a Multiplexer. The multiplexer selects the output appropriate for the selected band. This signal is then divided by two (IC17a) to develop the complementary signals at f_r required by the Mixer and Pulse Nibbler.

PULSE NIBBLER: As mentioned in the introduction, the Pulse Nibbler generates a cyclic stream

of pulses at $f_c + f_r$. This circuit consists of IC24a & b, IC25a & b, IC28a, and IC17b. Referring to the schematic, note that the f_c output of Multiplexer IC22 is applied to IC25a and IC25b. These two D flip-flops are configured as a Divide-by-Four counter, providing four quadrature-related outputs at $f_c/4$. These four signals are applied to Multiplexer IC28a, which is controlled by IC24a and IC24b. These two D flip-flops have as their inputs the quadrature-related $f_c/4$ outputs of IC21a and IC21b. IC24a and IC24b are clocked by the output of Multiplexer IC28a. Thus the inputs to IC24a and IC24b are at $f_c/4$, while being clocked at $f_c/4$. This arrangement results in pulses at $f_c/4$ being added to the $f_c/4$ pulse stream. In effect, the circuit acts as an "upper sideband only" mixer. This complex pulse stream is applied to IC17b and clocked out by f_c . The resultant f_r signal is routed to the integrator, located on Reference Board 1.

Note that the IC24a/b outputs are applied to Exclusive OR IC17c to develop the SAW SELECT signal that selects either of two analog sawtooth waveforms at Reference Board 1.

F/2 CIRCUIT: There are two dividers, IC18a and IC18b, in this circuit, together with Multiplexer IC22. IC18a has f_c as its input. IC18b has f_c as its input. The divided AND undivided versions of both signals are applied to Multiplexer IC22, which also looks at two different phases of f_c . This Multiplexer can be thought of as containing three single-pole, double-throw switches. The upper switch connects either pin 2 or 3 to pin 4, the middle switch connects either pin 5 or 6 to pin 7, and the bottom switch connects either pin 10 or pin 11 to pin 9. The selected signals, determined by whether the "f" or "f/2" mode has been selected, will be at the "full frequency" or at half that frequency. Thus the circuits driven by IC22 will see either of two frequencies, according to the selected Reference Mode.

PHASE VERNIER: The Phase Vernier setting is digitally encoded and placed on the data bus. This phase information is captured by latches IC2 and IC3, and applied to DAC IC5. IC8 buffers the resulting dc phase signal, which is then routed to Reference Board 1 where it is summed with the other levels that control the VCO.

5.6C REFERENCE BOARD 1 (schematic on page VI-14)

VCO: The VCO comprises Q16, Q17, Q18, and Q19, together with their associated components. This varactor-tuned oscillator is controlled by the voltage at the output of buffer IC16. Multiplexer IC14 applies the output of any one of four loop integrators to IC16. The multiplexer input is the summing junction for the various VCO control levels, of which there are three. The first is the pulse stream output of IC12, determined by f_r , $f_c/4$,

and ± 10 V reference levels. This is the input that contains the "error" information that corrects the VCO frequency. Next is the analog sawtooth from one or the other of the two Sawtooth Generators. This sawtooth compensates the "digital sawtooth" characteristic of f_r to prevent dithering of the VCO output. Third is the Phase Vernier potential developed by a DAC on Reference Board 2. This input "offsets" the phase loop as required to establish the desired phase at the output of the VCO.

SAWTOOTH GENERATORS: There are two identical sawtooth generators, operated in quadrature. They are controlled by the GATE, RESET, and SAMPLE and HOLD signals developed on Reference Board 2. The timing is such that each time a reference pulse is added in the Pulse Nibbler, IC133 switches, alternating the sawtooth output connected to the VCO Control summing line. This scheme is required for proper compensation of the "digital sawtooth". The actual sawtooth generators are IC2 in one circuit and IC4 in the other. The associated circuits are primarily concerned with maintaining constant sawtooth amplitude as a function of frequency (the ramping current must vary linearly with frequency to maintain constant amplitude). At all times IC13 connects one sawtooth or the other to the integrator summing line, in response to the SAW CLOCK and SAW SELECT signals developed on Reference Board 2.

DIGITAL SAWTOOTH GENERATOR: The "upper-two" gates of IC12 are controlled by IC8a, which is clocked by f_r . The "lower-two" gates of IC12, are controlled by IC8b, which is clocked by $f_c/4$. These two clocks are not synchronized but rather "slide" with respect to each other at a rate governed by the difference between the f_c and f_r frequencies. As a result, the output of IC12 is a stream of ± 10 V pulses at f_r , but with each successive pulse longer than the one preceding. At $f_c/4$ intervals, the changing-width resets to its narrowest width, and the process repeats. In effect, the circuit acts as a "digital-sawtooth" generator. Note that the -10 V regulated level is provided by IC15. The $+10$ V level is generated elsewhere. IC9a, b, and c simply provide delay in the Clear line.

REF LOW DETECTOR: IC17 is the Reference Low Detector. Observing the schematic, note that the non-inverting input of this comparator is returned to $+2.5$ V at the junction of R39 and R45. The inverting input is returned to the two sawtooth waveforms via diodes D9 and D10. If the amplitude of the sawtooth waveforms drops below the average 2.5 V level, which will happen if the amplitude of the applied reference signal is too low for proper reference channel operation, IC17 will switch and current will be supplied to the front-panel REF LOW indicator.

5.7 FRONT PANEL {pages VI-16 (M5205) and VI-17 (M5206)}

Except that the Model 5206 front-panel board has a few more LED's than does the M5205 front-panel board, the two are practically identical. Referring to either schematic, note that there are two LED drivers, IC3 and IC4, each of which can drive as many as 64 LED's. These drivers monitor the incoming data lines and supply current to the selected LED's and display elements. The front-panel switches are monitored by IC1 and IC2 and the obtained information is routed to the data bus where it can be read by the microprocessor.

5.8 CPU BOARD (page VI-19)

Referring to the schematic, note that the microprocessor is a 6809 (U9). This processor monitors and controls all unit functions. Note that its RESET input (pin 37) is driven by the circuit comprising Q1, Q2, and their associated components. This circuit monitors the +5 V supply level. When the unit is powered down, the falling +5 V is detected and the microprocessor is forced into reset, thereby preventing any disruptive logic sequences from being applied to the data bus as the microprocessor begins losing power.

There are several address decoders, U3, U4, U6, U5, U1, and U2. These address the CPU-board EPROMS, RAM, and various digital circuits located on other circuit boards. The instrument's firmware consists of the four 4 K EPROMS, U18, U19, U20, and U21. The eight 1 K x 4 RAMS, U10, U11, U12, U13, U14, U15, U16, and U17 are functionally organized into four 1024 byte blocks. Note that a 3.4 V lithium battery keeps U17 and U10 alive when the unit is powered down. This battery should have a life of at least four years. Timer U22 generates the interrupts that initiate such microprocessor functions as sampling data, checking the keyboard, auto-ranging if appropriate, and updating the display LED's. U8 is simply a data-line buffer.

5.9 GPIB/RS232 INTERFACE BOARD (page VI-21)

Referring to the schematic, note that U4 and U5 allow selection of the RS232 switches or the GPIB switches (or neither). The data on the switches is routed through buffer U10, and from there to the buffered data bus via pins 41 through 48 of J1. Two sections of U9, together with their associated components, make up the Baud-Rate Oscillator. U11 is a divider that provides the available baud rates, one of which is selected via the baud-rate jumper and applied to U3, the RS232 Interface Chip. U7 is the RS232 Transmit Buffer and U8 is the RS232 Receive Buffer. U12 and U13 are regulators that provide the +12 V and -12 V levels re-

quired by U7. U1 and U6 are buffers for the GPIB bus.

5.10 POWER SUPPLY (page VI-22)

Observing the schematic, note that the ac input power is routed through the line switch, through the fuse, and from there is applied to the split-winding power transformer. For operation from a line voltage of nominally 115 V ac, the two windings are in parallel. For operation from a line voltage of nominally 230 V ac, the two windings are in series. There are two secondary windings, one center-tapped, the other not. The output of the "lower" winding is applied to a bridge and from there to the two regulators, IC4 and IC5, which develop the two regulated +5 V levels distributed throughout the instrument. The center tapped winding is used to develop three different potentials, +24 V, +15 V, and -15 V. Note that the +24 V circuit includes a voltage doubler (C4, D1, D2, and C5) and a two stage regulator (Q1 and IC1). The +15 V and -15 V levels are developed by regulators IC2 and IC3, which accept the unregulated outputs of bridge BR2.

5.11 FIELD CALIBRATION

5.11A INTRODUCTION

The following field calibration procedure allows users to "touch up" those adjustments most likely to drift with time, and those adjustments which require setting if a Broadband, Audio, or Low Frequency card is installed in the field. The Ultra-Low Frequency Card is a special case. Although it cannot be installed in the field, its alignment can be "touched up" with this procedure. Simply proceed the same as for a Low-Frequency card. Take care not to disturb any adjustments other than those mentioned in the procedure. A complete alignment of this instrument requires special fixtures and ancillary equipment available at the factory only.

5.11B REQUIRED EQUIPMENT

- (1) Signal Generator with a fixed 1 V rms output and an in-phase variable output. **EXAMPLE:** Krohn-Hite M4200A.
- (2) Four digit (or better) DVM that measures rms volts.
- (3) Source of +10.00 V accurate to 5 mV.
- (4) Two BNC cables and a "tee" connector.
- (5) BNC shorting plug.

5.11C INITIAL SETUP

- (1) Remove the top cover.
- (2) Make sure the frequency-range cards are in

their proper slots as marked on the main board. Broadband cards are labeled for easy identification. Audio and Low-Frequency cards are not labeled. However, they can be readily distinguished by the number of trim-potentiometers. An Audio card has two trim-potentiometers. A Low-Frequency card has four. **CAUTION:** In the case of early units, the Audio card also has four trim-potentiometers.

Expand (M5205): ON
 CH 1 Expand (M5206): OFF
 Offset: OFF
 Reserve: HIGH STAB
 F Band: Any Installed Band
 Reference: F (EXT)
 Phase: 0° – 90° Quadrant Selected
 Time Constant: 100 ms, 6 dB
 Sensitivity: 5 V
 Select and Local: OFF

- (3) Power up the M5205/6 and allow it to warm up for one hour.
- (4) If the unit is equipped with an Audio Frequency Card (Option /98), do a system reset (Press SENSITIVITY and SELECT simultaneously) to establish the default parameters. If the unit is NOT equipped with an Audio Frequency Card, set the operating parameters as follows.

Display (M5206): CH 1
 Display (M5205): OUTPUT
 Output Mode: X,Y

5.11D PROCEDURE

NOTE: The following procedure makes provision for Broadband, Audio, and Low-Frequency Band cards. Make only those adjustments that apply to the cards actually installed in the unit. Note that the location of the adjustments is indicated in Figure V-1.

DEMODULATOR ZERO ADJUSTMENTS

(1) Steps That Apply to All F-Band Cards.

- (a) Apply a 1 V rms, 1 kHz sine wave to the Reference Input.

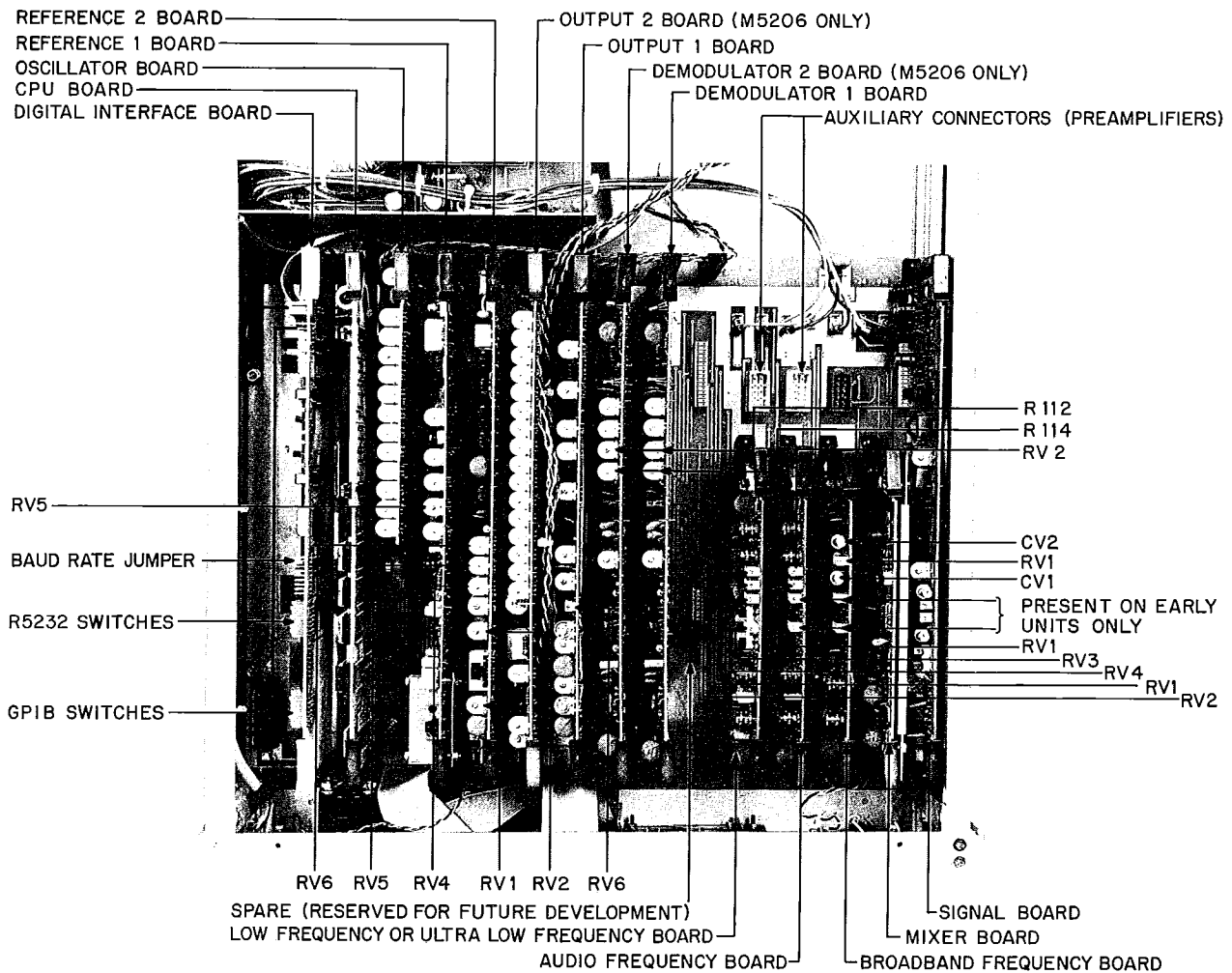


Figure V-1. FIELD CALIBRATION ADJUSTMENTS

- (b) Connect a BNC shorting plug to the signal "A" Input.
- (c) Set the A/A-B switch to "A".
- (d) Set the reserve to HIGH RES and the sensitivity to 5 mV.

(2) Audio Band

- (a) Select the AUDIO band.
- (b) Adjust R112 on the DEMOD 1 board for an indication of less than 0.005 mV on the M5205/6 display.
- (c) (Applies to M5206 Only) Select CH 2 Display. Then adjust R112 on the DEMOD 2 board for a display indication of less than 0.005 mV.

(3) Broadband

- (a) Select BROADBAND and CH 1 display (OUTPUT display if M5205).
- (b) Adjust R114 on the DEMOD 1 board for a display indication of less than 0.010 mV.
- (c) (Applies to M5206 Only) Select CH 2 Display. Then adjust R114 on the DEMOD 2 board for a display indication of less than 0.010 mV.

(4) Low Frequency

- (a) Select LOW BAND and CH 1 display (OUTPUT display if M5205).
- (b) Adjust RV4 on the Low Frequency card for a display indication of less than 0.005 mV.
- (c) (Applies to M5206 Only) Select CH 2 display. Then adjust RV3 on the Low Frequency card for a display indication of less than 0.005 mV.

A/D CONVERTER ADJUSTMENTS

- (1) Apply an accurate +10.00 V level to pin 6 of one of the Auxiliary Input Plugs (white connectors just behind the F Band Cards).
- (2) Select the AUX display mode.
- (3) Adjust RV6 (a ten-turn trim-potentiometer) on the Output 1 board for a display indication of 100.0.
- (4) Remove the +10 V level and select display CH 1 (display OUTPUT if M5205).

PHASE ADJUSTMENTS

- (1) Remove the shorting plug from the Signal "A" input.
- (2) Using a BNC "TEE" connector, connect the 1 V reference signal to both the Reference and Signal "A" Inputs.
- (3) Set the Signal Input switch to "A".
- (4) Set the sensitivity to 1 V and the phase quadrant to 90°-180°.
- (5) Adjust RV5 on the REF 1 board for a display indication of 0.000 V.
- (6) Set the sensitivity to 100 mV. Then reduce the amplitude of the signal applied to the signal and reference inputs to 100 mV rms.
- (7) Adjust RV1 on the REF 2 board for a display indication of 0.000 V.
- (8) Set the sensitivity to 1 V and increase the amplitude of the signal applied to the signal and reference inputs to 1 V rms. The display indication should be less than 0.05 V. If it isn't, repeat steps 5 through 8 until the reading is in tolerance.
- (9) Note and record the display indication. Then select the 0°-90° Phase Quadrant.
- (10) Select Display PHASE. Then, using the Phase FINE adjust function, set the phase for a display indication of exactly 90.0.
- (11) Select Display CH 1 (M5206) or Display OUTPUT (M5205).
- (12) Adjust RV2 on the REF 2 board for the same reading as was recorded in step 9.
- (13) Select Display PHASE.
- (14) Using the Phase FINE adjust function, set the phase for a display indication of 0.0.
- (15) Select the 90°-180° Phase Quadrant. Then, of the following outlined adjustments, do those that apply to the F Band cards in the unit.

