SECTION V
OPERATING INSTRUCTIONS

5.1 INTRODUCTION

Although operation of the Models 5207 and 5208 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, and noise improvement.

5.2 FRONT-PANEL CONTROLS, SWITCHES, AND INDICATORS

5.2A INTRODUCTION

The Models 5207 and 5208 Lock-In Amplifiers are well designed from a human engineering point of view. A combination of keys and LED (light-emitting 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.

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.

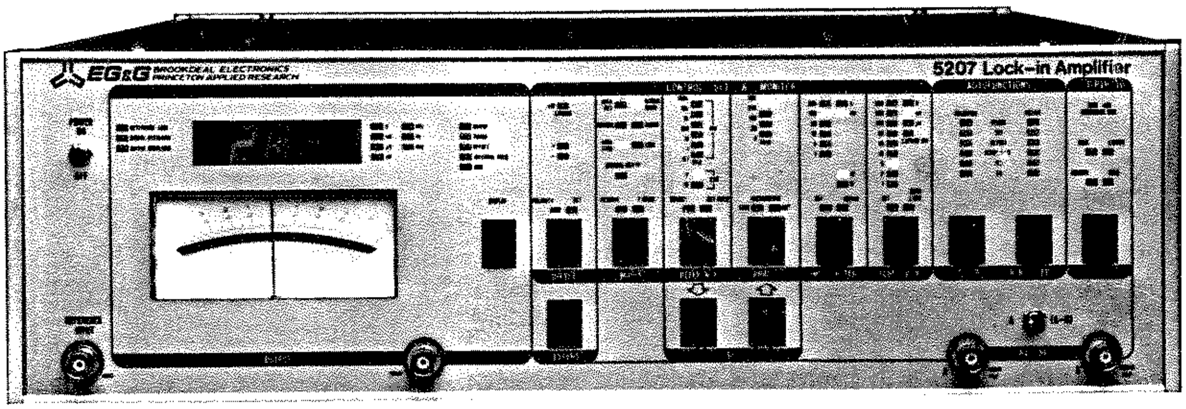


Figure V-1. MODEL 5207 FRONT PANEL

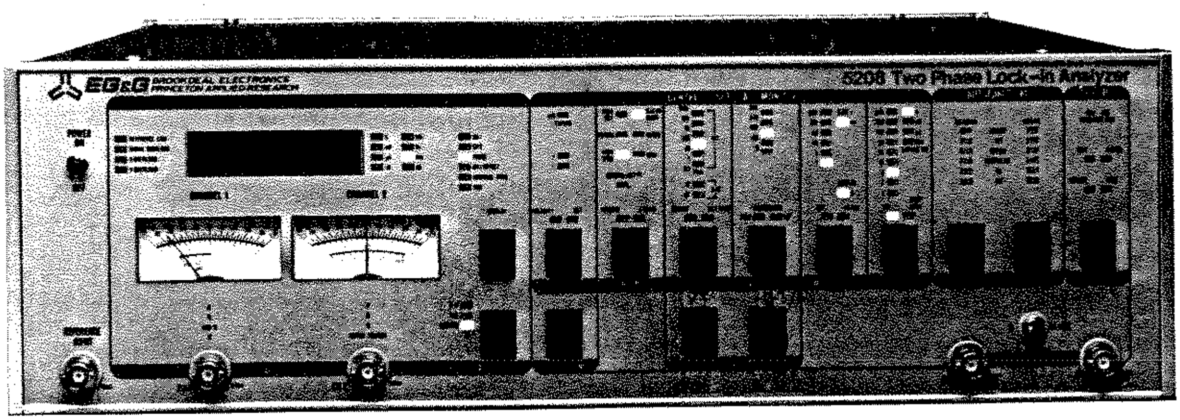


Figure V-2. MODEL 5208 FRONT PANEL

5.2B 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 5208), MODES, REFERENCE, PHASE, TIME CONSTANT, and SENSITIVITY keys to determine the corresponding functions and parameters as follows.

(a) OFFSET (CH1 OFFSET in the M5208): This key, used in conjunction with the UP/DOWN keys, controls the dc offset. In the case of the Model 5208, 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 M5208) 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 5208, 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 "X" 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 M5208): This key works directly to turn the ×10 output

expand feature on or off. When the expand 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 5208, note that the expansion affects Channel 1 only. The expand status is also indicated by an LED in the Sensitivity Grouping.

(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 μV through 5 V
NORMAL	10 μV through 50 mV
HIGH RES	1 μV 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 (5 Hz to 200 kHz), AUDIO (5 Hz to 20 kHz), and LOW (5 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 selected card isn't present, no message is displayed and F BAND is set to the next available card. The Crystal-Het function toggles each time you cause the F BAND selection to wrap around in either direction. (If there are no F BAND 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 preamplifiers. If the ×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 5208, the EXPAND function affects the Channel 1 sensitivity only; the Channel 2 sensitivity range is always 1 μV to 5 V.

*10 s maximum with HI STAB reserve setting.

Note that sensitivity and reserve interact. Sensitivities from 100 μV to 5 V inclusive are available with the reserve set to HIGH STAB. Sensitivities from 10 μV to 50 mV inclusive are available with the reserve set to NORMAL. Sensitivities from 1 μV through 5 mV are available with the reserve set to HIGH RES. Should the operator (or autorange) select a reserve inconsistent with the sensitivity, the closer available reserve will be selected. This happens in only two cases. If the reserve is HIGH STAB and HIGH RESERVE is wanted, HIGH RESERVE will be tried first. If not available, NORMAL will be tried. NORMAL is closer to the desired drive than is HIGH STAB. A similar sequence happens if the reserve is HIGH RESERVE and the desired reserve is HIGH STAB. HIGH STAB will be tried. If not available, NORMAL will be tried.

When the operator makes a reserve selection, that selection, if unavailable, is "remembered". Should the reserve become available later, it will be automatically adopted. If auto-ranging, the reserve should be selected according to the worst expected noise-to-signal ratio. If at any time the noise-to-signal ratio exceeds the ratio possible for the range currently in effect, auto-ranging will not work with your experiment. The sensitivity will jump from the overloaded range to a range where there is no overload, but will then jump right back to the overloaded range.

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 μV. To do so he has only to press SENSITIVITY to light AUTO LIMIT, followed by using the UP/DOWN keys to light the 10 μV LED. In the subsequent measurement, the sensitivity will be able to take values in the range of 10 μV 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 μV.

(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, A5 (RATIO) and then back to OFF. Position A6 is 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. Note that, except that NORMALIZE and A5 (RATIO) can be selected together, no two autofunctions can be activated at the same time.

(b) RUN/CLEAR: This key activates or deactivates the various auto functions. 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 M5207) 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 μV, the expected autorange would not occur because of the limit imposed by the AUTO-LIMIT function.

In the Model 5208, autoranging is always done with respect to the "R" output, independent of the selected Output Mode. **EXCEPTION:** AUTO-PHASE is computed as the arctan (Y/X). To do this, the Output Mode must be temporarily set to X,Y if it is not already there.

Three delays in series, RESERVE DELAY, SIGNAL DELAY, and TIME CONSTANT DELAY, assure that an autorange will not occur until the Lock-In Amplifier has fully settled from transients induced by the previous autorange. If there was a change in reserve, the Reserve Delay occurs first, and can take values from one second to eight seconds according to the combination of reserve and sensitivity. The Reserve Delay is followed by the Signal Delay, a two second delay that applies if there was a signal overload. Last is the Time Constant delay, either six times the selected time constant (6 dB/octave) or twelve times the selected time constant (12 dB/octave). Note that the Reserve and Signal Delays only apply if a Reserve Change or signal overload occurred. Also, in no case can auto-ranging occur faster than once every 1.2 s (2.4 s if 12 dB/octave).

Note that the AUTOSET 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 AUTOSET/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 AUTOSET)

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.

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 M5207) 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 (M5207). In the case of a Model 5208, 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 5207 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 autoset operation.

SET differs from RANGE in that it remains active only long enough to make a single sensitivity and phase adjustment. (An autoset operation in progress can be aborted with the RUN/CLEAR key, if desired.) As soon as an autoset 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 active 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 5208, 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 "X", 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 5207 the "X" (only) output is normalized. In the Model 5208 the "R" output is normalized. The signal level is read and the gain adjusted once only when AUTO-NORMALIZE 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

*OUTPUT in the M5207; "X", "Y", and "R" in the M5208.

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. Note that NORMALIZE has a lower priority than RATIO. If NORMALIZATION is selected without RATIO, X, Y, and R are displayed as a percentage of full scale. If selected with RATIO, they are displayed as the ratio of X, Y, or R to AUX.

A5 (RATIO): This selection turns the RATIO function ON and OFF. RATIO works with X, Y, R, or LOG R. If X, Y, or R is selected for display, the ratio of X, Y, or R to AUX is displayed and provided at the rear-panel RATIO connector. If LOG R is selected, the ratio of the LOG (R/AUX) is displayed and provided at the rear-panel RATIO connector. (Ratio of X/AUX only available in M5207.) Should neither CH1 nor CH2 be selected for display, then the ratio corresponding to the CH1 selection (output in M5207) is the one provided at the RATIO connector. AUX is the voltage applied to the rear-panel AUX connector.

NOTE: The RATIO OUT and AUX IN rear-panel BNC connectors may not be present in early units. In these units, the RATIO function can be displayed only. To gain access to the AUX input in one of these units, remove one of the rear-panel "slot-in" plates and note the two ten-pin, block connectors, J4 and J5, mounted on the edge of the Mother board. There are two rows of pins in each connector. The right-hand row of pins in each connector is numbered 1, 3, 5, 7, and 9, moving from the rear of the unit towards the front. Similarly, the left-hand row of pins is numbered 2, 4, 6, 8, and 10. Pin 6 of either J4 or J5 is the AUX IN contact. Ground is provided at pin 1.

When the output is the ratio of X, Y, or R to AUX, the voltage at the RATIO connector equals the ratio over a range of 10:1 to 1:100. In other words, a ratio of 10:1 yields 10 V out, a ratio of 1:1 yields 1 V out, and a ratio of 1:100 yields .01 V out. Results are invalid outside of this range. Outputs of either polarity are possible.

When the output is the ratio of the LOG of (R/AUX), the transfer function is 2 V/decade. For example, a ratio of 10:1 gives 2 V out, a ratio of 1:1 gives 0 V out, and a ratio of 1:10 gives −2 V out. Results are meaningless beyond nominally 2.5 V.