BROADBAND

- (1) Select Display CH 1 (Display OUTPUT if M5205).
- (2) Adjust CV1 and CV2 on the BROADBAND card for a display indication of less than 0.002 V.

- (3) Set the input frequency to 100 kHz. Then adjust RV6 on the REF 2 board for a display indication of less than 0.003 V.

LOW FREQUENCY BAND

- (1) Set the input frequency to 100 Hz. Then adjust RV2 on the LOW FREQUENCY card for a display indication of less than 0.003 V.
- (2) Set the input frequency to 1 kHz. Then adjust RV4 on the REF 2 board for a display indication of less than 0.003 V.

AUDIO BAND

- (1) Set the input frequency to 100 Hz. Then adjust RV2 on the AUDIO card for a display indication of less than 0.005 V.

- (2) Set the input frequency to 10 kHz. Then adjust RV5 on the REF 2 board for a display indication of less than 0.003 V.

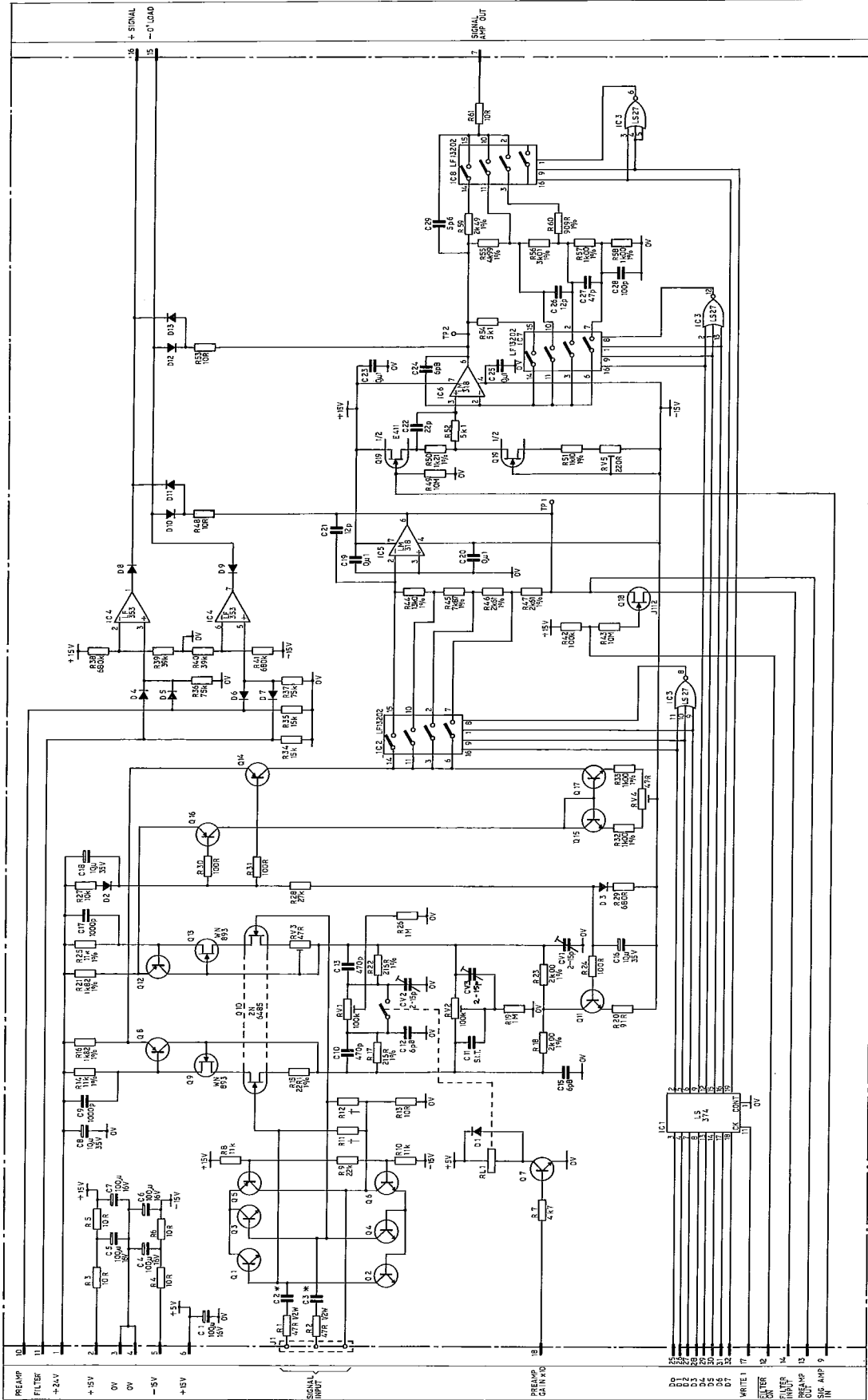
GAIN ADJUSTMENTS

- (1) Apply a 1 V, 1 kHz signal to the reference input and a synchronous 500.0 mV rms sine wave to the "A" input (measure with ac DVM).
- (2) Restore the parameters established in 5.11C with the exception that the sensitivity should be set to 500 mV and EXPAND (CH 1 EXPAND in M5206) should be set to OFF.
- (3) Select each installed frequency band sequentially and adjust RV1 on each Frequency Card for a display indication of 500.0 mV.

This completes the touch-up calibration.

SECTION VI SCHEMATICS

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NOTE
 * 0.01, 0.001, 0.005
 † MATCHED TO 1%
 ‡ 100M 5%
 § MATCHED TO 1%

NO'S	TYPE	QTY	REV	QTY	REV	QTY	REV
IC1	74LS374	10	20	-	-	-	-
IC2	LF3202	5	13	4	-	-	-
IC3	74LS374	7	14	-	-	-	-
IC4	LF3202	5	13	4	-	-	-
IC5	LM318	1	7	4	-	-	-
IC6	LF3202	5	13	4	-	-	-
IC7	LF3202	5	13	4	-	-	-
IC8	LF3202	5	13	4	-	-	-

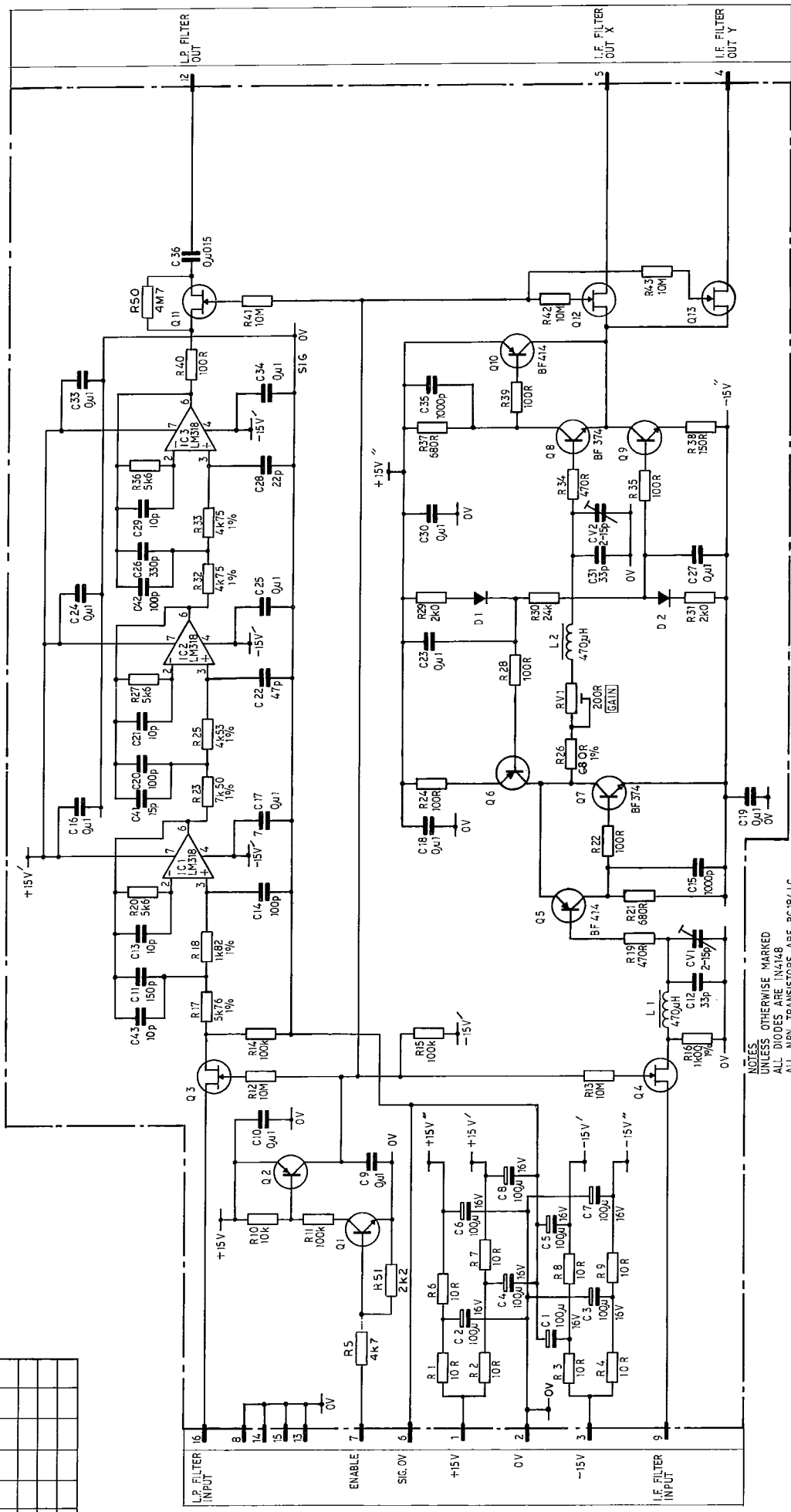
ALL DIODES IN THIS CIRCUIT ARE 1N4148 UNLESS OTHERWISE SPECIFIED.
 ALL PNP TRANSISTORS ARE BC214C UNLESS OTHERWISE SPECIFIED.
 ALL CAPACITOR VALUES IN PARAS.

REV	DATE	BY	CHKD	APP'D	DESCRIPTION
1	10/15/81
2	10/15/81

TITLE: SIGNAL CHANNEL CIRCUIT DIAGRAM
 INST. NO. 5205/6
 DRG. NO. 1A188-D-SD
 SHEET 1 OF 1

IG No 9.5205.40400
ISSUE
1
2
3
4
5

DO NOT SCALE. IF IN DOUBT ASK. DIMENSIONS IN MILLIMETRES.



NOTES
 UNLESS OTHERWISE MARKED
 ALL DIODES ARE 1N4148
 ALL PNP TRANSISTORS ARE BC184LC
 ALL PNP TRANSISTORS ARE BC214LC
 ALL RESISTOR VALUES IN OHMS
 ALL CAPACITOR VALUES IN FARADS
 ALL PETS JT12

9.5205.40400 SHT 1 OF 1		TITLE		BROAD BAND RANGE CARD CIRCUIT DIAGRAM	
PARTS LIST REFERENCE		DRAWN		C.A.S.	
CHECK'D		CHK'D		APP'D	
SCALE		SCALE		SCALE	
TOLERANCES NOT STATED:		GENERAL POSITION ANGLE		FINISH	
CUT OFF SIZE		MATERIAL		CUT OFF SIZE	
FINISH		MATERIAL		FINISH	
AMENDMENT		AMENDMENT		AMENDMENT	
POSN	TOL	ISSUE	DRAWN	DATE	CHK'D
6	1/8	5/11/84	SUL	6/6/84	SUL
5	AR3	3/7/81			
4	AR	15/81			
3	C.A.S.	21-1-81			
2	C.A.S.	16-12-80			
1	C.A.S.	11-1-80			

IF IN DOUBT ASK.

DIMENSIONS IN MILLIMETRES.

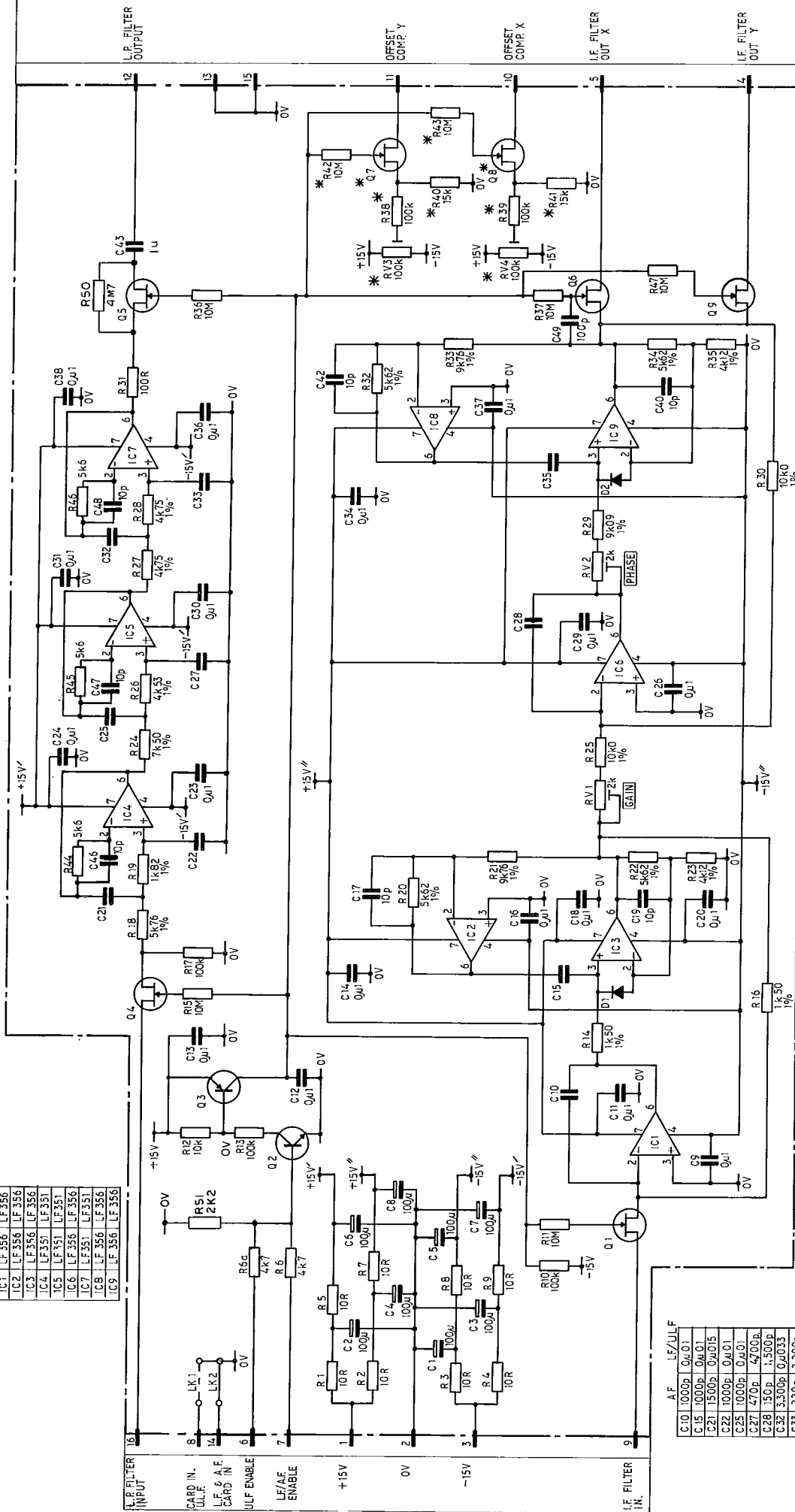
C

D

DO NOT SCALE.

IC1	LF 356	LF 356
IC2	LF 356	LF 356
IC3	LF 356	LF 356
IC4	LF 351	LF 351
IC5	LF 351	LF 351
IC6	LF 356	LF 356
IC7	LF 351	LF 351
IC8	LF 356	LF 356
IC9	LF 356	LF 356

A.F.	LF/ULF
C10	1000p
C15	1000p
C21	1500p
C22	1000p
C25	1000p
C27	470p
C28	150p
C32	3300p
C35	150p
C43	0.022
C44	0.033
C45	0.033



NOTES:
UNLESS OTHERWISE MARKED
ALL NPN TRANSISTORS ARE BC184LC
ALL PNP TRANSISTORS ARE BC214LC
ALL RESISTOR VALUES IN OHMS
ALL CAPACITOR VALUES IN FARADS
ALL FETS J112

R6g ADDED IN ULF.
LK7 ADDED IN ULF.
* USED ONLY ON LF/ULF CARDS.

HOLE OFF		DETAIL		POSN	TOL	ISSUE	DATE	CHKD	ECN NO	AMENDMENT	
				FINISH		CUT OFF SIZE		MATERIAL		SPECIFICATION	
				TOLERANCES NOT STATED:		GENERAL POSITION ANGLE		Brookdeal		PARTS LIST REFERENCE	
								inst.no. 5205/6		sht 1 of 1	
								DRG.No. 142G4-C-SD		REV A	
								9-5205-40300		SAT 1 OF 1	
								TITLE		AF, LF, ULF RANGE CARD	
								CIRCUIT DIAGRAM			

DO NOT SCALE.

IF IN DOUBT ASK.

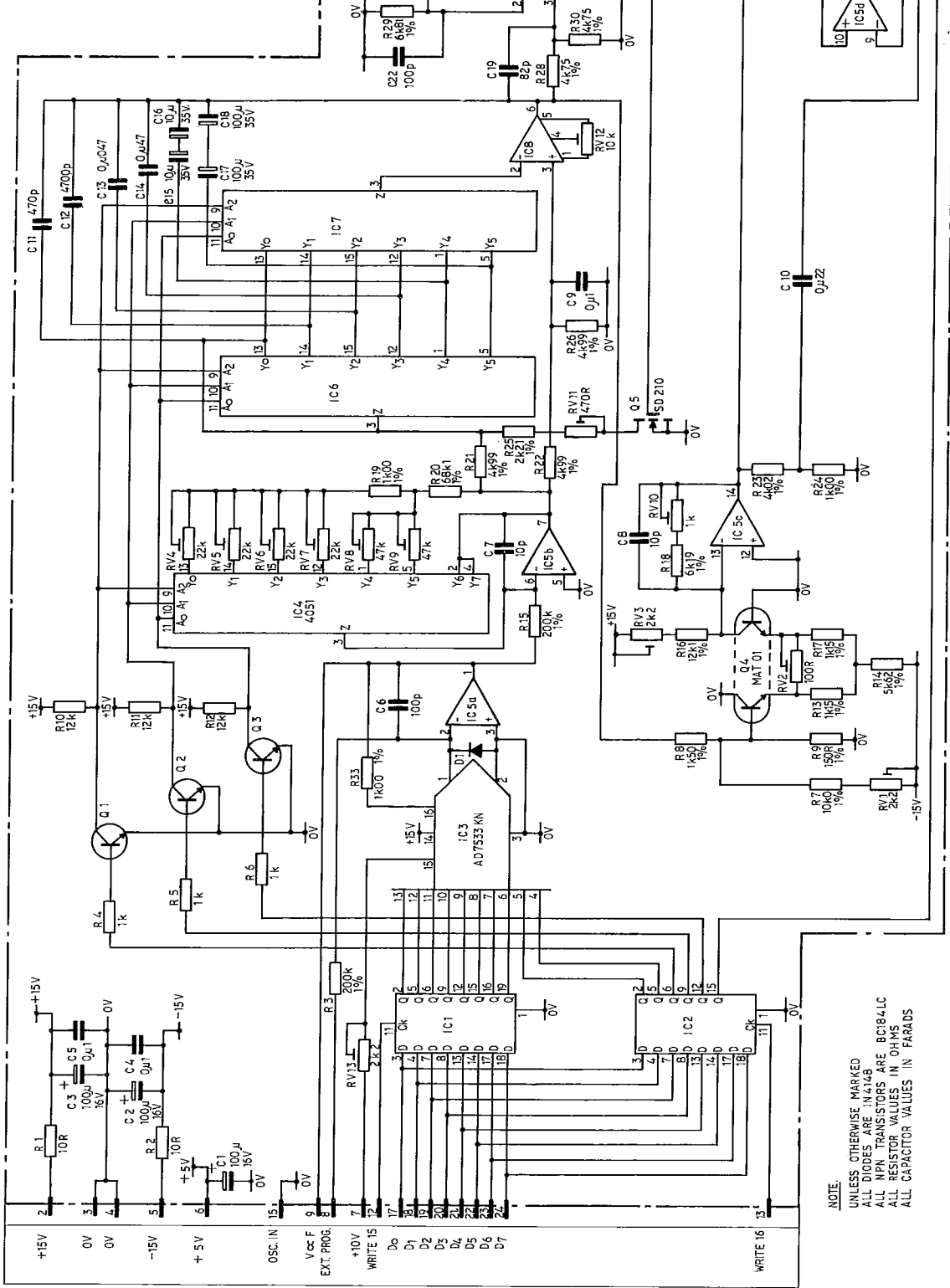
DIMENSIONS IN MILLIMETRES.

THIRD ANGLE PROJECTION.

DESCRIPTION

DRG No

IC No.	TYPE	0V	+5V	+15V	-15V
1	74LS374	10	20	-	-
2	74LS374	10	20	-	-
3	AD7533	3	3	16	-
4	HEF4051	8	-	16	-
5	LF347	-	-	16	-
6	HEF4051	8	-	16	-
7	HEF4051	8	-	16	-
8	LF351	-	-	7	4
9	LM311	1	-	8	4



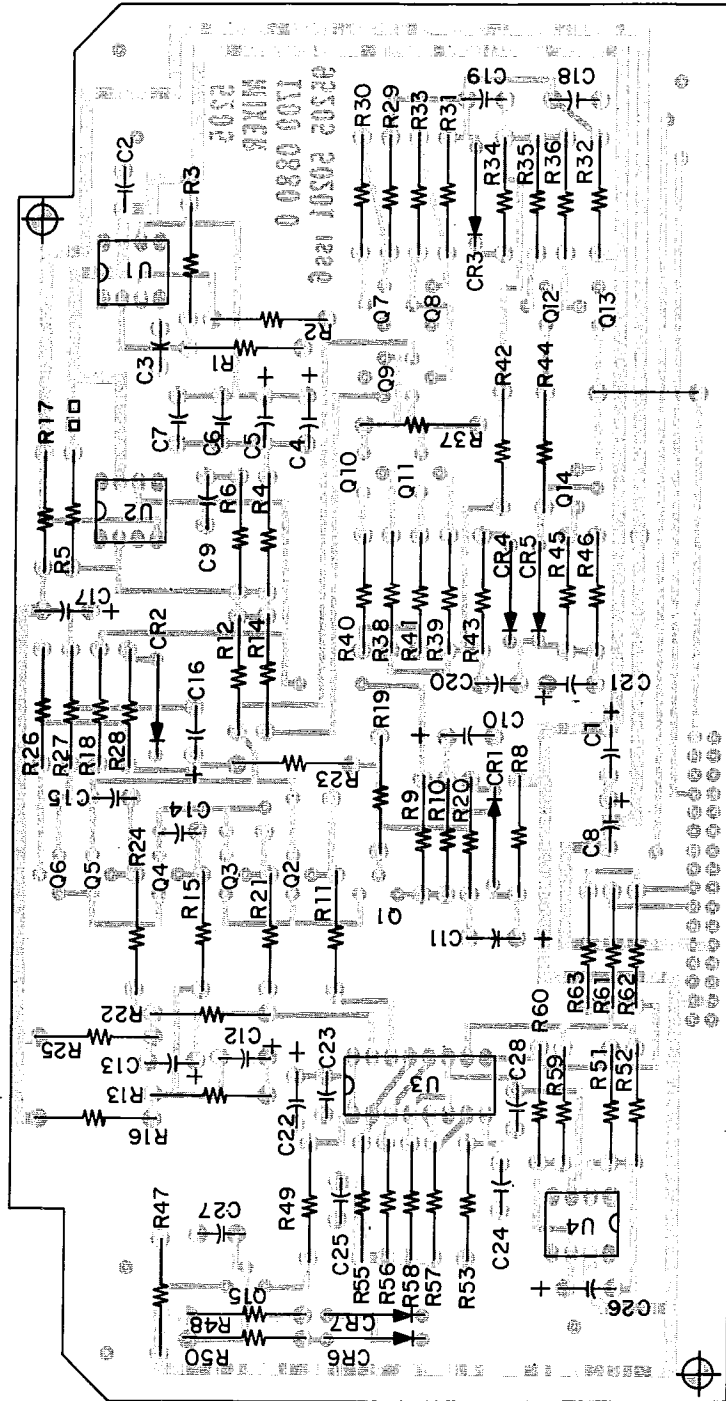
NOTE.
UNLESS OTHERWISE MARKED
ALL DIODES ARE IN 4148
ALL NPN TRANSISTORS ARE BC184-1C
ALL RESISTOR VALUES IN OHMS
ALL CAPACITOR VALUES IN FARADS

REV	DATE	ISSUE	POSH TOL	DETAIL	AMENDMENT	FINISH	CUT OFF SIZE	TOLERANCES NOT STATED:	GENERAL POSITION ANGLE	C.A.S. PARTS LIST REFERENCE	TITLE
1	1-12-80	1									OSCILLATOR CIRCUIT DIAGRAM
2	1-12-80	2									
3	1-12-81	3									
4	1-2-81	4									

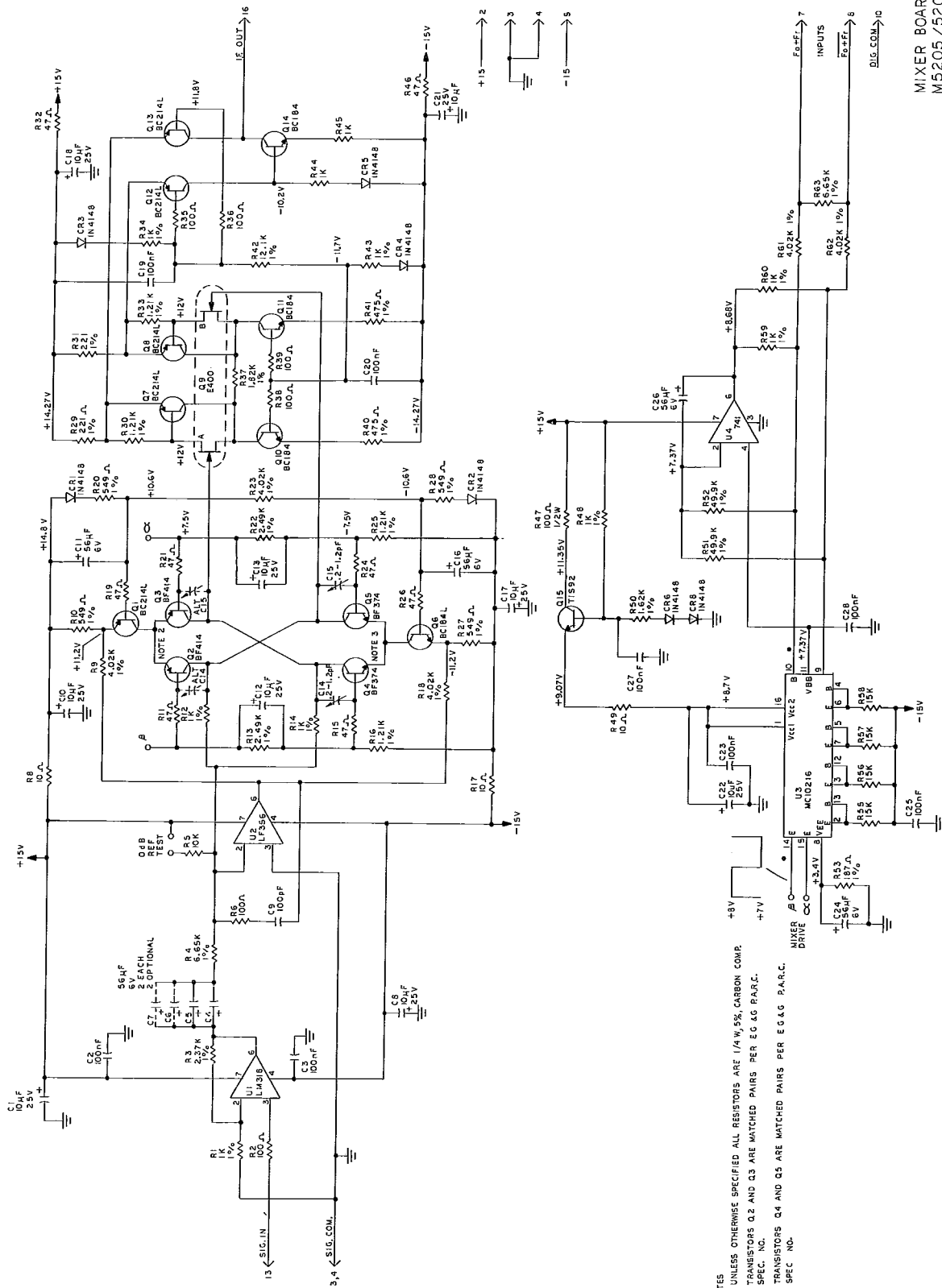
Inst. no. 5205/6 sht 1 of 1
D.R.G.C. DRG.No. 1A232-C-SD

9.5205.41200 SHT 1 OF 1

Brookdeal
A subsidiary of
LEGS COMPANY
Brookdeal Electronics Ltd, Bracknell 29931



MODEL 5206 & 5205
MIXER BOARD

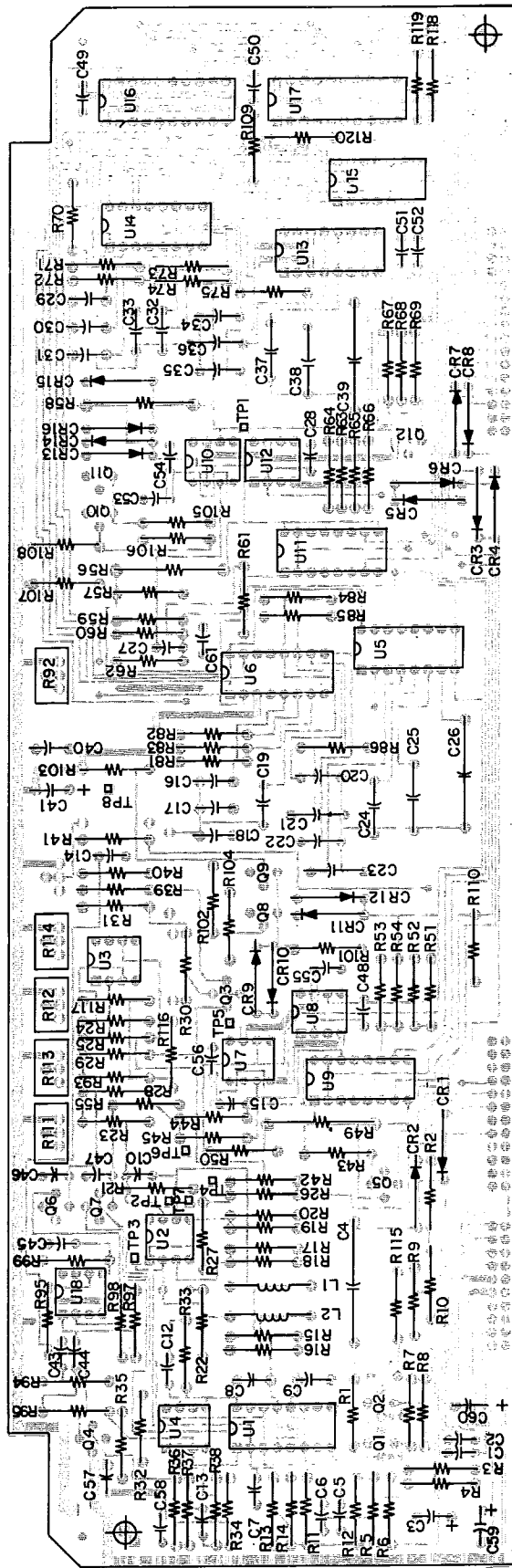


- NOTES
1. UNLESS OTHERWISE SPECIFIED ALL RESISTORS ARE 1/4 W, 5% CARBON COMP.
 2. TRANSISTORS Q2 AND Q3 ARE MATCHED PAIRS PER EG 4G P.A.R.C. SPEC. NO.
 3. TRANSISTORS Q4 AND Q5 ARE MATCHED PAIRS PER EG 4G P.A.R.C. SPEC. NO.