The resolution of the RATIO Output varies with the ratio. With large ratios (10:1), the resolution is very good, i.e., the Ratio Output varies almost linearly with the ratio. With small ratios (1:100), the resolution is poor, i.e., the Ratio Output varies in noticeable steps as the ratio changes.

The Ratio Output is updated five times a second. If the actual ratio is changing rapidly with respect to this rate, the voltage at the Ratio Output will move in large steps or jumps from one update to the next.

(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 (M5207 only): The digital panel meter displays the instrument's output level in units of V, mV, or μV, 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 unit's LED's will be unlighted. Similarly if the RATIO function is ON, the units LED's will be extinguished.

(b) CH1 (M5208 only): The digital panel meter displays the function selected with the OUTPUT MODE key. Either "X", "R", or LOG R 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). In RATIO operation, X/AUX is displayed and the units LED's are out.

"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. In RATIO operation, R/AUX is displayed and the units LED's are out. This output remains constant as the phase between the input and reference signal changes.

LOG R: This output is computed by find-

ing the logarithm to the base ten of the magnitude "R". The units are dB below full scale. In RATIO operation, Log (R/AUX) is displayed and the units LED's are out.

(c) CH2 (M5208 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. In RATIO operation, Y/AUX is displayed and the units LED's are out. They are also extinguished when indicating % 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.

(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 M5208): 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 M5207/8 is operating in the EXT. Reference mode. If the M5207/8 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 transfers the M5207/8 from REMOTE to LOCAL control if the LLO (LOCAL LOCKOUT) message has not been applied. It is effective even if REN is asserted. However, if REN continues to be asserted, the M5207/8 will return to REMOTE control if the unit's LISTEN address is applied.

NOTE: LOCAL versus REMOTE is a GPIB consideration only. The RS232C port is always active.

(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 active when interfacing via the RS232C data link. The specific function of each indicator is:

(a) REMOTE: This indicator lights when REMOTE operation has been established (REN asserted and LISTEN address applied). It remains lighted until LOCAL (front panel) control is restored. LOCAL can be restored by cycling the power, deasserting REN, pressing the LOCAL pushbutton (providing LLO message has not been applied), or applying the GTL message.

(b) LISTEN: This indicator lights when the M5207/8 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 M5207/8 is expecting more input before the current command is fully defined.

(c) TALK: This indicator lights when the M5207/8 has output ready to be sent to the host computer. It goes out when the M5207/8 has finished sending this output. The TALK indicator does NOT signal that the host computer has transmitted a TALK message. Rather it indicates that the M5207/8 has more output to dump before the command is completed.

(d) SRQ: This indicator lights when an event occurs that causes the M5207/8 to assert SRQ (make a service request). It remains

lighted until the controller (host computer) has completed a serial poll of the M5207/8.

(6) OUTPUT MODE (M5208 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.

(7) DOUBLE KEY FUNCTIONS

A number of special functions are provided that require the operation of two keys for activation. Each function is activated by pressing a specified key, and, while it is pressed, momentarily pressing another key as explained in the following paragraphs. It is strongly advised that NO autofunction be selected (all LED's above the SELECT key should be extinguished) before activating a double-key function that uses the RUN/CLEAR key. The reason is simply that, if an autofunction is selected, it 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) 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.

(b) 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.

(c) POWER-ON INITIALIZATION: Briefly pressing the OFFSET (CH1 OFFSET in the M5208) key while RUN/CLEAR is pressed causes the power-on initialization sequence to be executed.

(d) LED TEST: Briefly pressing the MODES key while RUN/CLEAR is depressed initiates a test of all of the front-panel LED's. Every LED on the panel should light. To terminate the test, press RUN/CLEAR and MODES again.

(e) SET GPIB ADDRESS: Briefly pressing the OFFSET key while LOCAL is pressed brings up the SET GPIB ADDRESS function. Details on how to set the GPIB Address are provided in Appendix A. To return to normal operation, press any key other than UP ARROW, DOWN ARROW, or LOCAL.

(f) SET GPIB PARAMETERS: Briefly pressing the MODES key while LOCAL is depressed brings up the SET GPIB PARAMETERS function. Details on how to set the GPIB Parameters are provided in Appendix A. Pressing any key other than UP ARROW, DOWN ARROW, or LOCAL will return the unit to normal operation.

(g) SET BAUD RATE: Briefly pressing the REFERENCE key while LOCAL is depressed brings up the SET BAUD RATE function. Details on how to set the Baud Rate are provided in Appendix C. Pressing any key other than UP ARROW, DOWN ARROW, or LOCAL will return the unit to normal operation.

(h) SET RS232C PARAMETERS: Briefly pressing the PHASE key while LOCAL is depressed brings up the SET RS232C PARAMETERS function. Details on how to set the RS232C Parameters are provided in Appendix C. Pressing any key other than UP ARROW, DOWN ARROW, or LOCAL will return the unit to normal operation.

(i) 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 (M5207)	OUTPUT
DISPLAY (M5208)	CH 1
OFFSET (M5207	ZERO and OFF
CH 1 OFFSET (M5208)	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 (M5208)	X, Y
EXPAND	OFF

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

*Or some other card if AUDIO is unavailable.

5.2C ERROR INDICATORS

There are two ways of indicating errors, first by means of the three (four in the M5208) 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. **NOTE:** If the REFERENCE input is left open, there may be enough stray signal pickup to extinguish this light.

(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 (Model 5207 only): 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 ×10 expansion when the pre-expand output signal level is too large to permit it.

(d) X OVERLOAD and Y OVERLOAD (Model 5208 only): These indicators work exactly the same as the OUTPUT OVERLOAD described in the preceding paragraph, the only difference being that, in the Model 5208, 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 F BAND card installed, ERR1 will be displayed continuously.

(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 RS232C. 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.

(e) ERR5: NOTHING TO SAY ERROR; occurs if the Model 5207/8 receives a TALK message without having anything to say. Usually it will have nothing to say because no information-request command was sent prior to the TALK message. For example, if the user wanted the Model 5207/8 to report its sensitivity, the I/E command would have to be sent prior to the TALK message. One error that is easily made is that of sending a parameter set command instead of the corresponding information-request command. For ex-

ample, should the user send the command S 5, the Model 5207/8 would range to the corresponding sensitivity, instead of preparing the sensitivity setting information for transmission on receipt of the subsequent TALK message.

An ERROR 5 will also be generated during a serial poll if the host computer sends the TALK message before sending the SERIAL POLL ENABLE message, or if the host computer does not send the UNTALK message before sending the SERIAL POLL DISABLE MESSAGE.

(f) ERR6: NUMERIC ERROR; occurs if numbers that do not follow the required format are applied.

(g) ERR7: MISSING SEPARATOR; generated if two or more commands are sent as a compound command without inserting a semicolon after each one but the last one (last one should be followed by a <CR>).

5.2D DIGITAL DISPLAY AND METER(S)
Both the Model 5207 and the Model 5208 use the same four-digit (plus sign) digital display. The parameter displayed is determined by the DISPLAY key and, in the Model 5208, 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 displayed is a ratio or percentage of full scale. In the Model 5207 there is a single analog panel meter directly below the digital display. In the Model 5208 there are two analog meters, located side by side below the digital display. The parameter displayed on the analog meter(s) depends on the LIA model, as follows.

(1) MODEL 5207: 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 ±2% of full scale.

(2) MODEL 5208: 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, or the log of the "R" output. The Channel 2 (right) meter can indicate the "Y" output, or the phase angle between the input and reference signals at the mixer. These meters have center-zero scales and are accurate to ±2% of full scale.

5.2E CONFLICTS
A conflict occurs when the user asks the lock-in amplifier to do something that is inconsistent with a setting or condition. For example, asking for HIGH RESERVE is in conflict with the Sensitivity setting on many Sensitivity ranges. The reaction to a conflict is either to ignore the user's request, or to honor it, adjusting one of the conflicting settings so that a conflict no longer exists. In all cases, the conflict is indicated to the user by a flashing LED. The LED flashed is related to the causes of the conflict.

Users of RS232C or GPIB must be particularly aware of the conflicts and their consequences because the host computer has no way of seeing the flashing light.

A description of each conflict follows. In the context of these descriptions, CONDITION means the conditions that existed prior to the conflict, ACTION means the action taken by the user to bring about the conflict, CONFLICT INDICATION identifies the means by which the instrument signals the user that a conflict is taking place, and RESOLUTION means the action taken by the machine to eliminate the conflict.

(1) CONDITION: RESERVE is HIGH STAB.
ACTION: Set time constant to value >10 s.
CONFLICT INDICATION AND RESOLUTION: SET TC flashes and the TC is automatically set to 10 s.

(2) CONDITION: TIME CONSTANT is set to value >10 s.
ACTION: Set RESERVE to HIGH STAB.
CONFLICT INDICATION AND RESOLUTION: SET TC flashes and the TC is automatically set to 10 s.

(3) CONDITION: SENSITIVITY and RESERVE compatible.
ACTION: Set new SENSITIVITY that is not compatible with RESERVE.
CONFLICT INDICATION AND RESOLUTION: SET RESERVE flashes and nearest compatible RESERVE is automatically selected.

(4) CONDITION: SENSITIVITY and RESERVE compatible.
ACTION: Set an incompatible RESERVE.
CONFLICT INDICATION: SENSITIVITY LED flashes.

(5) CONDITION: REMOTE
ACTION: Press any key but LOCAL.
CONFLICT INDICATION: REMOTE LED flashes.

(6) CONDITION: REMOTE with LOCAL LOCKOUT
ACTION: Press any key.

CONFLICT INDICATION: REMOTE LED flashes.

(7) CONDITION: OFFSET is ON and AUTO-RANGE or AUTO-SET is running.
ACTION: Set OFFSET.
CONFLICT INDICATION: AUTO-RANGE or AUTO-SET LED flashes.

(8) CONDITION: OFFSET is ON and AUTO-RANGE or AUTO-SET is running.
ACTION: Set OFFSET POLARITY.
CONFLICT INDICATION: AUTO-RANGE or AUTO-SET LED flashes.

(9) CONDITION: AUTO-RANGE or AUTO-SET is running.
ACTION: Set SENSITIVITY.
CONFLICT INDICATION: AUTO-RANGE or AUTO-SET LED flashes.

(10) CONDITION: AUTO-RANGE or AUTO-SET is running.
ACTION: Turn EXPAND to ON.
CONFLICT INDICATION: AUTO-RANGE or AUTO-SET LED flashes.

(11) CONDITION: AUTO-RANGE or AUTO-SET is running.
ACTION: A5 (RATIO) is turned ON.
CONFLICT INDICATION: AUTO-RANGE or AUTO-SET LED flashes.