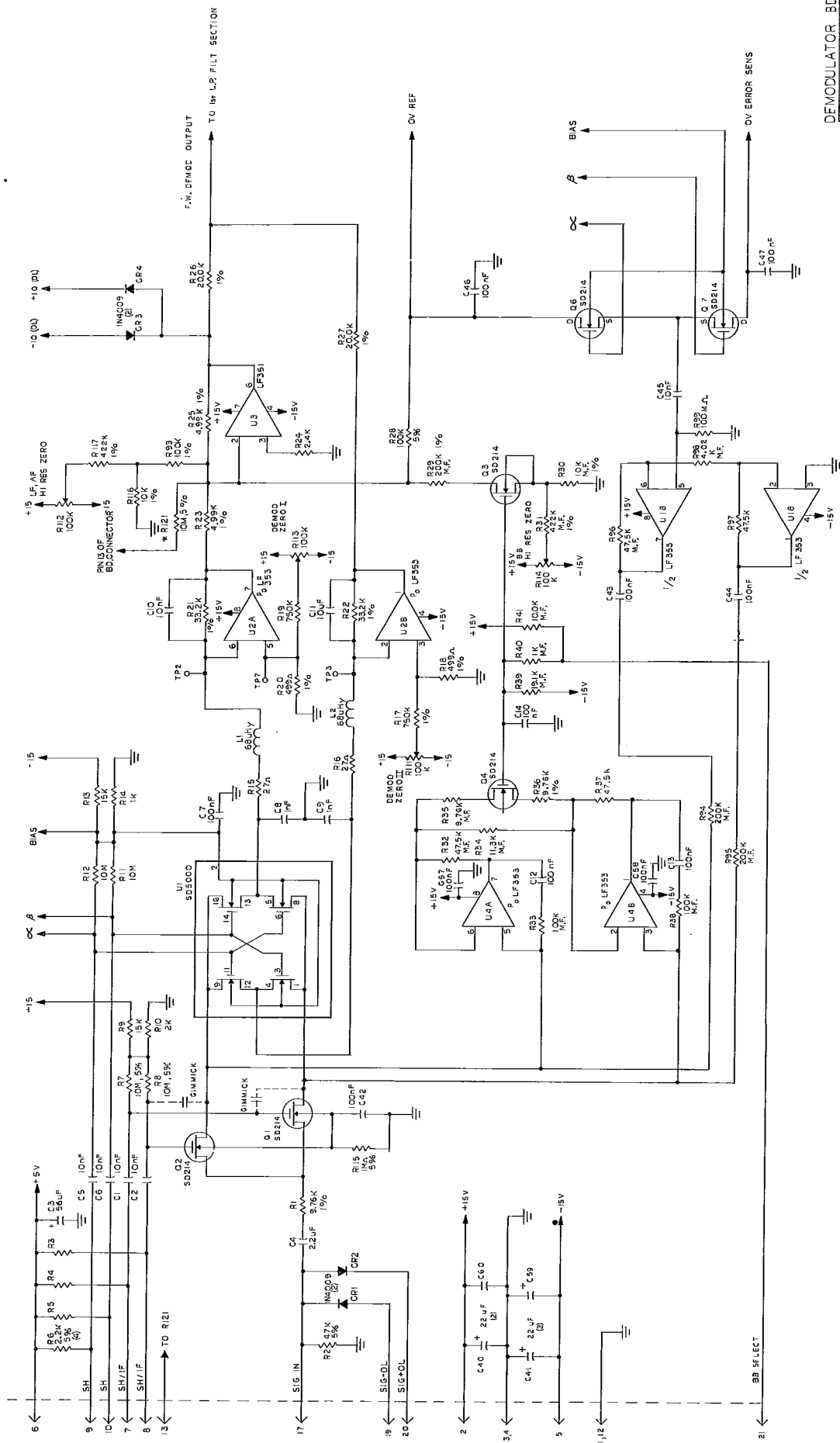
MIXER BOARD
M5205/5206

REF 9.5205.40200

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MODEL 5205 B 5206
DEMODULATOR BOARD



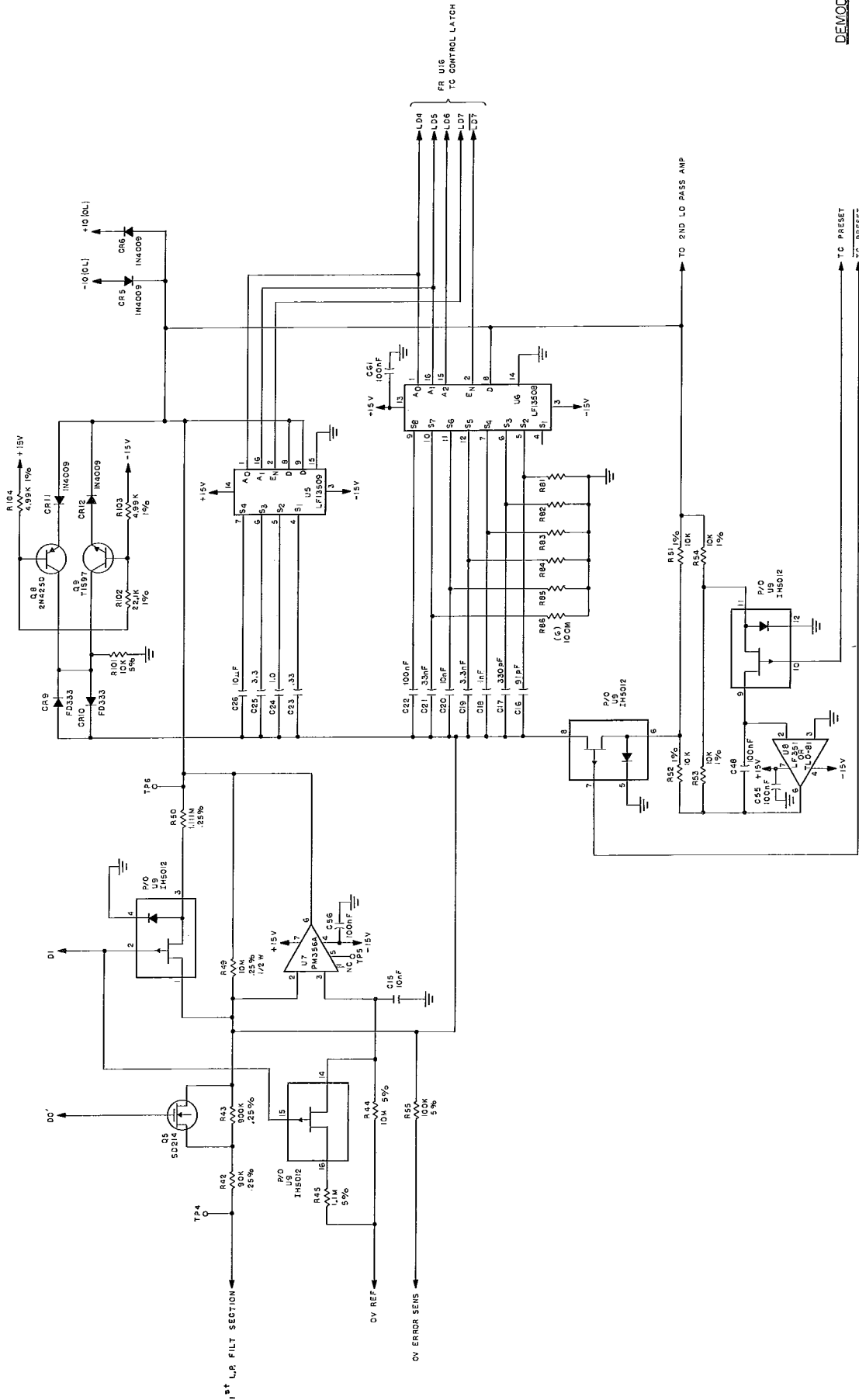
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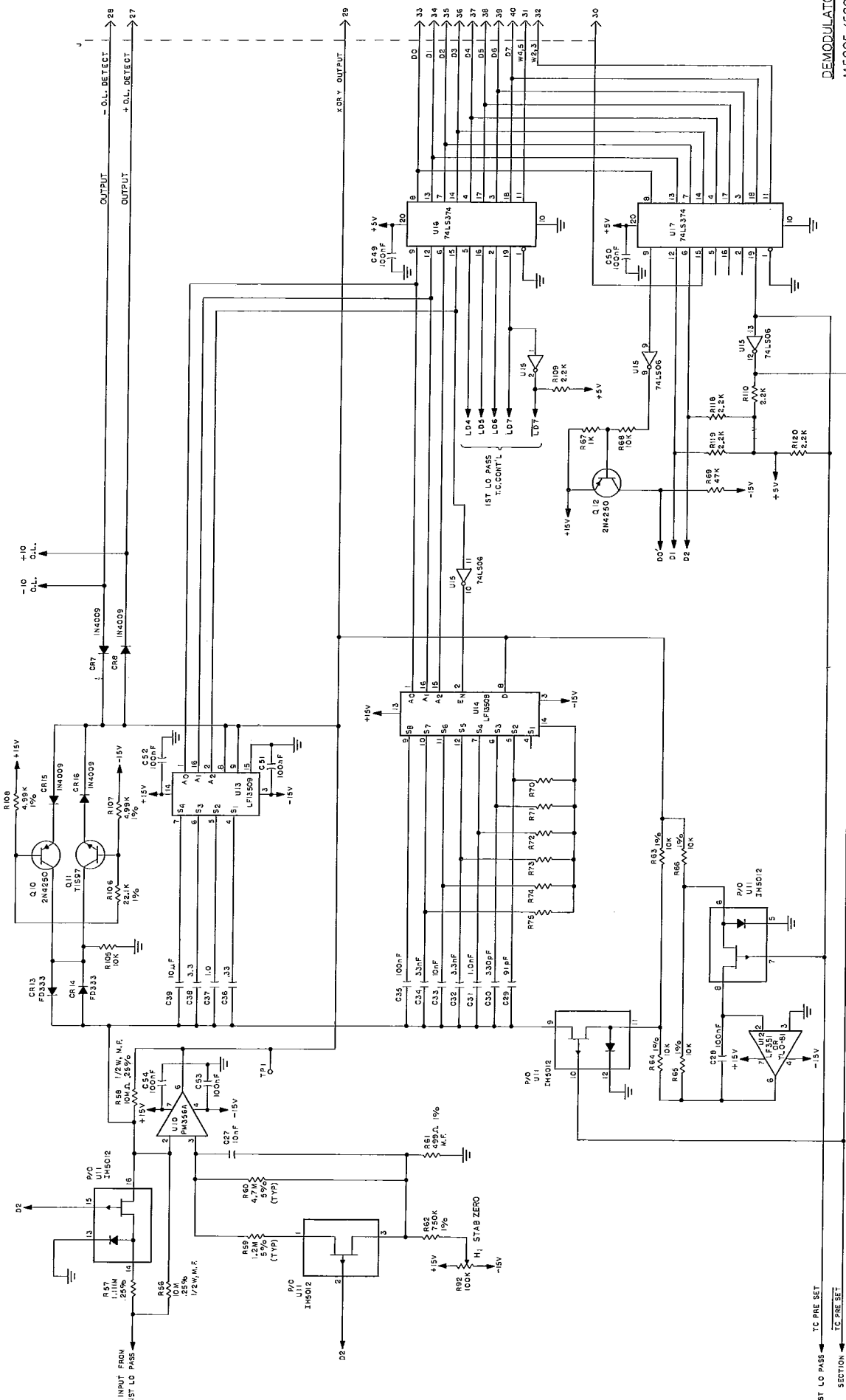
1. FOR BILL OF MATERIAL SEE
2. ALL RESISTORS ARE 1/4 W, 5% CARBON COMPOSITION UNLESS OTHERWISE SPECIFIED.
3. ALL CAPACITORS ARE 10% METAL FILM UNLESS OTHERWISE SPECIFIED.
- * USED ONLY IN INITIAL UNITS.

DEMULATOR BD.
M 5205 / 506

APPLIED RESEARCH
P.O. BOX 285, BRIDGEVILLE, PA. 15105
COMMERCIAL ELECTRONICS DIVISION

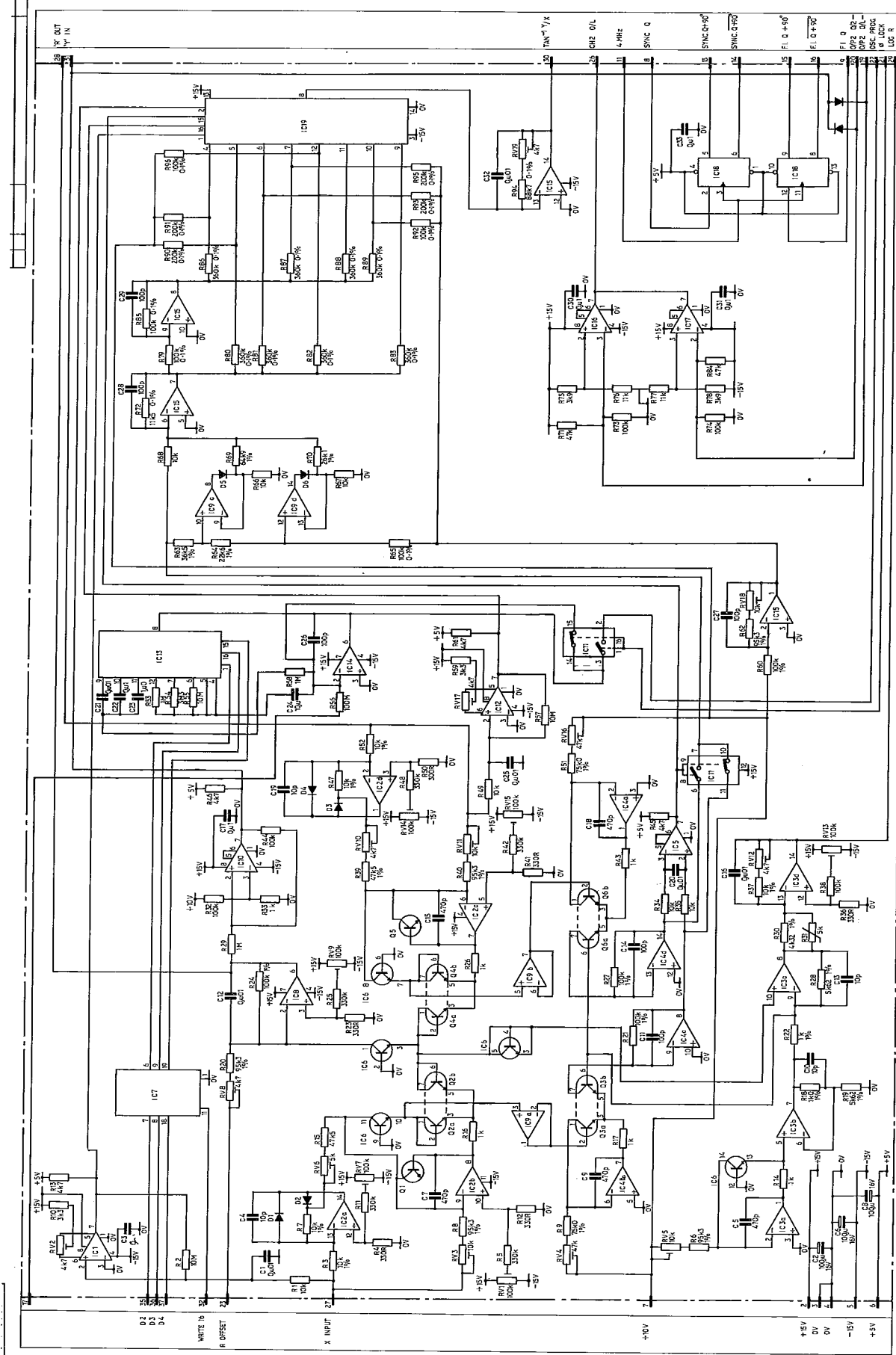
SHT. 1 of 3 [42] [D] [SD] [A]





DEMULATOR BD
M5205/5206

EG&G PRINCETON APPLIED RESEARCH
P.O. BOX 284, PRINCETON, NJ 08540
COMMERCIAL AND INDUSTRIAL RESEARCH
DIVISION
SHR 3 OF 3 1472081D1SD1A

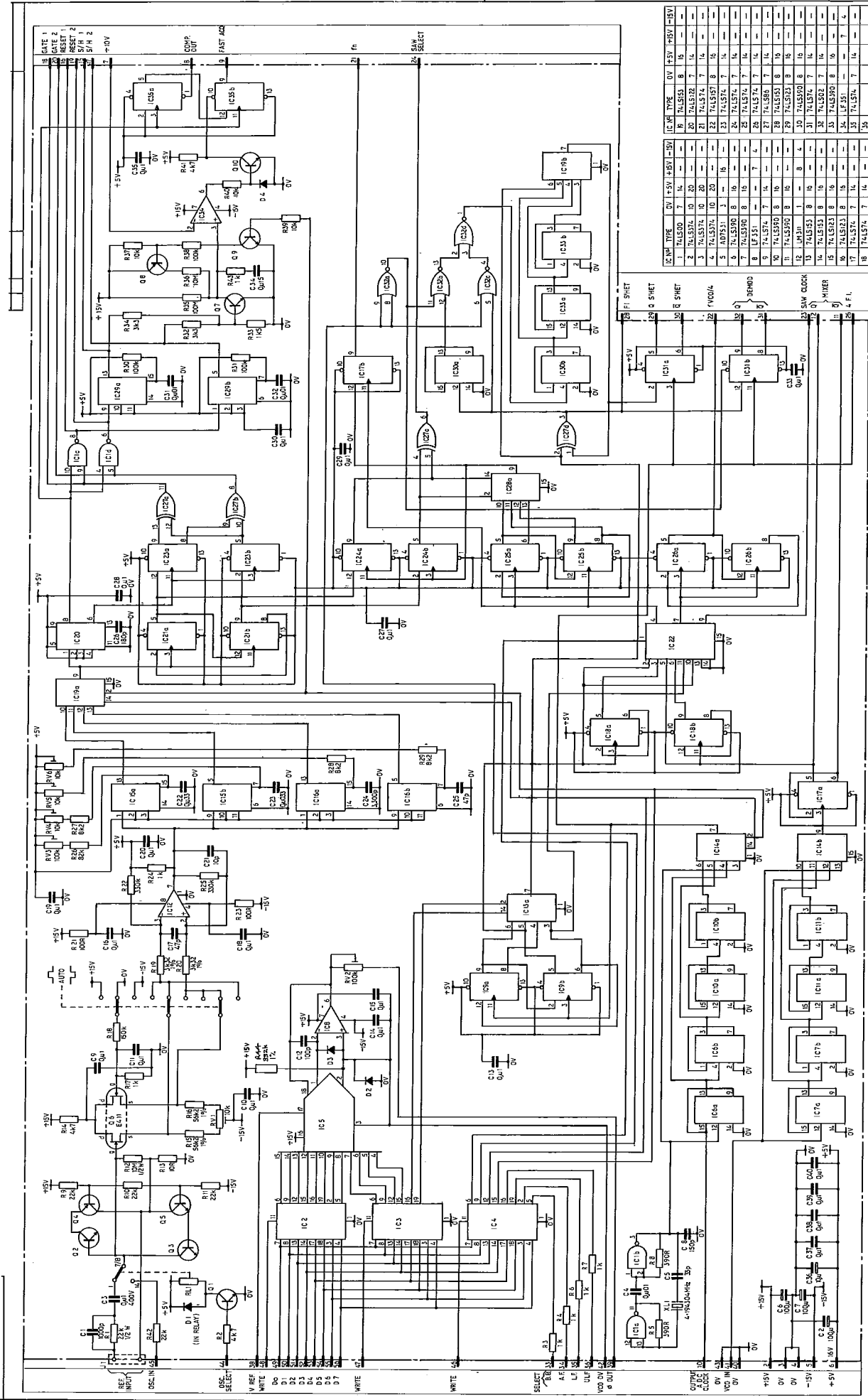


IC No.	Type	Part No.	Value	Notes
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2	LM311	IC19	1	
3	LM311	IC20	1	
4	LM311	IC21	1	
5	LM311	IC22	1	
6	LM311	IC23	1	
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13	LM311	IC30	1	
14	LM311	IC31	1	
15	LM311	IC32	1	
16	LM311	IC33	1	
17	LM311	IC34	1	
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19	LM311	IC36	1	
20	LM311	IC37	1	