(12) CONDITION: A5 (RATIO) is ON.
ACTION: AUTO-RANGE or AUTO-SET is turned ON.
CONFLICT INDICATION: A5 (RATIO) LED flashes.

(13) CONDITION: DISPLAY = CH2 with RATIO ON.
ACTION: Select OUTPUT MODE of R, θ or LOG R, θ.
CONFLICT INDICATION: A5 (RATIO) will flash.

(14) CONDITION: RATIO ON and OUTPUT MODE is R, θ or LOG R, θ.
ACTION: Select DISPLAY = CH2.
CONFLICT INDICATION: A5 (RATIO) will flash.

(15) CONDITION: DISPLAY = CH2 and OUTPUT MODE is R, θ or LOG R, θ.
ACTION: Turn A5 (RATIO) ON.
CONFLICT INDICATION: OUTPUT MODE LED will flash.

(16) CONDITION: OFFSET is ON.
ACTION: RATIO is turned ON.
CONFLICT INDICATION AND RESOLUTION: OFFSET is turned OFF and the SET POLARITY LED flashes.

(17) CONDITION: OFFSET is ON.
ACTION: NORMALIZATION is turned ON.
CONFLICT INDICATION AND RESOLUTION: OFFSET is turned OFF and the SET POLARITY LED flashes.

(18) CONDITION: RATIO is ON.
ACTION: OFFSET POLARITY is set to plus or minus.
CONFLICT INDICATION: A5 (RATIO) LED flashes.

(19) CONDITION: RATIO is ON.
ACTION: Try to turn AUTO-OFFSET ON.
CONFLICT INDICATION: A5 (RATIO) LED flashes.

5.2F OUTPUTS

In the Model 5207 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 5208 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.

5.2G 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 MΩ.). Symmetrical signals with amplitude in the range of 140 mV to 2 V 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 MΩ. The shell of both connectors "floats" off ground by 10 Ω.

5.2H 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.

5.3 REAR PANEL

5.3A INTRODUCTION

The rear panel of both models is the same. As can be seen in Figure V-3, there are a number of connectors 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.

5.3B INPUT CONNECTOR

There is only one, AUX IN. Its input impedance is 5 MΩ. Its purpose is described in the earlier discussion of the A5 (RATIO) function.

5.3C OUTPUT BNC CONNECTORS

In the case of a Model 5208, three connectors are provided, one for Channel 1, one for Channel 2, and one for the RATIO. The functions available at the CH1 and CH2 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. The RATIO Output was described in the earlier discussion of the A5 (RATIO) autofunction.

5.3D DIGITAL INTERFACE CONSIDERATIONS

The IEEE-488 and RS232C ports are located at the rear panel. See Section VI and Appendices A, B, C, & D for detailed information.

5.3E 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. The oscillator is always turned on if the Oscillator Option is present.

5.3F PREAMP POWER

Any of several different optional preamplifiers can be purchased for use with the Model 5207 or Model 5208. 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.

5.3G AC POWER

The Power Input Assembly is located at the lower right corner of the rear panel. Power and Safety Considerations are discussed in Subsection 1.1.

5.3H 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. **NOTE:** The installation of rear-panel accessories should only be performed by an experienced electronics technician, and then only with the instrument disconnected from all sources of power.

5.4 PRELIMINARY OPERATING CONSIDERATIONS

5.4A POWER REQUIREMENTS

As described in Subsection 1.1

5.4B WARM-UP

For most applications, five minutes should be sufficient (15 minutes for /93 Option). However,

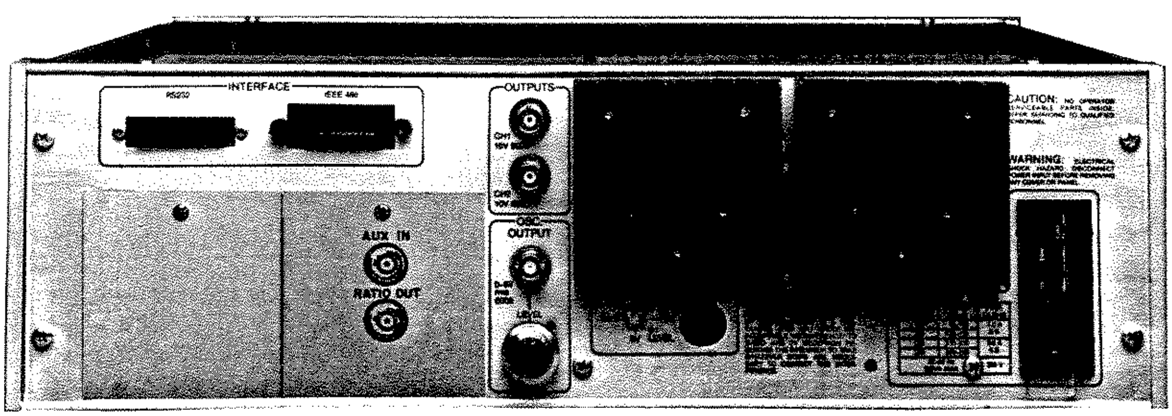


Figure V-3. MODEL 5207/8 REAR PANEL

where it is necessary to achieve the best possible gain and phase stability, allow an hour.

5.4C 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 5207/8 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.

5.4D 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 M5207/8, 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 adversly affecting the signal to be measured in any way. Figures V-4 and V-5 illustrate two ways of measuring single-ended signals. Referring to Figure V-4, note that the signal source is located inside a grounded enclosure to which signal source common is attached at one point. 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 5207/8 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 M5207/8 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 M5207/8 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.

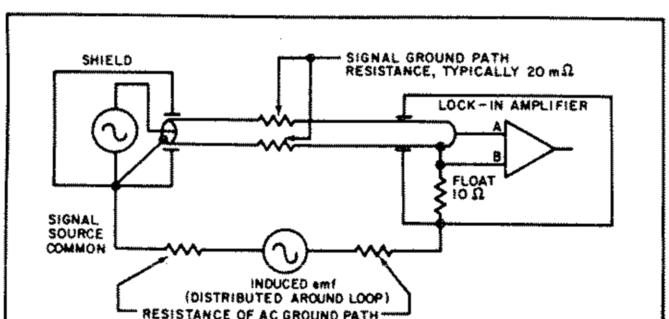


Figure V-4. GROUND LOOP SUPPRESSION BY 10 Ω INPUT GROUND

Conceivably, there might be applications where input ground-loop signal would still be a source of significant interference. Figure V-5 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 Ω ground

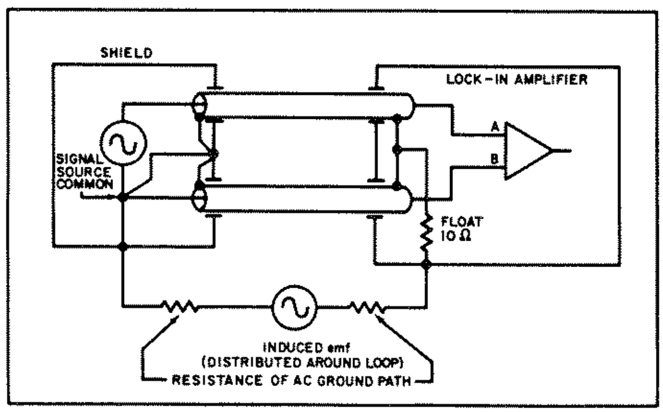


Figure V-5. DIFFERENTIAL MEASUREMENT OF SINGLE-ENDED SIGNAL

serves to attentuate 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 Ω ground return, but rather from the use of the differential measurement technique. In the example illustrated in Figure V-4, the amplifier "looked" at the potential difference between the center conductor of the cable and the braid. In the differential measurement (Figure V-5), 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 V-6 shows the M5207/8 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 M5207/8 (see specifications).

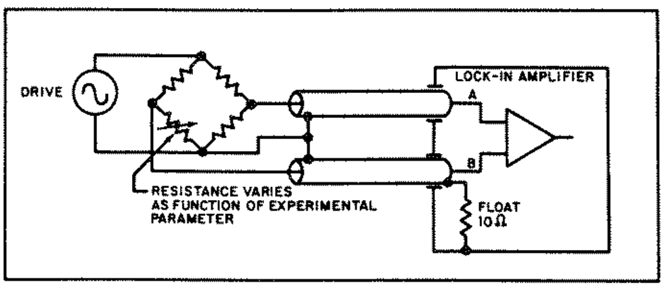


Figure V-6. DIFFERENTIAL MEASUREMENT OF "OFF GROUND" SIGNAL

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 V-7 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 M5207/8 is 10 MΩ) applied to the M5207/8 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

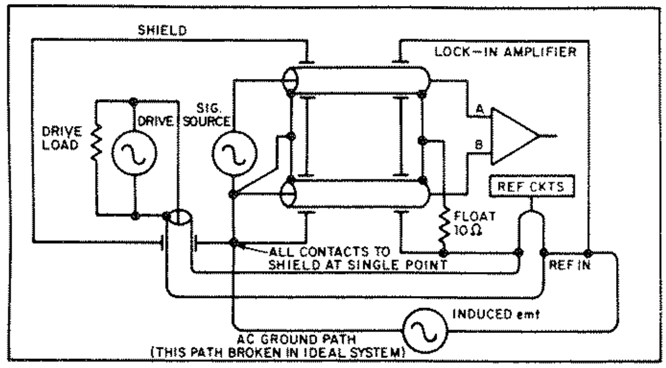


Figure V-7. COHERENT INTERFERENCE MINIMIZED

signal in the parallel path of the signal cable braid is a small portion of that allowed by the 10 MΩ 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.

5.4E NOISE

Any electronic signal processing system adds noise to that already accompanying the signal to be measured, and the M5207/8 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 M5207/8 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:

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

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 M5207/8 *per se*, they are available for most of the preamplifiers that can be used with the M5207/8. 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:

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

where E_t 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 overemphasize 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 MΩ 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 kΩ, one could use a 1:100 step-up transformer so that the preamplifier would see a source resistance of 100 kΩ. At 100 kΩ 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.

5.5 OPERATING THE M5207/8

5.5A INTRODUCTION

Operation of the M5207/8 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 M5207/8 controls as on taking the proper steps with respect to the constraints discussed in Subsection 5.4. Factors such as proper grounding and operating inside the 3 dB contour of the preamplifier can be important in making low level measurements.

5.5B 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 AUTOSELECT 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.