IC No.	Type	Part No.	Value	Notes
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2	LM311	IC19	1	
3	LM311	IC20	1	
4	LM311	IC21	1	
5	LM311	IC22	1	
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13	LM311	IC30	1	
14	LM311	IC31	1	
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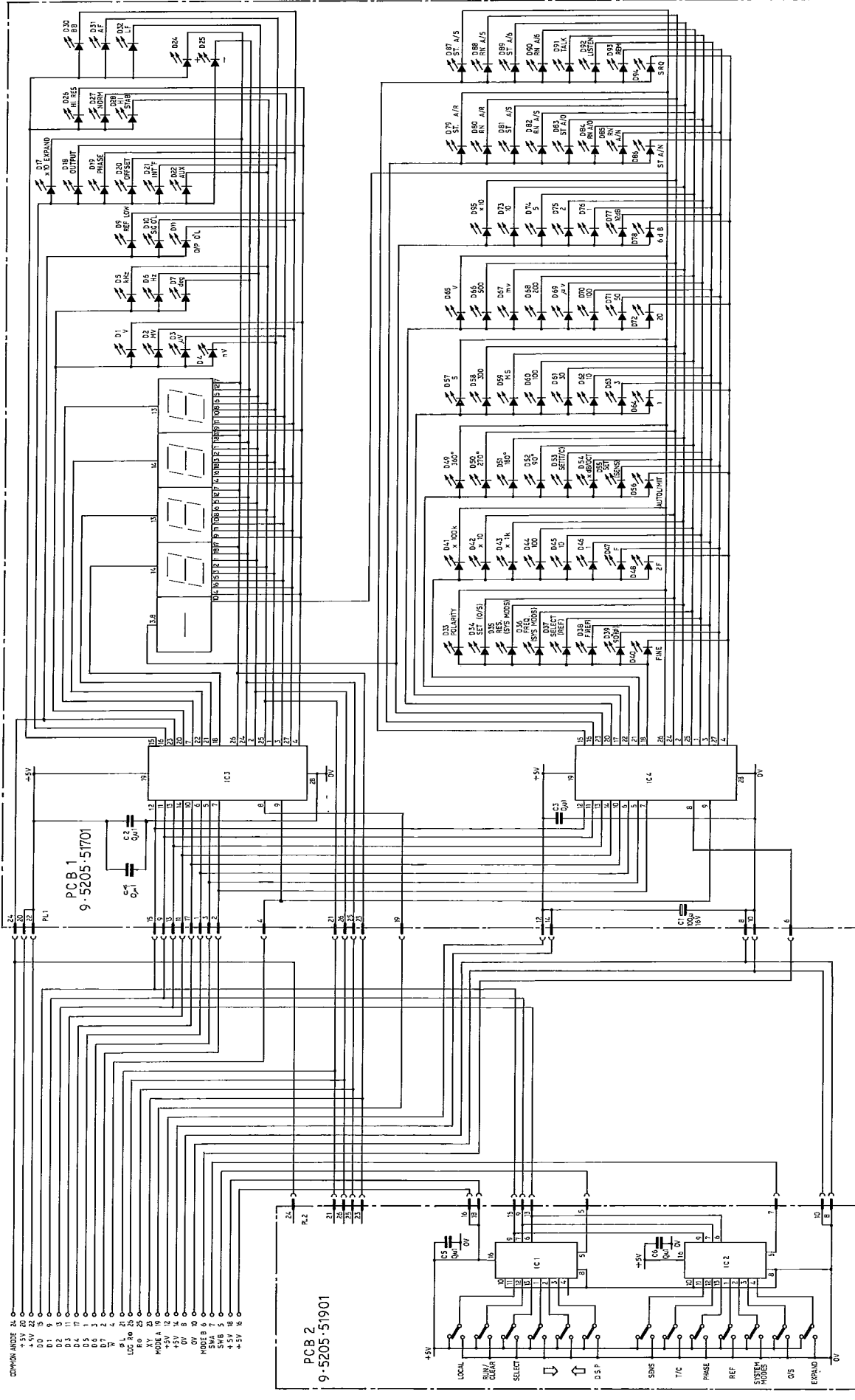
IC No.	Type	Part No.	Value	Notes
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15	LM311	IC32	1	
16	LM311	IC33	1	
17	LM311	IC34	1	
18	LM311	IC35	1	
19	LM311	IC36	1	
20	LM311	IC37	1	

Inst. No. 3206 SMT 1 OF 1
 BRG. No. 14720 D-SD
 Brookdeal
 GENERAL INFORMATION
 TOLERANCES NOT STATED
 FINISH
 CUT OFF SIZE
 MATERIAL
 SPECIFICATION
 DATE LIST REFERENCE
 C.A.S.



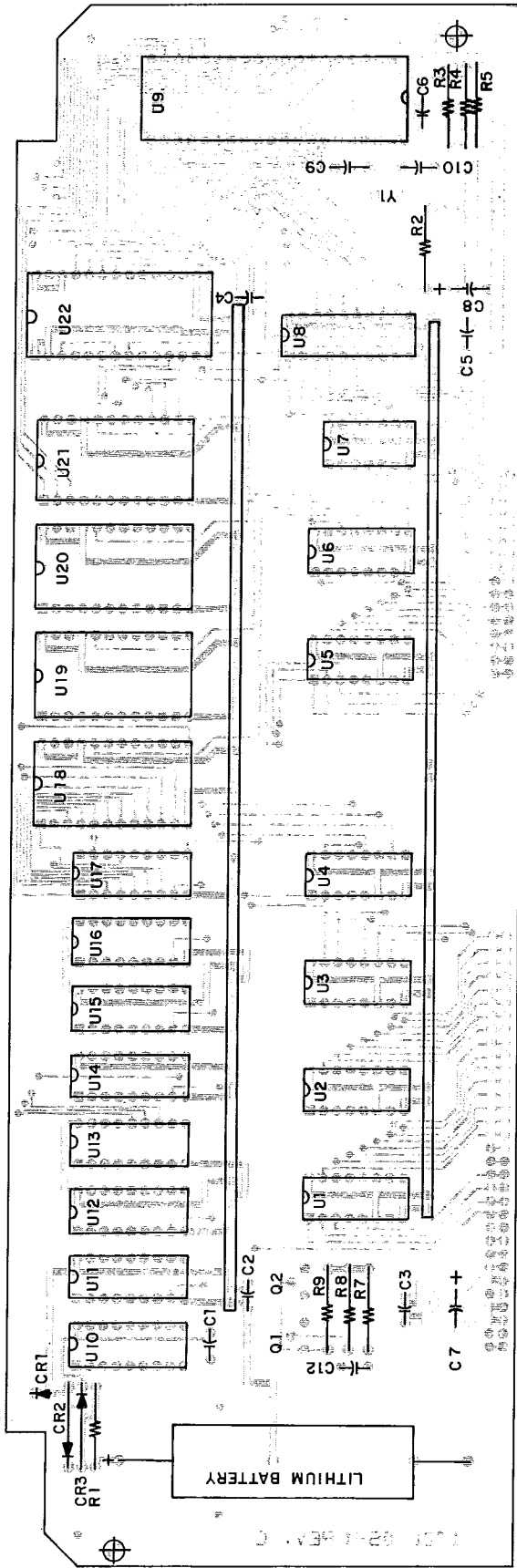
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1	IC2 74LS164	1	IC11 74LS164
1	IC3 74LS164	1	IC12 74LS164
1	IC4 74LS164	1	IC13 74LS164
1	IC5 74LS164	1	IC14 74LS164
1	IC6 74LS164	1	IC15 74LS164
1	IC7 74LS164	1	IC16 74LS164
1	IC8 74LS164	1	IC17 74LS164
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1	IC90 74LS164	1	IC90A 74LS164
1	IC91 74LS164	1	IC91A 74LS164
1	IC92 74LS164	1	IC92A 74LS164
1	IC93 74LS164	1	IC93A 74LS164
1	IC94 74LS164	1	IC94A 74LS164
1	IC95 74LS164	1	IC95A 74LS164
1	IC96 74LS164	1	IC96A 74LS164
1	IC97 74LS164	1	IC97A 74LS164
1	IC98 74LS164	1	IC98A 74LS164
1	IC99 74LS164	1	IC99A 74LS164
1	IC100 74LS164	1	IC100A 74LS164

NOTE
 UNLESS OTHERWISE MARKED
 ALL DIMENSIONS ARE IN INCHES
 ALL DIMENSIONS ARE IN MILLIMETERS
 ALL DIMENSIONS ARE IN INCHES
 ALL DIMENSIONS ARE IN MILLIMETERS
 ALL DIMENSIONS ARE IN INCHES
 ALL DIMENSIONS ARE IN MILLIMETERS

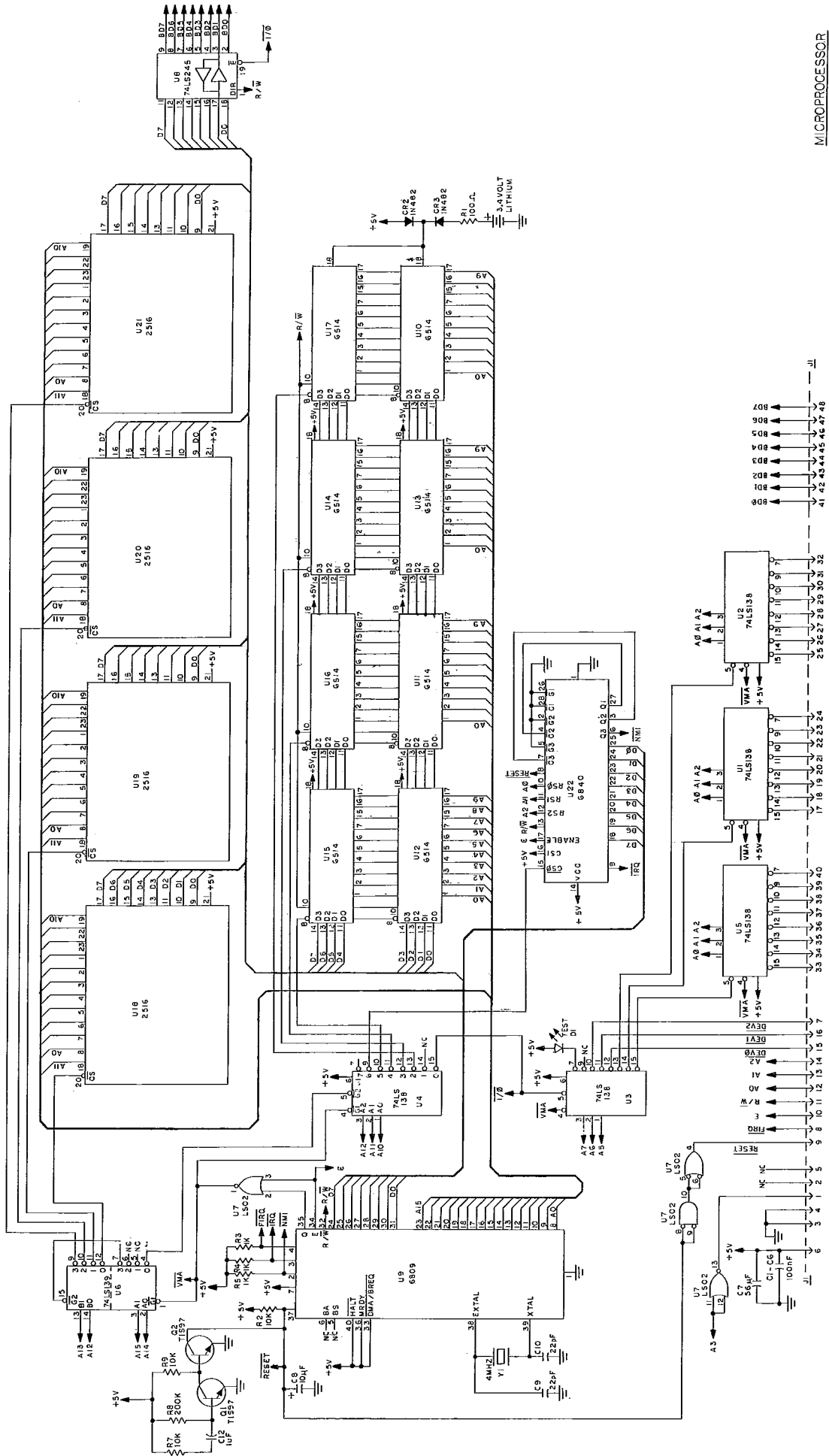


9.5205.4.1700 SAT 1 OF 1

DETAIL		POSN	NO	QTY	DATE	CHKD	TECH	NO
MATERIAL								
SPECIFICATION								
PARTS LIST REFERENCE								
TITLE								
FRONT PANEL CIRCUIT DIAGRAM								
DRAWN		CIS		PARTS LIST REFERENCE		TITLE		
DESIGNED	DATE	SCALE	NO	REV		INST. NO. 3205		
BROOKDEAL		REV		REV		SHEET 1 OF 1		
DESIGNED		REV		REV		DRAWN No. 14252-D-SD		
REVISIONS NOT SHOWN								
ORIGINAL POSITION								
AMOUNT								
REVISIONS								
IC F - 20000 D24 000000								
20000 FUNCTIONS DELETED FROM CIRCUIT.								
INITIAL INITIAL								
DATE 4/7/5								
DATE 10/5/5								
DATE 10/5/5								
DATE 10/5/5								