5.5C REFERENCE CHANNEL

REFERENCE SIGNAL REQUIREMENTS: The M5207/8 can lock onto and track a wide range of possible signals. Once locked on, the reference channel remains locked, even if the reference in-

put signal changes frequency. The time to achieve reference lock depends on the frequency of the applied signal. 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 M5207/8 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 M5207/8 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 M5207/8 is 5° maximum phase shift if the nominal slewing rate is 1 decade/second (F_r>50 Hz), .1 decade/second (F_r>5 Hz), or .01 decade/second (F_r>0.5 Hz).

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 M5207 and M5208 differ primarily in that, where the M5207 has one phase-sensitive detector (demodulator), the M5208 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 5208, 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 5207

(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 neces-

sary 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 5208

(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 M5208 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.

5.5D 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 M5208) 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/°C. In NORMAL it is 100 ppm/°C, and in HIGH STABILITY it is 20 ppm/°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 uV through 5 V, NORMAL measurements can be made with sensitivity settings of 10 μV through 50 mV, and HIGH RESERVE measurements are restricted to the range of 1 μV 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 M5208, 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, the next available card will be selected. XTAL-HET ON/OF selection takes place on alternate passes through the bands if unit is equipped with /93 Option. 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, 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 AUTO-SET. 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. If the sensitivity is later changed to a range that will accommodate the previously selected reserve, that reserve will be restored.

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 situations 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.

5.5E 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 M5208), 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 ±100 μV with respect to the 70 μV zero indication, allowing amplitude variations to be easily tracked. If the signal level were to increase to 80 μV, the meter would indicate +10% of full scale. If it were to decrease to 60 μV, the meter would indicate −10% of full scale. For greater sensitivity, the EXPAND function could be activated, giving a sensitivity of ±10 μV 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 5208, 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 M5207/8 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 M5207/8. 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 M5207/8 would be adjusted for an output between 40% and 110% of full scale. Next, AUTO-NORMALIZE would be activated, automatically adjusting the M5207/8'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 5207 there is a single front-panel OUTPUT connector. In the Model 5208, 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 600 Ω and full scale output is ± 10 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 5208, the user can choose to display any of several different parameters on these meters as selected with the OUTPUT MODE switch. In the M5207, 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 5207, 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 5208 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 M5207. 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.

5.6 INTERNAL (CIRCUIT CARD) OPTIONS

5.6A F BAND CARDS

The M5207/8 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 installed in its correct location. Since the cards look so much alike, and can be physically installed in the wrong slot, it is essential that the user absolutely know which card is which. The card locations are indicated in Figure V-8. Installation consists of nothing more than plugging a card into the designated slot. Should it become necessary, an F BAND card can be identified by means of the following procedure.

Hold the board component side up with the card-edge connector towards you. With the board in this position, pin 1 will be to the left and pin 15 to the right. Using pin 15 as a reference, identify pins 10, 11, and 12. There will be a small jumper connected to one of these three pins. The jumper position identifies the board as follows.

JUMPER POSITION	BOARD TYPE
10	LOW FREQUENCY
11	AUDIO FREQUENCY
12	BROAD-BAND

NOTE: For personnel safety, a board should only be installed by a qualified service technician, and then only with the M5207/8 disconnected from all sources of power.

5.6B 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 V-8. 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. 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 M5207 and the M5208. **NOTE:** FOR PERSONNEL SAFETY, THE INSTALLATION SHOULD ONLY BE PERFORMED BY A QUALIFIED SERVICE TECHNICIAN, AND THEN ONLY WITH THE INSTRUMENT DISCONNECTED FORM ALL SOURCES OF POWER.

5.6C I.F. OPTIONS

As described in the Specifications, there are two different I.F. characteristics, normal and crystal-het. The normal I.F. characteristic (only) is provided in units equipped with the /92 Option (a non-charge option). Both characteristics are provided in units equipped with the /93 Option. The components required to implement the /93 Option are located on the I.F. and Ref. 2 Circuit boards. These two boards are always provided. The difference is that, in the case of units ordered with the /93 Option, additional components are present as required to implement the option. These boards cannot be upgraded in the field.

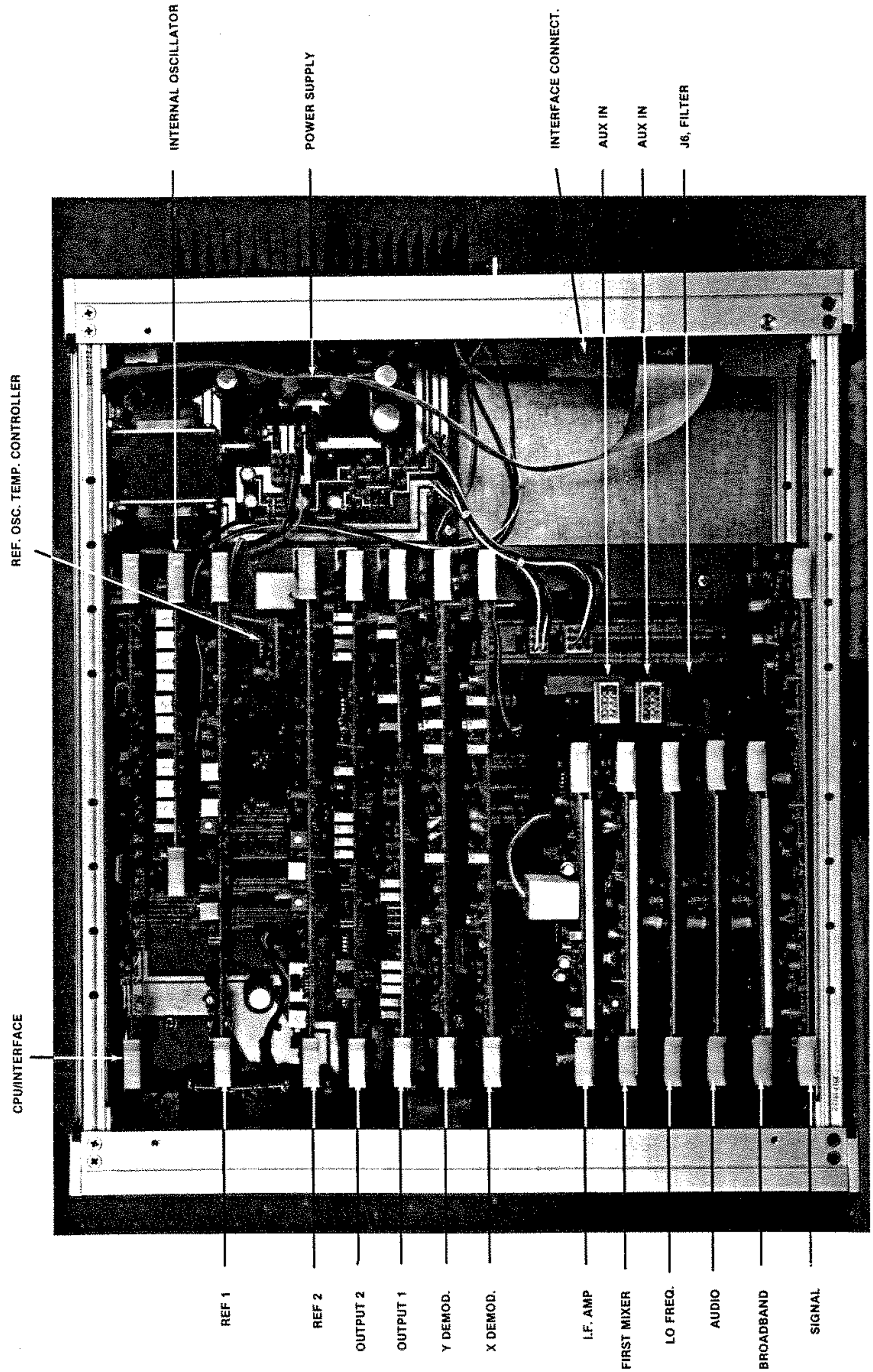


Figure V-8. BOARD IDENTIFICATION

SECTION VI
DIGITAL INTERFACE CONSIDERATIONS

6.1 INTRODUCTION

An interface, literally a shared boundary, is the interconnection between two devices, usually for the purpose of communication. A digital interface permits transmission of digital signals between devices.

In general, digital interfaces can be divided into two categories, parallel and serial. Serial interfaces transfer data one bit at a time, while parallel interfaces transfer data one byte at a time. As a result, parallel interfaces are capable of higher communications rates than serial interfaces. However, parallel interfaces require more data lines (one per bit) and are more expensive and complex.

The Models 5207 and 5208 provide both kinds of interfaces. Specifically, they can be controlled from an external computer via a GPIB (IEEE-488) parallel data link or an RS232C serial data link. The Digital Interface 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.

This section of the manual discusses the command set used to communicate via the RS232C and GPIB data links. The details of GPIB and RS232C communications (pinouts, rear-panel switch considerations, protocol, useful routines, etc.) are located in the appendices at the back of the manual. Appendices A and B discuss communications via the GPIB. Appendix C discusses RS232C communications. Appendix D discusses interfacing and protocol considerations for both data links. Most users will find it necessary to review these appendices before attempting to use the data links.

6.2 DEVICE DEPENDENT COMMANDS

6.2A INTRODUCTION

Independent of the choice of data link (serial or GPIB), most messages from the controller to the M5207/8 will be device-dependent commands. These commands are listed in Table VI-1 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> or by <CRLF> characters, as set at the front panel (details of how to set the interface parameters are provided in Appendices A (GPIB) and C (RS232C). The Model 5207/8 uses integer numbers only.

COMMAND	FUNCTION	PARAMETER RANGE
D #	Selects which data DPM will display.	(0 to 5)
M #	Selects data indicated by panel meter(s).	(0 to 2)
X #	Turns EXPAND on or off.	(0 or 1)
O #1,#2	Sets OFFSET.	
	#1 is offset.	(0 to 1000)
	#2 is the polarity.	(0 to 2)
R #	Selects RESERVE.	(0 to 2)
F #	Selects FREQUENCY BAND.	(0 to 2)
J #1,#2	Selects frequency of Oscillator and Reference.	
	#1 is the numerical frequency.	(100 to 1000)
	#2 is the band.	(0 to 7)
OO #	Turns Oscillator on or off.	(0 or 1)
P #1,#2	Selects Phase Shift.	
	#1 is the Quadrant.	(0 to 3)
	#2 is the value. (100 gives −2.5°) (3900 gives 92.5°)	(100 to 3900)
T #1,#2	Selects TIME CONSTANT and dB/octave.	
	#1 selects the Time Constant.	(0 to 10)
	#2 selects the dB/octave.	(0 or 1)
S #	Selects the SENSITIVITY.	(0 to 20)
L #	Selects the sensitivity LIMIT.	(0 to 20)
A1 #	Turns the AUTORANGE on or off.	(0 or 1)
A2 #	Turns the AUTOSET function on or off.	(0 or 1)
A3	Causes the AUTO-OFFSET routine to run.	
A4 #	Turns AUTONORMALIZE function on or off.	(0 or 1)
A5	Controls RATIO function.	
A6	Reserved for future use.	
A7	Causes the AUTOPHASE routine to run.	
Q1	Reads integer value of CH 1 output.	
Q2	Reads integer value of CH 2 output.	
Q3	Reads integer value of AUX output.	
Q5	Reads both CH 1 and CH 2 output values.	
G #	Sets output gain (both channels in 5208).	(0 to 4095)
H #	Selects mode of front-panel LED's.	(0 to 2)
K #	Causes the routine associated with the specified key to run exactly the same as if the key had been pressed at the front panel.	(0 to 13)
VER	Reads software version number.	
V	Same as VER command.	
ERR	Causes ERROR NUMBER of previous command to be sent.	
E	Same as ERR command.	
ST	Causes STATUS byte to be sent.	
Z	Same as ST command.	
MSK #	Specifies SRQ MASK byte.	(0 to 255)
B #	Same as MSK command.	
DD #	Defines delimiter to be used between numbers sent to host computer.	(any ASCII character)
C #	Same as DD command.	
N	Reads status of Overload Indicators.	(1 to 7)
CH #	Turns Crystal Het on or off.	(0 or 1)
ID	Reads model number.	
OPTION #1,#2	Reads status of specified option.	
	#1 (sent by host) specifies option.	(92 to 99)
	#2 (sent by 5207/8) specifies presence or absence of option.	(0 or 1)

Table VI-1. 5207/8 DEVICE DEPENDENT COMMANDS

Each command consists of one or more upper case letters and an operand or operands if necessary. The command mnemonics suggest the function, where possible. Where there is a conflict, an arbitrary selection was made. For example, the letter "R" is appropriate for both reserve and reference. As it turns out, "R" has been assigned to the reserve function and "J" to the reference function. In the case of ON/OFF commands, "1" is always used to denote ON and "0" to denote OFF.

Many commands can be sent with or without an operand. Where such a command is followed by an operand (symbolized in this manual by #), 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 "VER", "ERR", and "ST" are always commands to send information, and never take an operand. A few commands, such as "A3" and "K #", are used solely to initiate routines, specify control parameters, or turn functions on or off.

Note that users of the RS232C or GPIB ports must be particularly mindful of conflicts (Subsection 5.2E) because the host computer has no way of knowing when a conflict occurs.

6.2B DETAILED DESCRIPTION OF COMMANDS

(1) D #: When followed by #, the D (DISPLAY) command sets the parameter displayed by the digital panel meter. If sent without an operand, the command is a request for the display parameter currently selected. The selections as a function of # are:

#	M5207	M5208
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 #: When followed by #, the M (METERS) command selects the parameter to be displayed by the analog panel meters in the 5208. If sent without an operand, the command requests the 5208 to report the current meter "selection". The command has no validity for the 5207. The selections as a function of # are:

#	CH 1 METER	CH 2 METER
0	X	Y
1	R	θ
2	LOG R	θ

(3) X #: When followed by #, the X (EXPAND) command switches the EXPAND on and off. If # is omitted, the command requests the 5207/8 to report the expand status. The status as a function of # is:

#	STATUS
0	OFF
1	ON

(4) O #1,#2: When followed by #1 and #2, the O (OFFSET) command controls the offset. If #1 and #2 are omitted, the command requests the 5207/8 to report the offset status. The magnitude is set by #1, where #1 can range from 0 to 1000. The units are tenths of one percent of full scale. #2 switches the offset on or off and sets the polarity. The codes for #2 are:

#2	STATUS
0	OFFSET OFF
1	OFFSET ON AND POS.
2	OFFSET ON AND NEG.

(5) R #: When followed by #, the R (RESERVE) command controls the dynamic reserve. If # is omitted, the command requests the 5207/8 to report the reserve setting. The codes are:

#	RESERVE
0	HIGH RES.
1	NORMAL
2	HIGH STAB

(6) F #: When followed by #, the F (FREQUENCY BAND) command selects the Frequency Band. If # is omitted, the command requests the 5207/8 to report the selected band. The codes are:

#	BAND
0	BROADBAND
1	AUDIO
2	LOW

(7) J #1,#2: When followed by #1 and #2, the J command selects the reference mode and controls the Internal Oscillator Option. If #1 and #2 are omitted, the command requests that the Reference Status be reported. If an Internal Reference Band is selected, #1 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. #2 selects the reference mode, EXT F, EXT 2F, or, via any of the Internal Frequency bands, INT, as follows.

#1	#2	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

*#1 value must be entered, even if selecting EXT. Mode operation. "100" is a suitable value.

NOTE: If the oscillator is *not* installed and you send the "J" command with the first (frequency band) parameter value in the range of 0 to 5, you get an Error 1 (Option Not Installed).

(8) OO #: When followed by #, the OO (OSCILLATOR OUTPUT) command determines whether the oscillator will be ON or OFF. An operand value of "0" turns the oscillator OFF. An operand value of "1" turns the

oscillator ON. If # is omitted, the command requests the 5207/8 to report the Oscillator Output status. **NOTE:** If this command is applied and the Oscillator Option has not been installed, you get an Error 1 (Option Not Installed).

(9) P #1,#2: When followed by #1 and #2, the P (PHASE) command sets the Phase Shift. If #1 and #2 are omitted, the command is a request for the 5207/8 to report the current PHASE setting. #1 selects the quadrant, 0 (0° to 90°), 1 (90° to 180°), 2 (180° to 270°), or 3 (270° to 360°). #2 specifies the phase shift within the quadrant in increments of 0.025 degrees. The range of #2 is 100 to 3900. The phase shift contributed by #2 equals 0.25 * (#2-200). For example, if #2 were 100, the phase shift contributed by #2 would be −2.5°. If #2 were 3900, the phase shifted contributed by #2 would be 92.5°. The formula relating total phase shift to #1 and #2 is:

Total Phase Shift in degrees equals
(#1 * 90) + [0.025(#2 − 200)]

If you know the desired phase shift, P, and want to find #1 and #2, use:

#1 = INT (P/90)
#2 = (40 * P) − (3600 * #1) + 200

Two convenient reference points are 0° (#2 = 200) and 90° (#2 = 3800).

(10) T #1,#2: When followed by #1 and #2, the T (TIME CONSTANT) command selects the Time Constant and the dB/octave rolloff rate. If #1 and #2 are omitted, the command is a request for these parameter settings. The codes are:

#1	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	3 ms
10	1 ms

#2	dB/OCTAVE
0	12
1	6

(11) S #: When followed by #, the S (SENSITIVITY) command sets the sensitivity. If # is omitted, the command requests that the 5207/8 report the set sensitivity. The range for # extends from 0 to 20, corresponding to a Sensitivity Range of 5 V to 1 μV rms full scale in 5-2-1 sequence.

(12) L #: When followed by #, the L (LIMIT) command sets the auto-range sensitivity limit. If # is omitted, it is a request to report the limit. The range for # 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:

= INT(ABS(3.0*LOG(V) − 2.4))

where # = 5207/8 code and S = sensitivity in volts.

The formula for finding S, given #, is:

S = 10! − (INT(#/3))*#1

The following BASIC program uses this formula to find the sensitivity in volts, given #.

```
10 T1 = # − (INT(#/3)*3) + 1
20 IF T1 = 1 THEN T1 = 5
30 IF T1 = 3 THEN T1 = 1
40 V = (10! − INT(#/3))*T1
```

(13) A1 #: If followed by #, the A1 (AUTORANGE) command turns the AUTORANGE function on and off. If # is omitted, the command request that the function's status be reported. The codes are:

#	AUTORANGE STATUS
0	OFF
1	ON

(14) A2 #: If followed by #, the A2 (AUTOSET) command turns the AUTOSET function on and off. If # is omitted, the command is a request to report the function's status. The codes are:

#	AUTOSET STATUS
0	OFF
1	ON

(15) A3: The A3 (AUTO-OFFSET) command causes the Auto-Offset routine to run. [The sequence O 0 0 (that's OH ZERO ZERO) turns the Offset function off.]

(16) A4 #: If followed by #, the A4 (AUTONORMALIZE) command controls the Autonormalize routine. If # is omitted, it is a request to report the function's status. The codes are:

#	AUTONORMALIZE STATUS
0	OFF
1	ON

(17) A5: If followed by #, the A5 (RATIO) command controls the Ratio routine. If # is omitted, it is a request to report the function's status. The codes are:

#	RATIO STATUS
0	OFF
1	ON

Ratio works with X, Y, R, or LOG R. If LOG R is selected, the log of the ratio of R to AUX is displayed. If X, Y, or R is selected, the ratio of X, Y, or R to AUX is displayed. **NOTE:** Ratio of X to AUX is only ratio available in the 5207.

Ratio has a higher priority than Normalized. If Normalization is selected, normally X, Y, and R are displayed as a percent of full scale. However, if Ratio is selected, they are displayed as the ratio of X, Y, and R to AUX.

(18) A6: Reserved for future use.

(19) A7: In the 5208, the A7 (AUTOPHASE) command invokes a single iteration of the Auto-Range routine and then an Auto-Phase routine. In the 5207, each time an A7 command is applied, 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 5207. (For both the Model 5207 and the Model 5208, the AUTO-SET comand, A2, is preferred.)

Some examples of Q1 commands interleaved with Q2 commands follow.

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

(21) Q5: This command, OUTPUT CH1,CH2, is a read-only command. It is applied without operands and requests that the 5207/8 respond with the Channel 1 Output level followed by the Channel 2 Output level. The numbers sent are integers, with −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 a Model 5207, #2 is always reported as "0".

(22) G #: If followed by #, the G (GAIN) command sets the gain of the 5207/8 output channel(s). If # is omitted, it is a request to report the gain value. The allowable range for # is 0 to 4095. The default or "normal" value is 1638. With this value, a full-scale input signal gives a full-scale output. The gain adjustment factor then is simply #/1638. For example, if # were 4095, the gain would be increased by a factor of 2.5. Similarly, if # were 819, the gain would decrease to 0.5 its normal value.