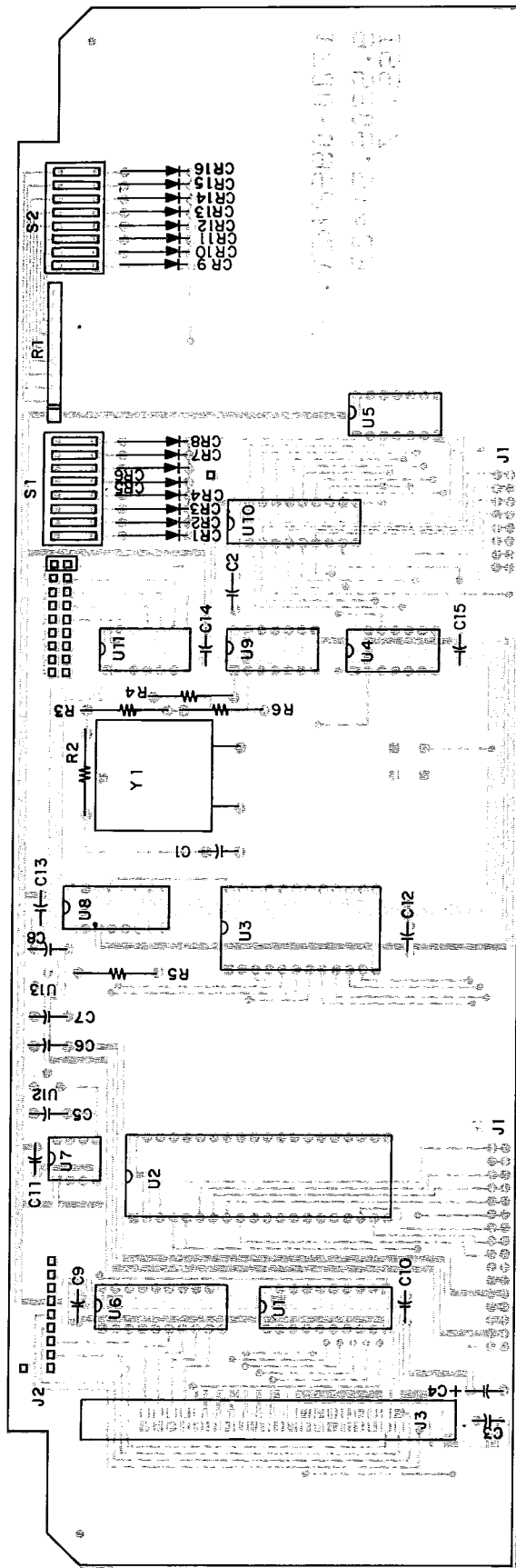
MODEL 5205 & 5206
MICROPROCESSOR BOARD



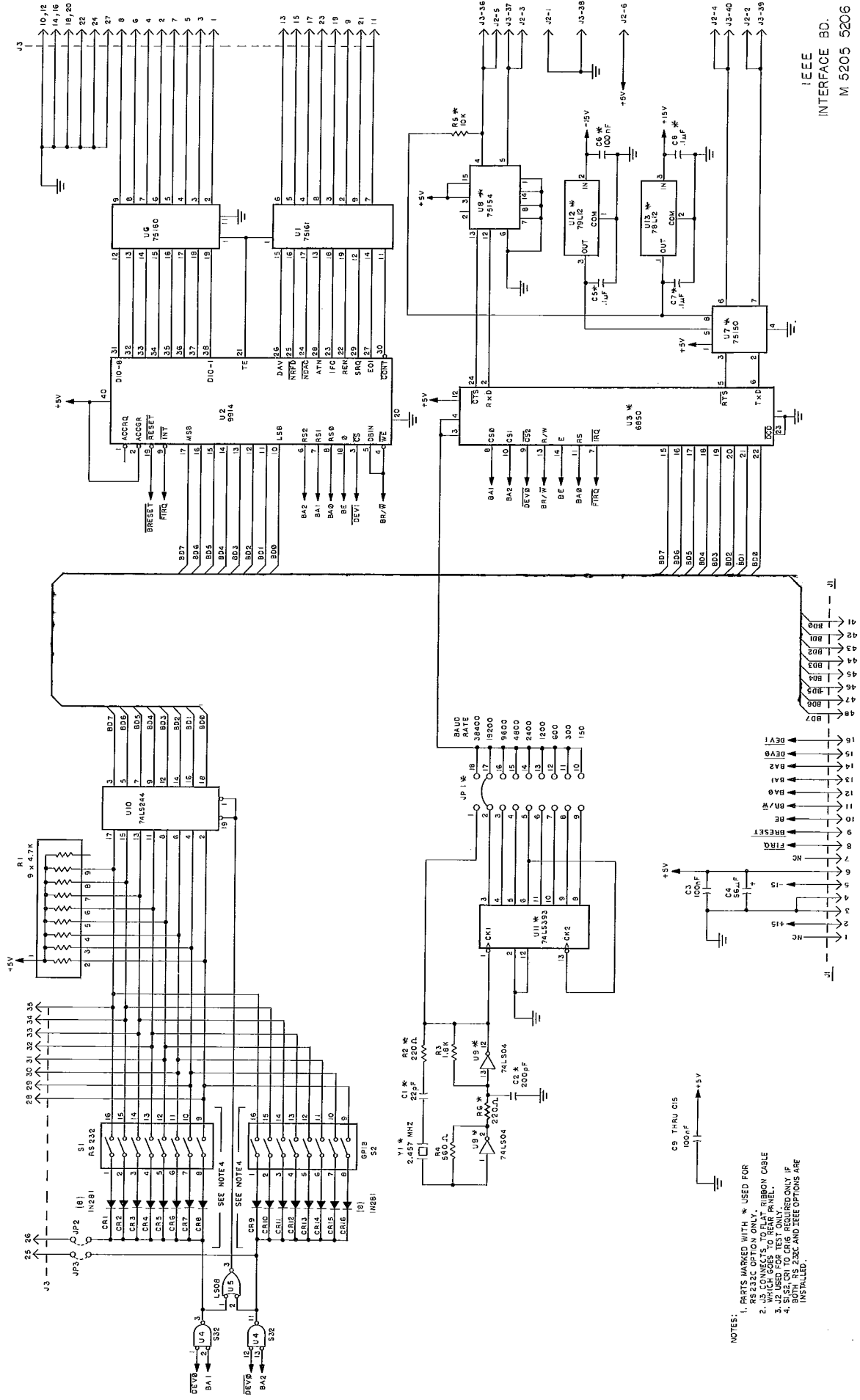
MICROPROCESSOR
(CPU)BD
M5205-S206

ROBERT BRINCKEN APPLIED RESEARCH
P.O. BOX 206, BRINCKEN, WISCONSIN 53001
COMMERCIAL - ALL RIGHTS RESERVED

SHT. 1 of 1 1:12:36 DSD B



MODEL 5205 - 5206
IEEE INTERFACE BOARD



IEEE
INTERFACE BD.
M. 5205 5206

EGG PRINCETON APPLIED RESEARCH
A. S. BOSTON, PRINCETON, N.J. 08540
COPYRIGHT © 1984 BY EGGR
ALL RIGHTS RESERVED
SMT... or ... [4240] [SD] C

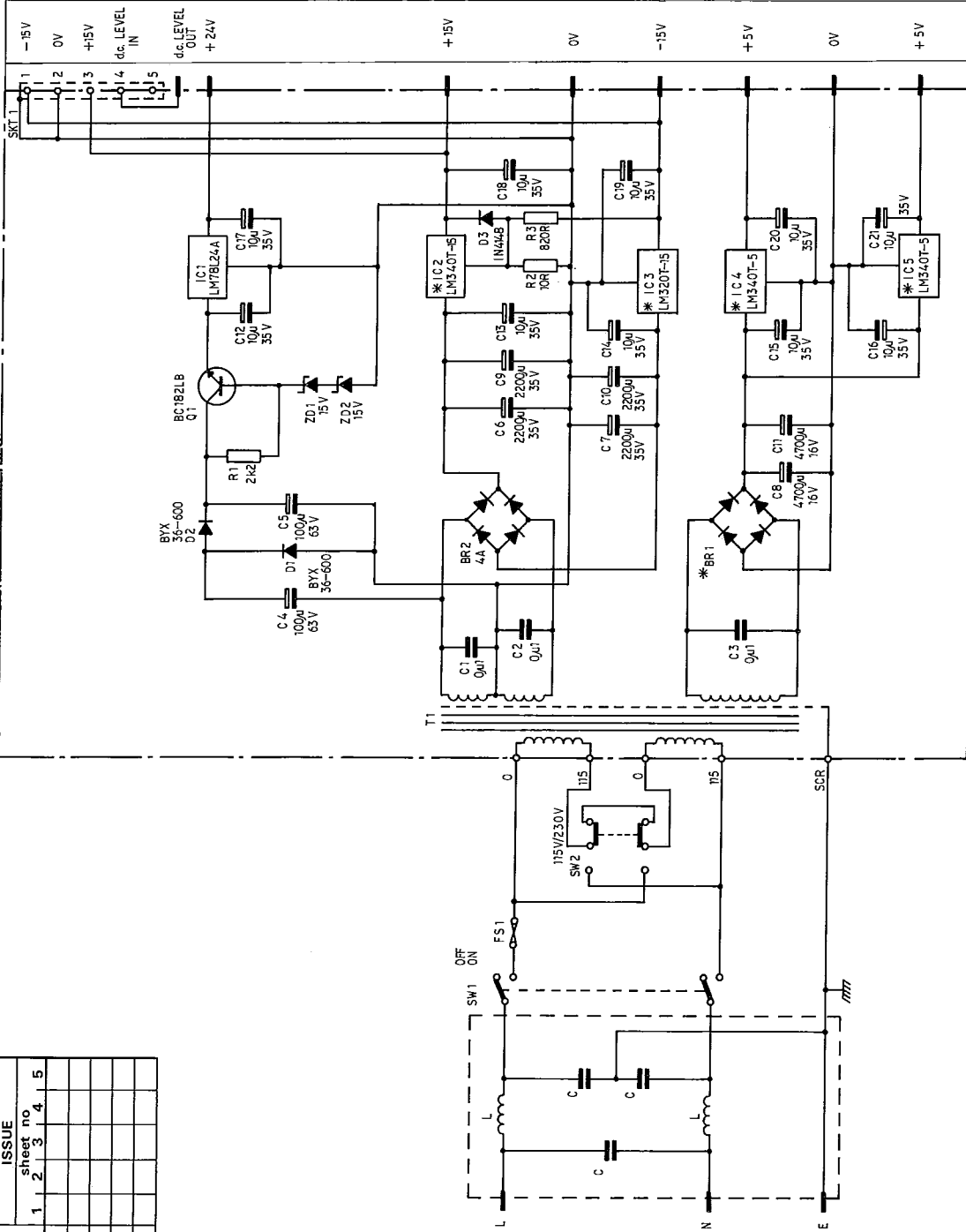
- NOTES:
1. PARTS MARKED WITH * USED FOR RS 232C OPTION ONLY.
 2. U5 CONNECTS TO FLAT RIBBON CABLE.
 3. U7 USED FOR TEST ONLY PANEL.
 4. SIZE CR1 TO CR6 REQUIRED ONLY IF BOTH RS 232C AND IEEE OPTIONS ARE INSTALLED.

IG No. 9.5205-41800

DATE	ISSUE	sheet no
1	1	1
2	2	2
3	3	3
4	4	4
5	5	5

DO NOT SCALE. IF IN DOUBT, ASK.

DIMENSIONS IN MILLIMETRES



NOTE: COMPONENTS MARKED WITH * ARE MOUNTED ON HEATSINK

D

C

B

A

9.5205-41800 SAT 1 OF 1

PARTS LIST REFERENCE

TITLE

POWER SUPPLY

CIRCUIT DIAGRAM

inst. no. 5205/6

sheet 1 of 1

REV

DRG. NO. 14256-C-SD

DRAWN	C.A.S.	APPRO'D	SCALE
	AP/S		

Brookdeal
ANALOG
 Brookdeal Electronics Ltd., Bracknell 29931

MATERIAL	SPECIFICATION

TOLERANCES NOT STATED:
GENERAL POSITION
ANGLE

FINISH	OUT OFF SIZE

IC1 COMMON LINE REROUTED TO 0V
 REDRAWN

ISSUE	DATE	CHK'D	ECN No
3	31.12.81		
2	9.2.81		

DETAIL	POSN TO	ISSUE	DATE	CHK'D	ECN No

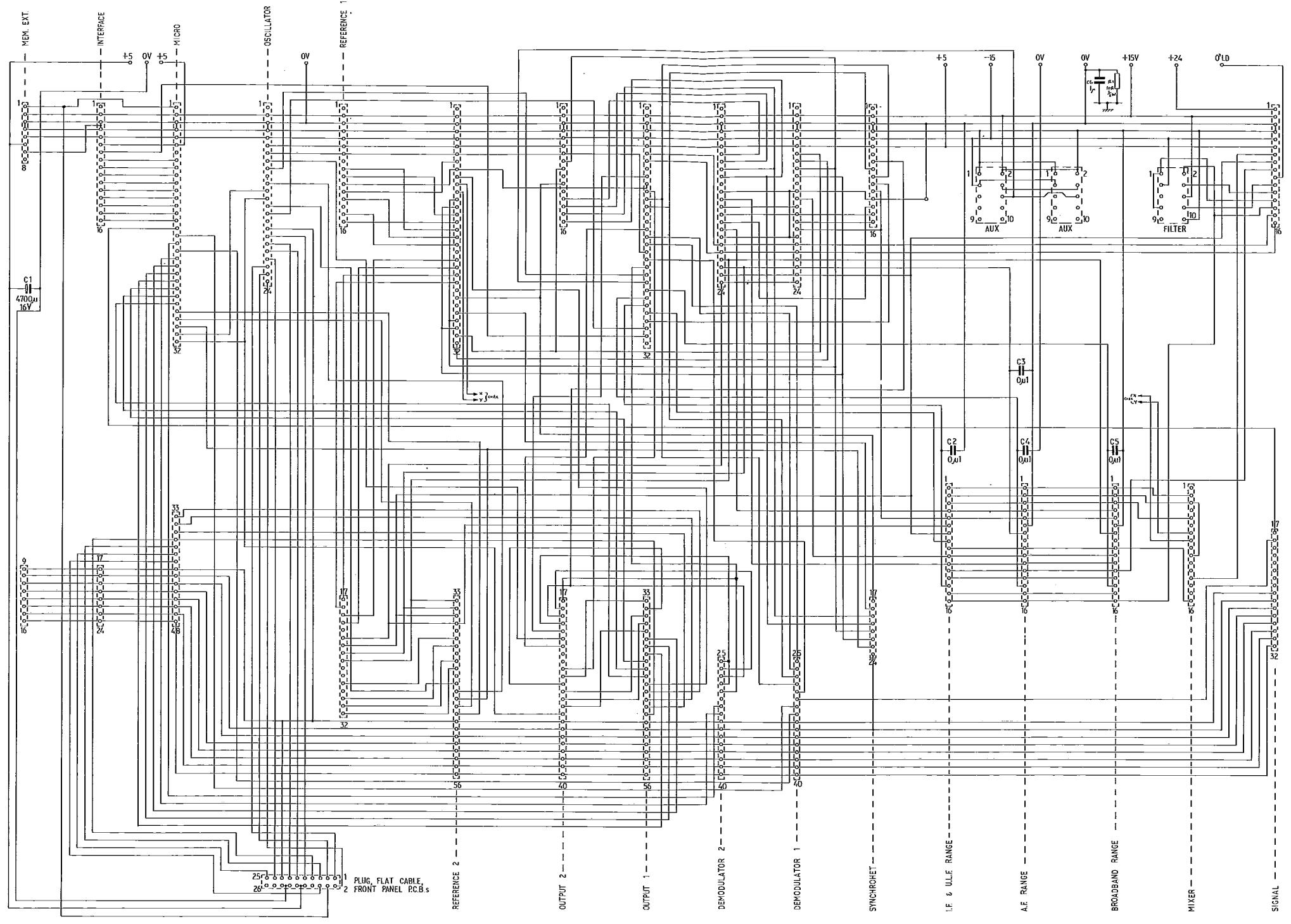
A

B

C

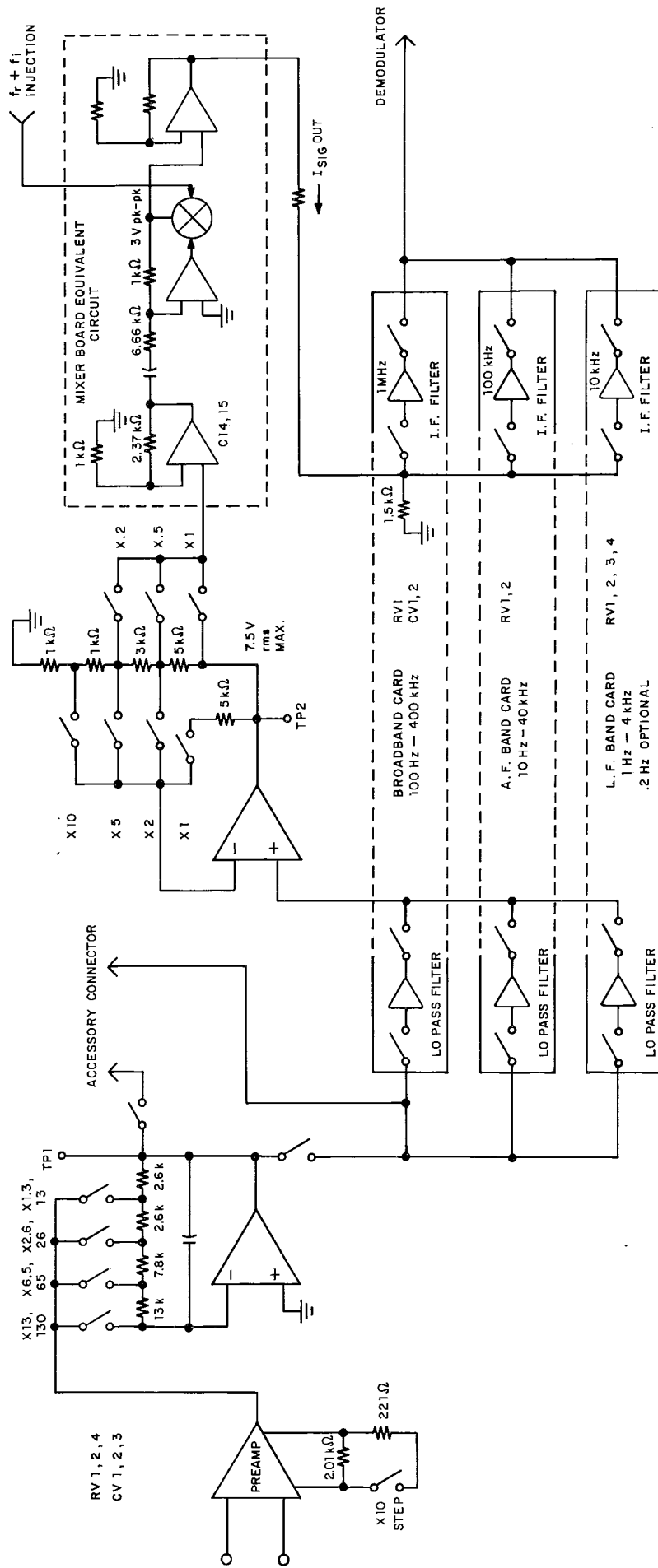
D

A2

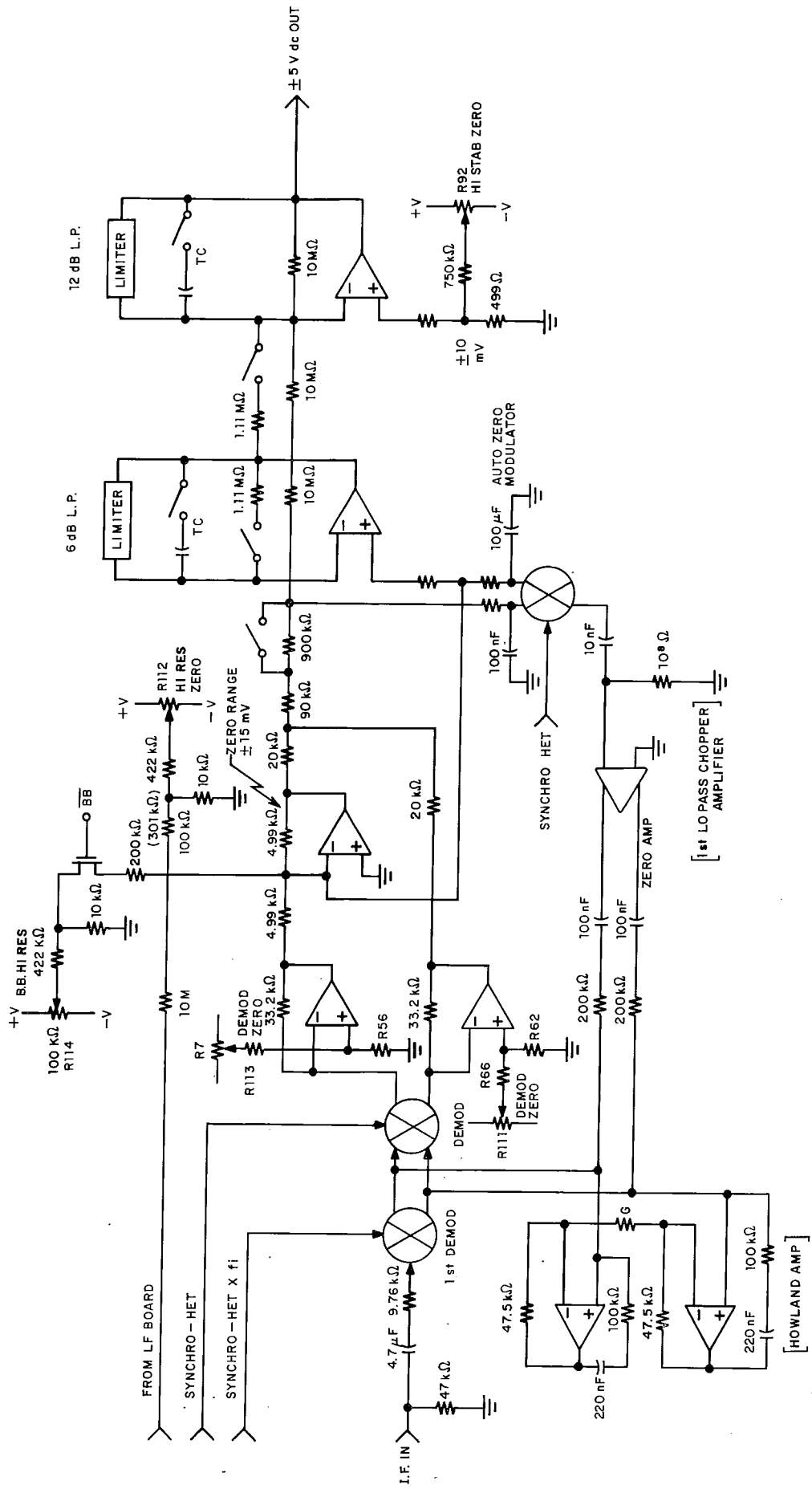


9.5205-41600 SH1 1 OF 1

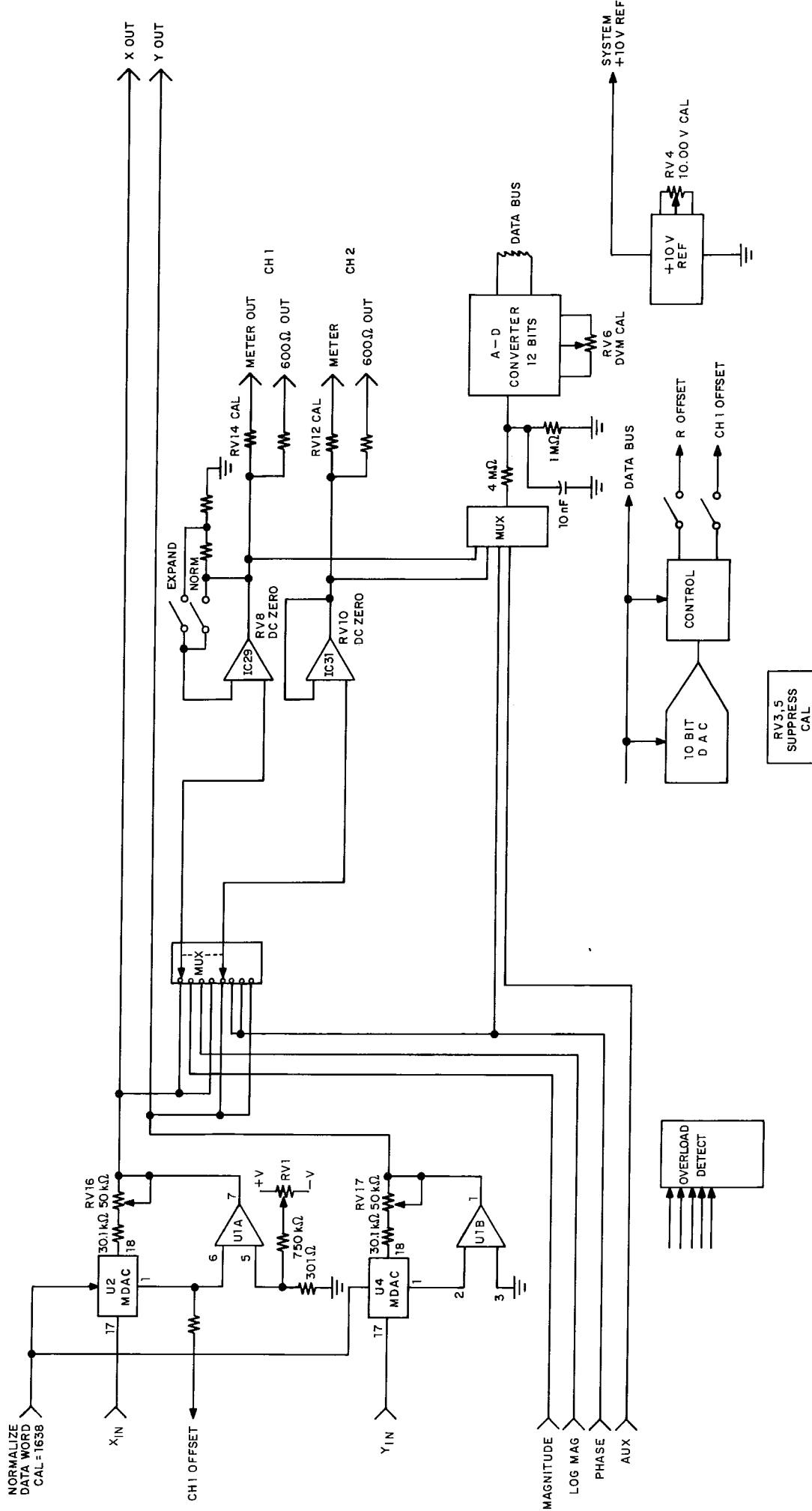
2	46	1678	AMS	RI	40	CG	4000
1	CAS	3324					
C.A.S.							TITLE
Brookdeal							inst. no
							sh1
							DRG. No 14243-E-5D