(23) H #: If followed by #, the H command controls the front-panel LED's. If # is omitted, the command requests that the LED's status be reported. The codes are:

#	STATUS
0	All LED's OFF
1	NORMAL OPERATION
2	ALL LED's ON (test function)

(24) K #: If followed by #, the K (KEY) command has exactly the same effect as pressing a front-panel key. The value of # designates the key. If # is omitted, the command is invalid. The codes are:

#	SELECTED KEY
0	DISPLAY
1	CH 1 OFFSET (OFFSET IN 5207)
2	MODES
3	REFERENCE
4	PHASE
5	TIME CONSTANT
6	SENSITIVITY
7	SELECT
8	RUN/CLEAR
9	LOCAL
10	OUTPUT MODE (5208)
11	CH 1 EXPAND (EXPAND IN 5207)
12	SET (↓)
13	SET (↑)

(20) Q1, Q2, and Q3: These commands cause the Channel 1 Output, the Channel 2 Output (5208 only), or the Auxiliary Output value respectively to be reported. 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 5207, the output (analog meter reading or AUX potential) is the actual parameter reported. To convert this number to volts, apply the equation:

$$\text{Volts} = (\text{Output}/2000) * \text{Full-Scale Sensitivity}$$
(For AUX, full scale = 10 V)

In the case of a 5208, the quantity reported can be any of several parameters according to the selected OUTPUT MODE.

If X, Y, or R is reported, the voltage can be determined from the equation:

$$\text{Volts} = (\text{Output}/2000) * \text{Full-Scale Sensitivity}$$

To obtain the log of the signal magnitude, select the output mode LOG R,θ and use the command Q1. Then Log R can be computed as:

$$\text{Log R} = \text{Output}/20$$

The phase angle θ is reported using the output mode R,θ and the command Q2. The number reported can be converted to degrees using the equation:

$$\theta = \text{Output}/10$$

The instrument can execute a Q1 command once in approximately 45 ms. If Q1 and Q2 commands are interleaved, one reading can be taken every 90 ms, and both channels can

be read in approximately 180 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 one.

Some examples of Q1 commands not interleaved with Q2 commands follow.

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

There is an ambiguity problem that has to be taken into consideration in using a "K" 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 would 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 which occurs 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 activates the key of interest. Applied to the example, this would assure that MODES-RESERVE would be selected.

(25) VER: 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 a particular lock-in amplifier.

(26) V: This command is exactly the same as the previously defined VER command. It is provided to maintain software compatibility with the 5205/6.

(27) ERR: A read-only command, ERR (ERROR) 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. ERR is most useful during program development via the RS232C Interface. The error codes are:

ERROR CODE	MEANING
0	NO ERROR
1	OPTION NOT INSTALLED
2	INVALID COMMAND
3	INVALID PARAMETER
4	COMMAND OVERRUN; STILL EXECUTING PREVIOUS COMMAND
5	NOTHING TO SAY
6	NUMERIC ERROR
7	MISSING SEPARATOR

(28) E: This command is exactly the same as the previously defined ERR command. It is provided to maintain software compatibility with the 5205/6.

(29) ST: A read-only command, ST (STATUS) requests that the 5207/8 report its status to the host computer. The number reported is the decimal equivalent of the contents of the Serial Poll Status Byte. The significance of each bit is:

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. Applying the ST command clears this bit.
1	INVALID COMMAND: This bit is set if the previous command was invalid. The principle utility of this bit would be in program development.
2	PARAMETER ERROR: This bit is set if a parameter in the previous command was invalid. The principle utility of this bit is 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 powerup 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 μs through 100 ms, it is set or updated after 1.2 s (2.4 s with 12 dB/octave).
6	$\overline{\text{SRQ}}$ 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.

When the condition in the MEANING column exists, the corresponding bit is set. When the condition in the MEANING column does not

exist, the corresponding bit is cleared. The decimal values of the set bit are added and the sum transmitted to the host computer as an ASCII decimal number. For example, if bits 5 (SETTLED) and 7 (OUTPUT READY) were set and ST were applied, the response would be ASCII decimal 160. Note that sending the ST command is not the same as doing a serial poll. A serial poll can be done anytime. An ST command, like any other command, cannot be sent if the 5207/8 is busy executing a previously applied command. Another difference is that the response to a serial poll is an eight-bit binary byte, while the response to the ST command is an ASCII coded decimal number. The ST command is provided so that RS232C users will have access to essentially the same information as a serial poll provides in GPIB operation.

(30) Z: This command is exactly the same as the previously defined ST command. It is provided to maintain software compatibility with the 5205/6.

(31) MSK #: A READ/WRITE command, MSK (SRQ MASK) determines which events must take place to cause a GPIB service request. If # is omitted, MSK is a request for the 5207/8 to report the decimal value of the mask byte. The range is 0 to 255. In setting #, each bit for which a service request is to be generated should be a "1". The other bits should be "0".

A service request will be generated ($\overline{SRQ}$ asserted) when both the Status Byte and the Mask Byte have a "1" in the same bit. Digitally speaking, the mask byte and the status byte are AND'ed bit by bit. Anytime the result is a non zero, $\overline{SRQ}$ is asserted. The codes are the same as for the ST command.

EXAMPLE: If the Mask Byte operand is such as to give a Mask Byte of:

1000001

a service request will be generated any time bit 1 or bit 7 of the STATUS byte is a "1". Service requests will not occur for bits 2, 3, 4, 5, or 6 regardless of the STATUS BYTE status.

DISCUSSION: Use of the MSK command to force a SERVICE REQUEST is but one of the ways of initiating a serial poll. It is best suited to use in complex systems where there are many devices connected to the GPIB. By having the controller do a serial poll only when necessary, the computer can optimally allocate its time. Alternatively, the computer can periodically poll each device on the bus as part of its basic operating routine. In simpler systems where the computer is dedicated to the 5207/8, it is generally more efficient to have the computer perform repetitive serial polls whenever possible. That way, the computer will detect the 5207/8's need for service as soon as possible. However, MASK byte controlled Service Requests can certainly be made in simple systems too, if desired.

(32) B #: This command is exactly the same as the previously defined MSK command. It is provided to maintain software compatibility with the 5205/6.

(33) DD #: A write-only command, when followed by #, DD (DEFINE DELIMITER) 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 printing ASCII character could be specified. For example, if # were 59 (decimal), the delimiter would be a semicolon. Note that this command governs only the delimiter for responses transmitted by the 5207/8. The 5207/8 accepts any non-numeric character as a delimiter. **NOTE:** The Apple II computer does not accept comma delimiters on INPUT statements.

(34) C #: This command is exactly the same as the previously defined DD command. It is provided to maintain software compatibility with the 5205/6.

(35) N: This command allows the status of the three front-panel overload indicators to be read. The 5207/8 responds with a binary-coded decimal number from 1 to 7. A "1" in bits 0, 1, or 2 indicates an overload condition.

BIT	5208	5207
0	CH 2 OVERLOAD	
1	CH 1 OVERLOAD	OUTPUT OVERLOAD
2	SIGNAL OVERLOAD	SIGNAL OVERLOAD

(36) CH #: A read/write command, CH (CRYSTAL HET) allows the crystal-het feature to be turned ON and OFF. If sent without the operand, the command requests the 5207/8 to report the crystal-het status. The codes are:

#	STATUS
0	OFF
1	ON

(37) ID: A read-only command, the ID (IDENTIFICATION) command requests the 5207/8 to report its model number to the host computer.

(38) OPTION #1,#2: This is a special read/write command. It allows the computer to inquire whether a specific option is present. The computer sends #1, and the 5207/8 responds with #2. The codes are:

#1	#1 MEANING
92	NO CRYSTAL HET
93	CRYSTAL HET
94	OSCILLATOR
97	BROAD-BAND
98	AUDIO-BAND
99	LOW-FREQ.

#2	#2 MEANING
0	OPTION NOT PRESENT
1	OPTION PRESENT

Note that an invalid value for # will result in #2 response of 0.

APPENDIX A
GPIB INTERFACE

A.1 INTRODUCTION

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, to operate the 5207/8 from a remote computer, it is necessary to know and use both standard GPIB and device-dependent commands as required to accomplish the intended measurement. This appendix contains detailed information about the GPIB as implemented in the Model 5207/8, together with a more detailed general description of the GPIB (Subsection A.7). The device dependent commands recognized by the Model 5207/8 are described in Section VI.

A.2 GPIB ADDRESS AND PARAMETERS

INTRODUCTION

The GPIB Address and GPIB Parameters are set from the front panel. Function 1, invoked by pressing LOCAL and OFFSET, is used to set the GPIB address. Function 2, invoked by pressing LOCAL and MODES, is used to set other GPIB parameters. Note that these are double-key functions; each is invoked by pressing LOCAL and, while it is held in, pressing either OFFSET or MODES, according to the desired function. When any one of these special functions are invoked, F# is displayed for about one second and then the parameter value is displayed. At the same time, all of the other LED's on the panel extinguish to indicate that the 5207/8 is not in a normal mode of operation. The parameter value is incremented or decremented using the UP-ARROW (↑) and DOWN-ARROW (↓) keys respectively. Each time a new value is set, it is immediately adopted and an asterisk is transmitted to the RS232C port. Another special function may be invoked via the appropriate double-key sequence. Normal lock-in operation can be re-established by pressing any key other than UP-ARROW (↑), DOWN-ARROW (↓), or LOCAL. A detailed description of how Functions 1 and 2 are used follows.

FUNCTION 1 (ADDRESSING)

When the controller wishes to communicate with a 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.

Each address is seven bits long. A listen address begins with "01", and a talk address with "10", with the controller supplying the "01" or "10" as required. Thus, when we speak of a device's decimal GPIB address, we are but defining the decimal equivalent of the five-bit sequence under the user's control. To determine the actual hex LISTEN and TALK addresses, simply precede the binary sequence by "01" or "10" as appropriate, and convert the resulting sequence to hex. An alternative technique for determining the hex LISTEN address is to begin with the decimal equivalent of the five-bit sequence, add 32, and convert to hex. Similarly, the hex TALK address can be determined by adding 64 to the decimal address and then converting to hex. Table A-1 shows the available addresses.