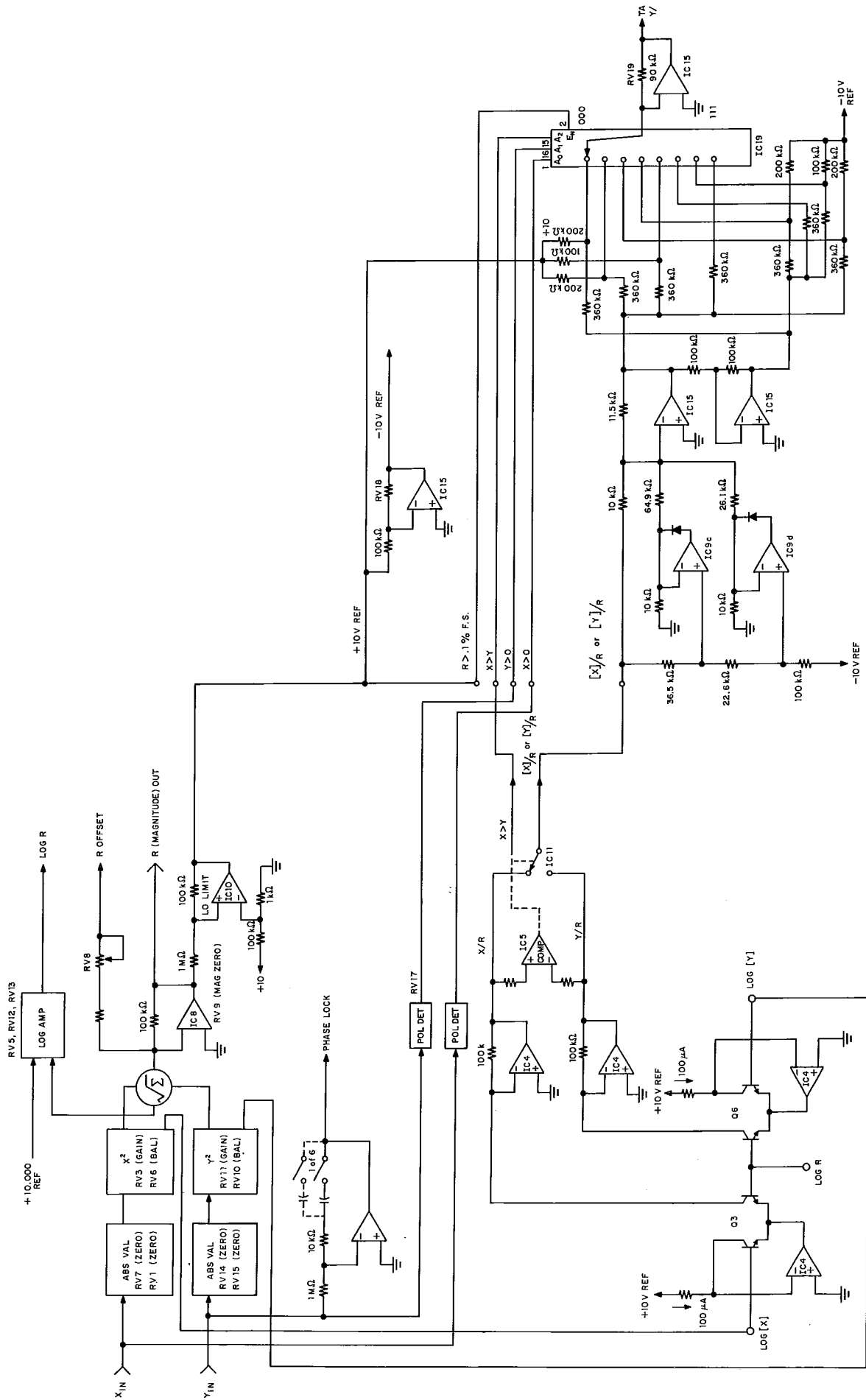
SIGNAL CHANNEL BLOCK DIAGRAM



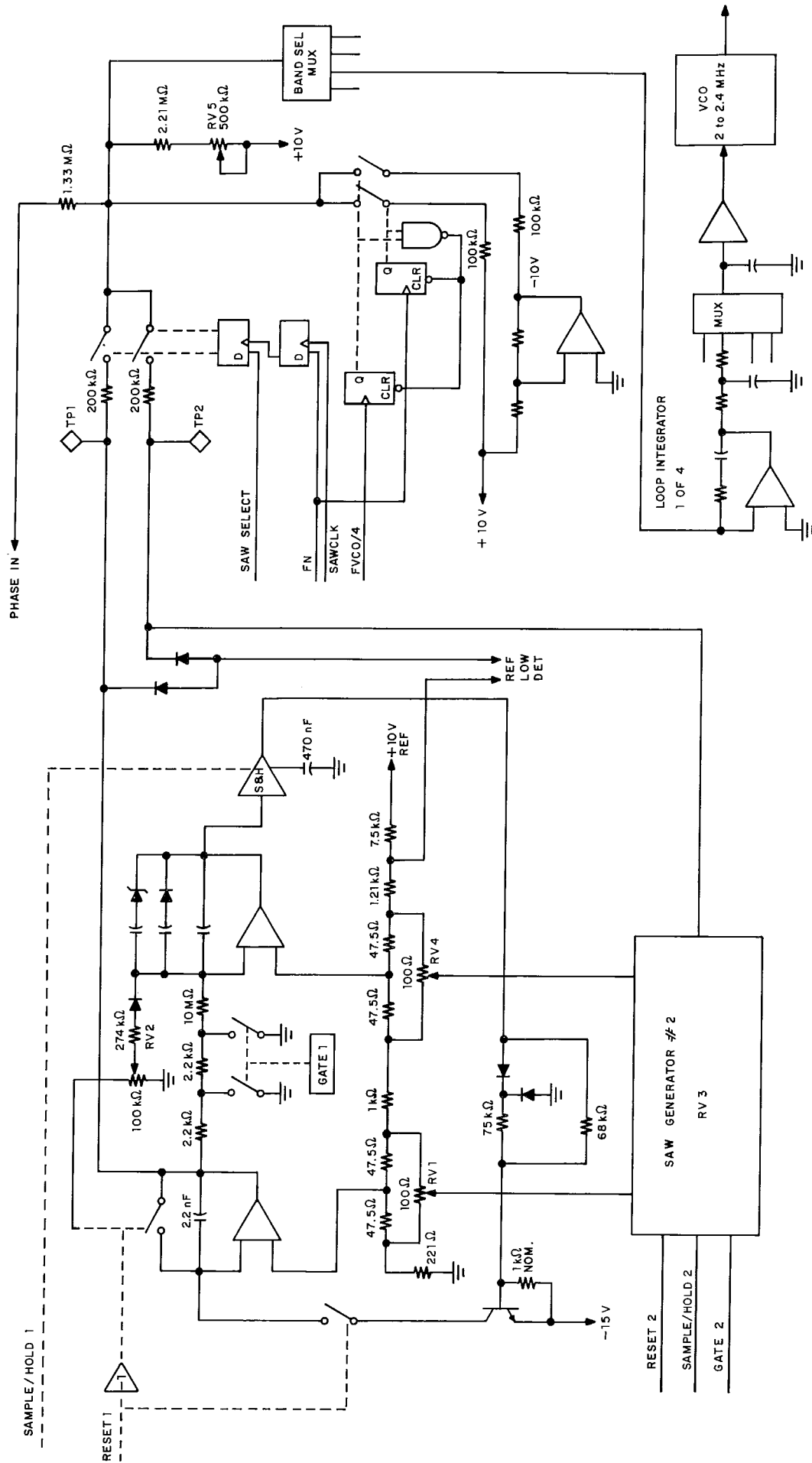
DEMODULATOR BLOCK DIAGRAM



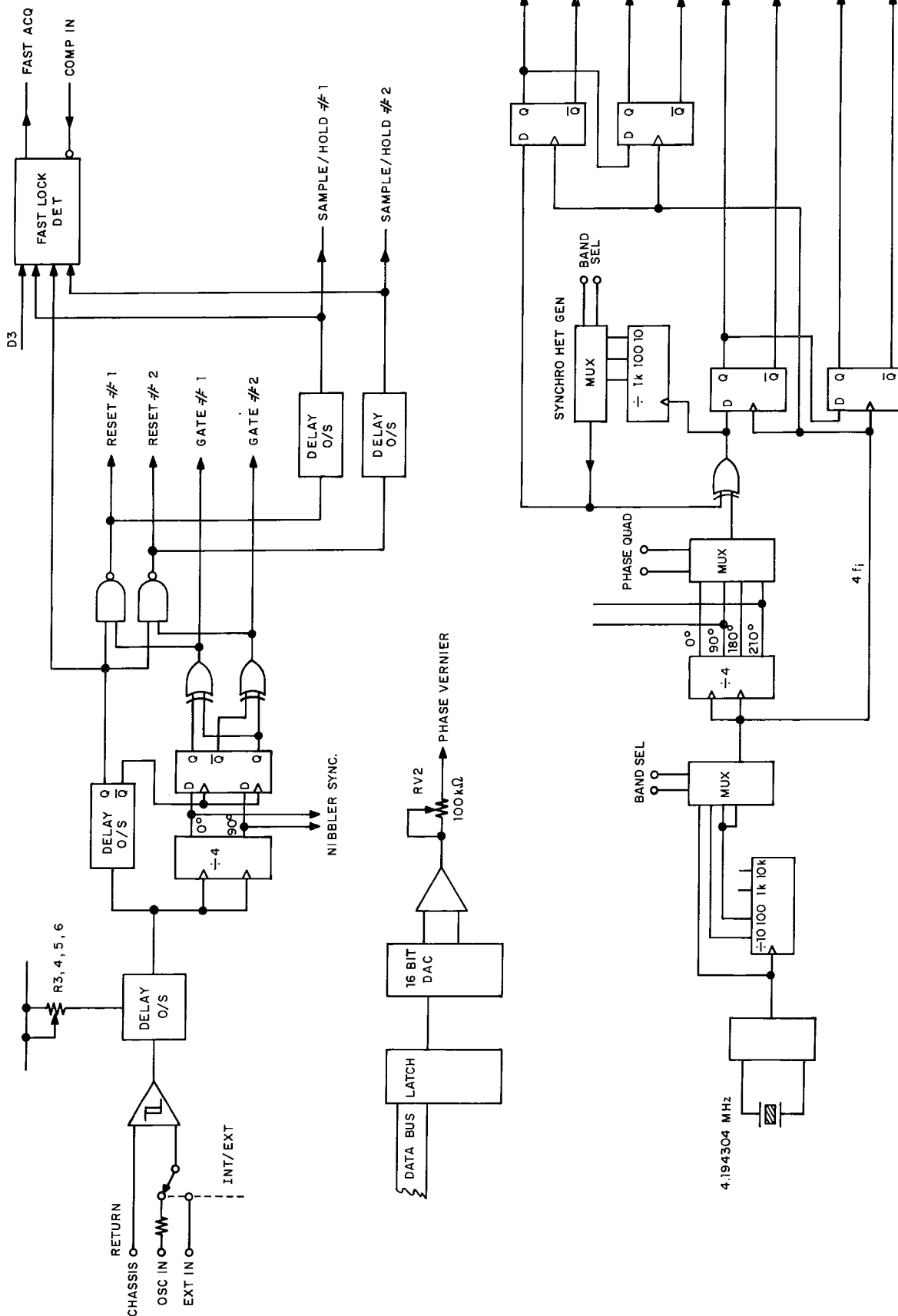
OUTPUT 1 BLOCK DIAGRAM



OUTPUT 2 BLOCK DIAGRAM



REFERENCE 1 BLOCK DIAGRAM



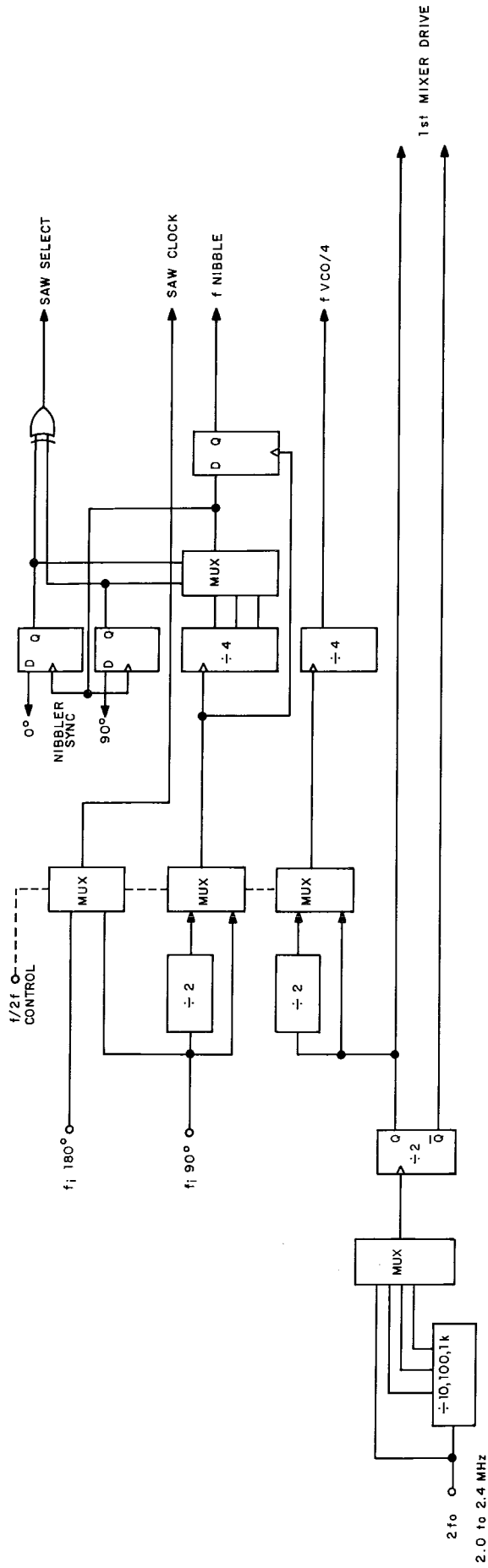
REFERENCE 2 BLOCK DIAGRAM, SHEET 1

HP 9825 SIMPLE STATIC INTERFACE

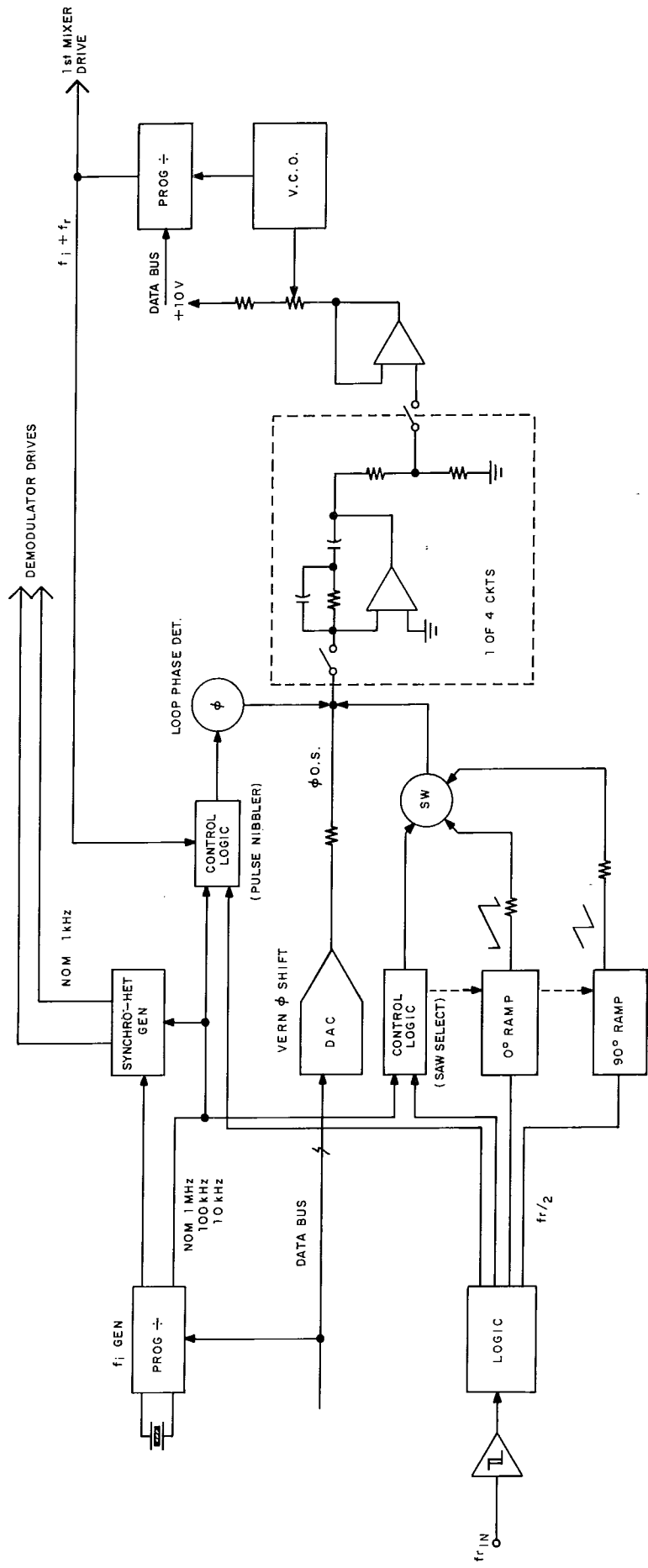
```

0: "HP9825 SIMPLE STATIC INTERFACE":
1: "":
2: "INITIALIZE I/O":
3: fxd 0
4: ent "Enter device GPIB address: ",A
5: "HPIB ADDRESS ADDED TO DEVICE ADDRESS": 700 + A -> A
6: dim B[500],C#[20],D#[30]
7: 1 -> N
8: beep;dsp "Set PARC device to CRLF terminator"
9: wait 2000;beep
10: "main loop":ent "Enter command: ",C#
11: gsb "Device driver"
12: if bit(1,S)=1;beep;dsp "COMMAND ERROR";beep;wait 2000
13: "COMMAND: " & C# -> D#;prt D#
14: if I=0;gto 20
15: for K=1 to I
16: "rsp#" & str(K) & ": " & str(B[K]) -> D#
17: prt D#
18: next K
19: spc
20: gto "main loop"
21: " ":
22: "SUBROUTINE 3":
23: "Device driver":
24: gsb "Output command"
25: gsb "Read responses"
26: ret
27: " ":
28: "SUBROUTINE 1":
29: "Output command":
30: gsb "Serial poll"
31: if bit(0,S)=0;jmp -1
32: wrt A,C#
33: ret
34: " ";
35: "SUBROUTINE 2":
36: "Read responses":
37: 0 -> I
38: gsb "Serial poll"
39: if bit(7,S)=0; gto 42
40: I+1 -> I
41: red A,B[I]
42: if bit(0,S)=0;gto 38
43: ret
44: "Serial poll":
45: rds(A) -> S
46: ret

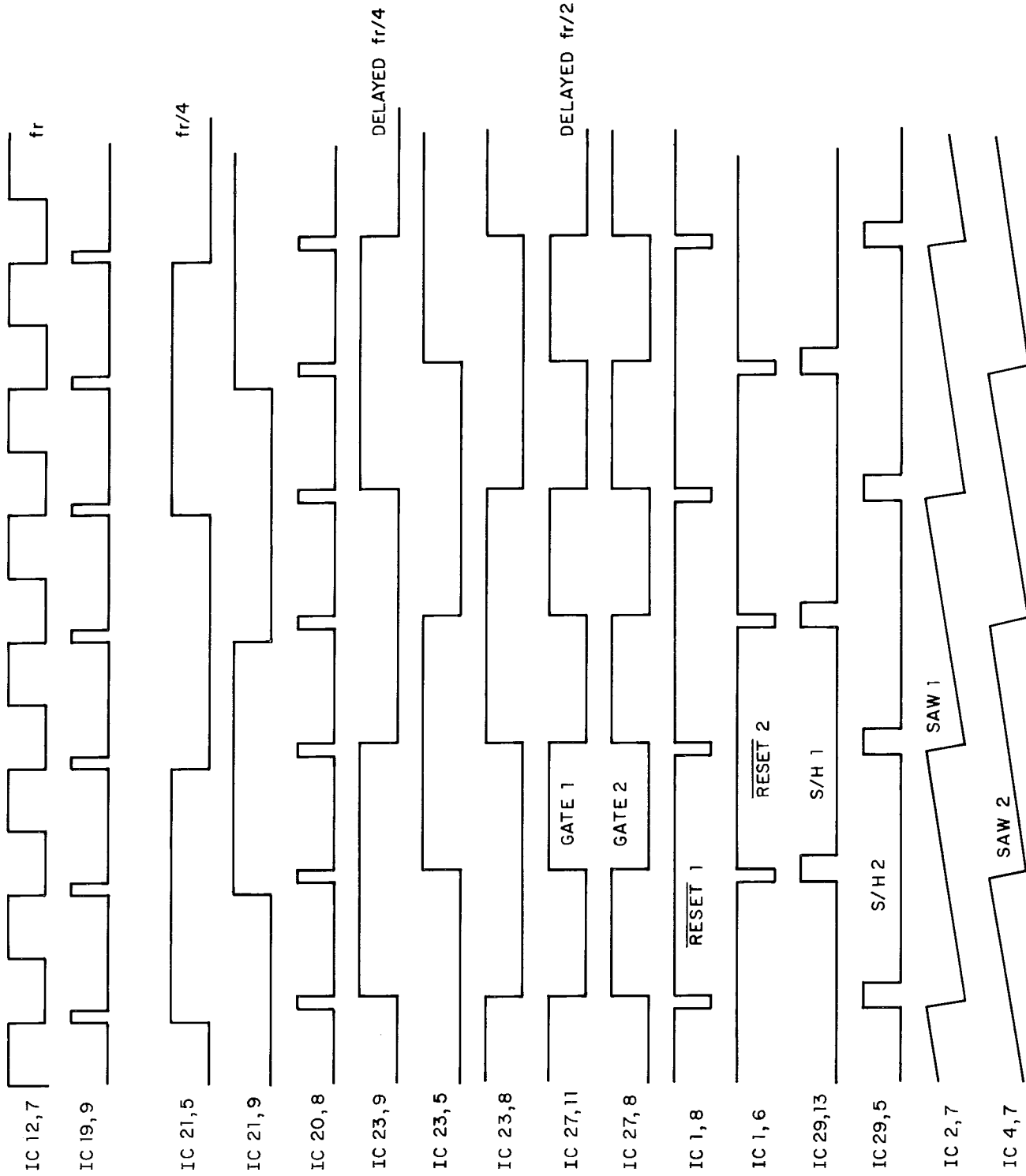
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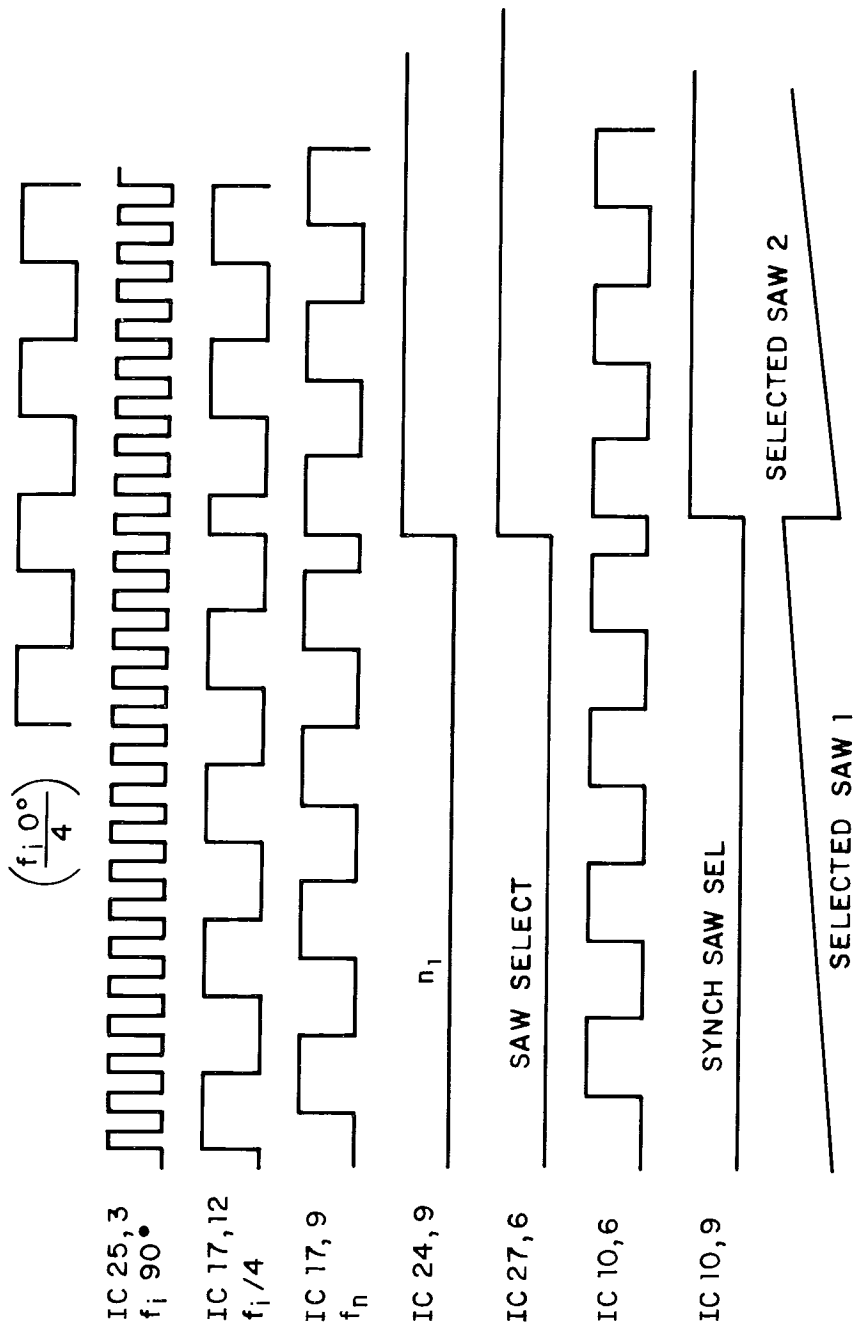
REFERENCE 2 BLOCK DIAGRAM, SHEET 2



REFERENCE 1 and 2 BLOCK DIAGRAM



REFERENCE TIMING DIAGRAM, SHEET 1



REFERENCE TIMING DIAGRAM, SHEET 2