BIT SEQUENCE	DECIMAL EQUIV	HEX LISTEN ADDRESS	HEX TALK ADDRESS
00000	0	20	40
00001	1	21	41
00010	2	22	42
00011	3	23	43
00100	4	24	44
00101	5	25	45
00110	6	26	46
00111	7	27	47
01000	8	28	48
01001	9	29	49
01010	10	2A	4A
01011	11	2B	4B
01100	12	2C	4C
01101	13	2D	4D
01110	14	2E	4E
01111	15	2F	4F
10000	16	30	50
10001	17	31	51
10010	18	32	52
10011	19	33	53
10100	20	34	54
10101	21	35	55
10110	22	36	56
10111	23	37	57
11000	24	38	58
11001	25	39	59
11010	26	3A	5A
11011	27	3B	5B
11100	28	3C	5C
11101	29	3D	5D
11110	30	3E	5E

Table A-1. ADDRESS SWITCH CODING

When Function 1 is invoked, the digital panel meter displays "F1" and then the decimal equivalent of the current five-bit GPIB address. The parameter value can be changed using the UP-ARROW (increments value) and DOWN-ARROW (decrements value) keys.

FUNCTION 2 (GPIB PARAMETERS)
This function allows selection of the terminator, the character that marks the end of each transmission from the Model 5207/8 to the host computer or from the host computer to the Model 5207/8, together with ON/OFF control of the TEST ECHO feature.

The terminator is either a CARRIAGE RETURN, <CR>, or a CARRIAGE RETURN followed by a LINE FEED, <CRLF>, and *MUST BE SELECTED ACCORDING TO THE REQUIREMENTS OF THE HOST COMPUTER*. Failure to satisfy this requirement is one of the most common causes of problems in establishing communications via the GPIB. Note that the Model 5207/8 also accepts EOI asserted as a terminator, and will itself assert EOI with the last character in each message.

When the Test Echo function is ON, every character transmitted or received via the GPIB port will be echoed to the RS232C Interface Connector. This feature is particularly useful when developing programs. If a "dumb" CRT terminal is connected to the RS232C Interface, the programmer will see all communications on the CRT. Such a terminal will allow direct interaction, thereby facilitating the programmer's understanding of the commands and responses. In addition, the programmer will be able to monitor the program data and intervene if necessary. The RS232C baud rate should be high (see Appendix C) to prevent slowing down the GPIB.

The range for Function 2 is 0 to 3 (default value is 0). The codes are:

F2 VALUE	MEANING
0	<CR> TERMINATOR and GPIB TEST ECHO OFF
1	<CR> TERMINATOR and GPIB TEST ECHO ON
2	<CRLF> TERMINATOR and GPIB TEST ECHO OFF
3	<CRLF> TERMINATOR and GPIB TEST ECHO ON

A.3 GENERAL INTERFACE MANAGEMENT LINES

There are five general interface lines. Their function is defined by the standard and briefly discussed in Subsection A.7. Some additional comment is appropriate for them as they apply to the Model 5207/8.

First, the instrument recognizes ATN and IFC as defined in the standard.

REN (Remote Enable) transfers the Model 5207/8 from local (front-panel controlled) to remote (GPIB or RS232C port) operation. The Model 5207/8 powers up in the local mode. When REN is asserted and the proper LISTEN address applied, it transfers to the remote mode, in which the front-panel controls are locked out. Return to local can be accomplished either by deasserting REN, by applying the multi-line GTL (GO TO LOCAL) message, or by pressing the front-panel LOCAL pushbutton. Note, however, that if the LLO (LOCAL LOCKOUT) multi-line message is applied, transfer to local via the LOCAL pushbutton will be inhibited.

A command sent via the GPIB bus when the Model 5207/8 is in the local mode (under front-panel control) will be ignored and an ERROR 2 (invalid command) generated. The Model 5207/8 accepts EOI as a terminator for a multi-byte message and asserts EOI with the last byte of each response. The instrument asserts SRQ when the conditions established by the MSK (MASK) command are satisfied (see description of MSK command in Section VI).

A.4 REMOTE MESSAGES

IEEE-488 defines a large number of multiline messages the controller can place on the bus when ATN is asserted. Of these, the Model 5207/8 recognizes TALK, UNTALK, LISTEN, UNLISTEN, GTL (GO TO LOCAL), LLO (LOCAL LOCK OUT), DCL (DEVICE CLEAR), SPE (SERIAL POLL ENABLE), and SPD (SERIAL POLL DISABLE). Each is discussed in the following paragraphs.

(1) TALK, UNTALK, LISTEN, and UNLISTEN: The TALK and LISTEN messages direct the Model 5207/8 to assume the talker and listener states respectively. Similarly the UNTALK and UNLISTEN commands direct the Model 5207/8 to assume the talker-idle and listener-idle states respectively.

(2) GTL (GO TO LOCAL) returns the instrument to local control. Other ways of restoring local (front-panel) control are to cycle the power, deassert REN, or to assert IFC.

If GTL is used to return to local control, it is only necessary to place the Model 5207/8's listen address on the bus to re-establish control via the bus.

(3) LLO (LOCAL LOCK OUT) inhibits returning the Model 5207/8 to the local mode with the front-panel LOCAL button.

(4) DEVICE CLEAR: The DEVICE CLEAR (DCL) message restores the default values of all Model 5207/8 parameters.

(5) SERIAL POLL ENABLE and SERIAL POLL DISABLE: These messages control the serial polling process. The SERIAL POLL ENABLE message tells the Model 5207/8 to prepare to place its status byte (eight-bit binary) on the bus. This actually occurs when the TALK address is applied. The SERIAL POLL DISABLE message directs the 5207/8 to take its Serial Poll Status Byte off of the bus. In making a serial poll, the correct sequence is:

(a) The host computer sends the SERIAL POLL ENABLE message (ATN asserted).

(b) The host computer sends the TALK message (ATN asserted).

(c) The host computer deasserts ATN.

(d) The 5207/8 sends the Serial Poll Status Byte to the host computer.

(e) After reading the Serial Poll Status Byte, the host computer reasserts ATN.

(f) The host computer sends the UNTALK message (ATN asserted).

(g) The host computer sends the SERIAL POLL DISABLE message (ATN asserted).

When the host computer reads the serial poll status byte, it must transmit the UNTALK and SERIAL POLL DISABLE messages and go on to its next operation. Table A-2 indicates the meaning of each bit of the serial-poll status byte.

By monitoring the COMMAND DONE and OUTPUT READY bits of the serial poll response byte, the computer can obtain the information it needs to pace the flow of commands so as to proceed as rapidly as possible without interfering with the Model 5207/8; the polling response is handled entirely by the Model 5207/8's GPIB Interface chip, and does not involve the microprocessor. When the 5207/8 has finished carrying out the previous command, Bit 0 will be set. Whenever it has output of any kind ready to send to the computer, Bit 7 will be set. By polling frequently, the computer will know as soon as possible that there is data available for processing, and/or that the Model 5207/8 is free to accept another command.

The question of when to perform the poll is important. If the computer is dedicated solely to the 5207/8, simply have the computer continually poll the 5207/8 whenever it isn't busy performing another function. The approach is incorporated into the Static Interface Routines provided in Appendix B.

Two approaches can be taken in a multitasking system. The first is to have the computer poll the 5207/8 from time to time as part of its basic operating routine. The second is to have the 5207/8 make a service request (assert SRQ) to generate an interrupt that causes the computer to do a serial poll. The MSK (MASK) command provides the means for determining which events must occur to cause a service request.

The MASK byte and SERIAL POLL STATUS byte are AND'ed in the 5207/8. When any corresponding bits of both the MASK and STATUS bytes are a logic 1, SRQ is asserted. This is the mechanism by which the 5207/8 makes a service request. The computer's response should be to do a Serial Poll, that is, to read the Serial Poll Status Byte of every device on the bus. In so doing, the computer will determine which instrument requires service and take the appropriate action. The serial poll clears SRQ.

BIT	MEANING	COMMENT
BIT 0 (LSB)	COMMAND DONE	Bit 0 is cleared when Model 5207/8 is busy executing a command. It is set when execution of previous command is completed and the Model 5207/8 is ready for a new command.
BIT 1	COMMAND ERROR	Bit 1 is cleared if previous command did not contain an error. It is set if the previous command did contain an error.
BIT 2	PARAMETER ERROR	Bit 1 is cleared if previous command did not contain a parameter error. It is set if there was a parameter error in the previously applied command.
BIT 3	REFERENCE LOW	Bit 3 is cleared if the amplitude of the Reference Input signal is okay. It is set if the amplitude is too low for proper Reference Channel operation.
BIT 4	OVERLOAD	Bit 4 is cleared if no OVERLOAD is detected. It is set if an overload condition is detected.
BIT 5	SETTLED	Bit 5 is cleared when autoranging is started. It 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 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 μs through 100 ms, it is set or updated after 1.2 s (2.4 s with 12 dB per octave).
BIT 6	SRQ	Bit 6 is cleared if service is not being requested. It is set if service is being requested.
BIT 7 (MSB)	OUTPUT READY	Bit 7 is cleared if the Model 5207/8 has no output to dump to the host computer. It is set if the Model 5207/8 does have output to dump to the computer.

Table A-2. SERIAL POLL STATUS BYTE BIT WEIGHTING

NOTE: Understand that it is not *necessary* that the 5207/8 make a service request (assert SRQ) for the computer to do a serial poll. The computer can do a serial poll at any time. The service request is simply one means of initiating a serial poll, one best suited to use in complex systems where the computer is controlling many devices.

A.5 GPIB PINOUT

PIN #	FUNCTION
1	D101
2	D102
3	D103
4	D104
5	EOI
6	DAV
7	NRFD
8	NDAC
9	IFC
10	SRQ
11	ATN
12	SHIELD
13	D105
14	D106
15	D107
16	D108
17	REN
18	GND 6
19	GND 7
20	GND 8
21	GND 9
22	GND 10
23	GND 11
24	LOGIC GROUND

Table A-3. GPIB PINOUT

A.6 TROUBLESHOOTING GPIB COMMUNICATIONS PROBLEMS

(1) Check the GPIB Address.

(2) Check the Controller's Timeout function. Many controllers (early PET's, HP, etc.) will only wait a short time for an instrument to respond on the bus. However, some 5207/8 commands could take some time to execute.

(3) Check that each command executes fully before sending another one. Some commands take time to execute and must not be interrupted while in execution. Characters received while another command is executing will cause an Error 4 (command overrun). As discussed in A.4, the OUTPUT READY and COMMAND COMPLETE bits of the Serial Poll Status byte provide a convenient means for maintaining orderly, efficient communications between the 5207/8 and the host computer.

(4) Check the output format of the host computer. Sometimes extra characters may be added to the command being sent. For instance, the default output format for sending a single string from the HP 85 pads the string with blanks until it is twenty characters long. The 5207/8 can normally ignore extra blanks, but the HP puts out too many. The solution here is to use the HP 85's PRINT USING "K" statement, which causes the HP 85 to print only the command.

(5) Check the terminator options on both the controller and the 5207/8. The terminator selected at the 5207/8 *must* be that of the host computer.

A.7 GPIB (IEEE 488, 1978), AN OVERVIEW

INTRODUCTION

It is not necessary to understand the material in the following paragraphs to use the GPIB interface. This information is provided for background only. You may find it helpful in the sense that any background information gives insights useful in problem solving.

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 a device (Model 5207/8) 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 5207/8 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 bidirectional and carry both data and commands. 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 DAV (data valid), NRFD (not ready for data), and NDAC (no data accepted). The following sequence occurs each time a data word or command is transferred. Figure A-1 illustrates a data transfer.

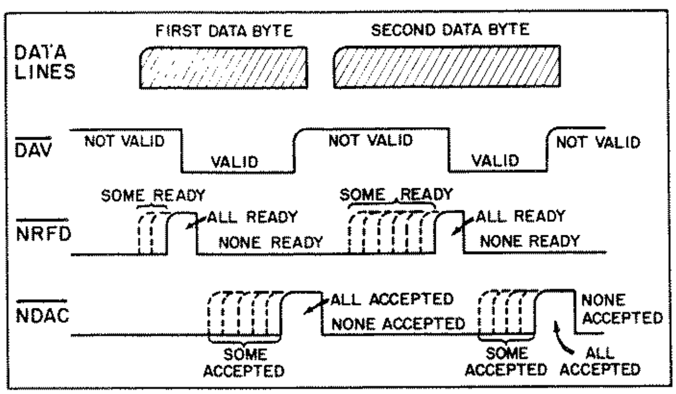


Figure A-1. GPIB DATA TRANSFER

(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 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, NRFD will be low. Once all active listeners are ready, NRFD goes high, initiating the transfer.

(3) On sensing that NRFD has gone high, the talker is free to put data on the bus and pull DAV down. If the data is already on the bus (it may have been there for some time), 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 2 μs later, DAV is pulled down, signaling the active listeners that they can read the data byte.

(4) On sensing that 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 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 NDAC line. It is held low during the quiescent state and while the data is being accepted. The active talker monitors the 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 NDAC, the talker releases DAV, allowing it to return to the high state. The listeners sense this and respond by again pulling down on 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) ATN (Attention): This is a critically important line. When asserted (low), it causes the active talker to relinquish control of the DAV line. The controller takes the place of the active talker, and both talkers and listeners alike accept the specific control information transmitted when ATN is asserted.

Some of the codes transmitted when ATN is asserted will have different but equally valid meanings if transmitted when ATN isn't asserted. The commands that can be transmitted when ATN is asserted, Remote Message Commands, are defined by the standard. ATN is also asserted when transmitting an address. A device becomes an active talker when its talk address is placed on the bus. It becomes an active listener when its listen address is placed on the bus. Commands transmitted when ATN is not asserted are device dependent.

A given device connected to the bus needn't understand all of the standard commands. Individual device manufacturers can select the commands their device will recognize. Should the others appear on the bus, they will simply be ignored.

(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 not used, but is reserved for system initialization or 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 enable transfer of devices on the bus from local to remote control. The device does not actually go from the local control to remote control until it is addressed to listen while $\overline{REN}$ is asserted.

(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. This is referred to as the END message. Second, it can be used as part of the parallel polling process described in the following paragraph. **NOTE:** The 5207/8 does *NOT* support parallel polling.

(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 tell the controller it's 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, the SERIAL POLL ENABLE message is transmitted by the controller to put all devices into the serial-poll mode. Then, 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 message to return the device to the data mode. Assuming the devices on the bus support serial polling, 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. THE 5207/8 DOES NOT SUPPORT PARALLEL POLLING.

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 at the device. When the controller wishes to communicate with a specific device on the bus, it places the listen address of the device on the bus. Only the device having the corresponding address will respond to the subsequent message. Similarly, if the controller wants a device to talk, it sends the talk address of the device in question. The addressed device only will transmit until a different talker is designated.

SUMMARY

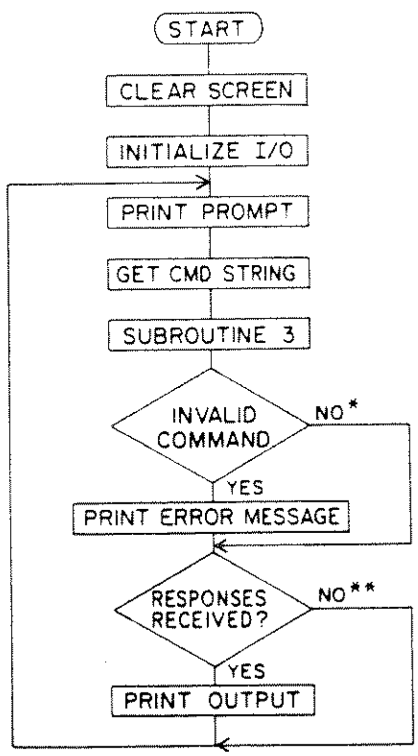
The preceding discussion of how the GPIB functions is by no means complete. A great deal of additional detail has to be considered by device designers. The principal responsibility of the user is to provide the controller program that coordinates all the bus activity necessary to accomplish the task 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 St.
New York, New York 10017

APPENDIX B
ROUTINES AND FLOWCHARTS

B.1 SIMPLE STATIC INTERFACE ROUTINE

This program provides the software necessary to control the 5207/8 from a host computer via the GPIB port. The routine follows the program flow illustrated in Figure B-1. It has been coded for several different computers. The code listing are provided in B.4. The utility of the routine is that it facilitates controlling the 5207/8 from the host computer's keyboard. Every command and function can be checked and studied in a controlled, methodical manner. Actual measurements would most probably be entirely controlled by appropriate complex programs running on the host computer and not by typing individual commands at the computer's keyboard using the simple static interface routine. Nevertheless, the static routine can be used to achieve system familiarity, and variations of the routine can be readily incorporated into complex control programs with good effect.



* BIT 1 OF SERIAL POLL STATUS BYTE IS "Ø"
** WAS DATA RECEIVED FROM 5207/8 WITHIN SUBROUTINE 2 ?

Figure B-1. SIMPLE STATIC INTERFACE ROUTINE

Note that the routine illustrated in Figure B-1 reads the Serial Poll Status Byte to maintain orderly data/command flow. As indicated, Bit Ø tells the computer whether execution of the previously transmitted command was complete, Bit 1 tells the computer whether the command is valid, and Bit 7 tells the computer whether the 5207/8 has output ready to send. As shown in the figure, the routine 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 the 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 5207/8 software control. These include sending commands, receiving responses, and checking the instrument's SERIAL POLL status register.

B.2 THE DEVICE DRIVER SUBROUTINES

Programmers are advised to use these subroutines (Figure B-2) 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 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. Note that Subroutine 3 is incorporated into the Static Interface Routine (Figure B-1). In these subroutines, responses from the 5207/8 are read on a number-by-number basis, using the OUTPUT READY bit to determine when all response have been read. To take output from the 5207/8 on a byte-by-byte basis, use the END message ($\overline{EOI}$ asserted with the last byte of data) to determine when all responses have been read, instead of the OUTPUT READY bit.

B.3 USER'S ROUTINES

The factory's engineers seek additional implementations of the Simple Static Interface Routine for other computers. Anyone willing to share an implementation is encouraged to get in touch with the factory.

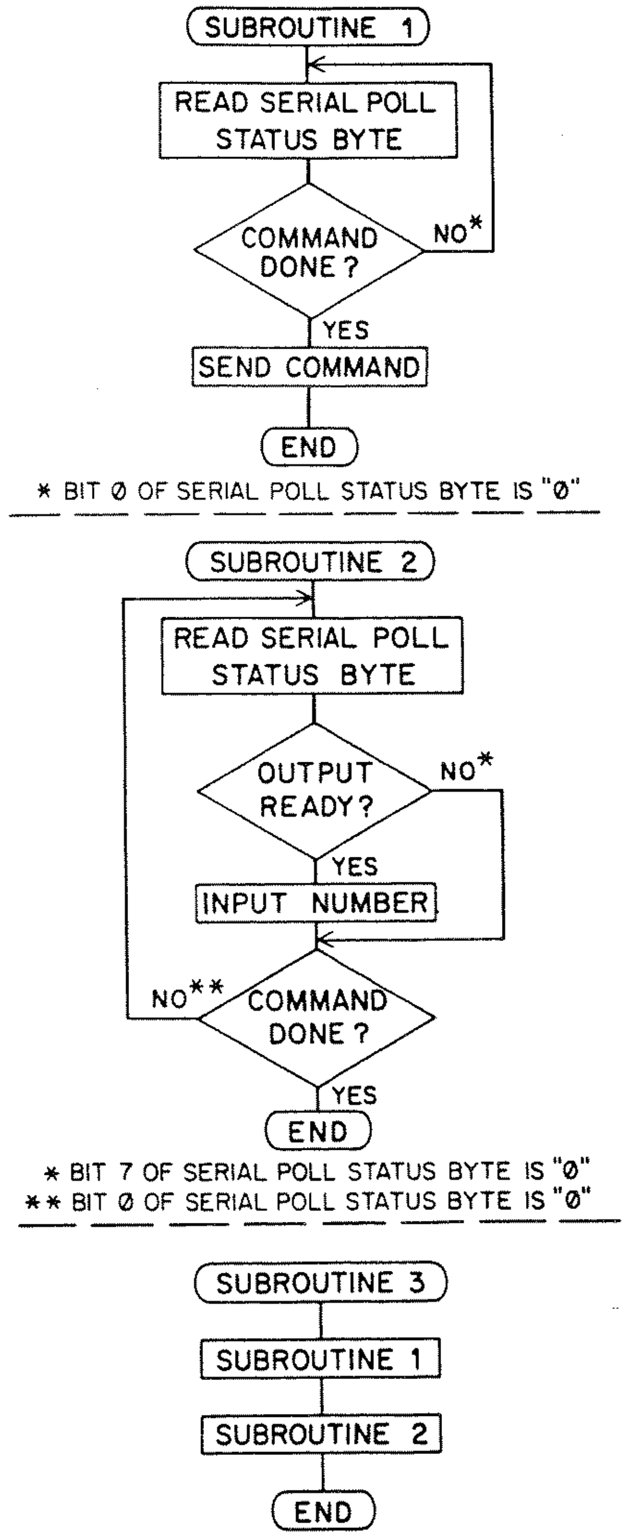


Figure B-2. DEVICE DRIVER SUBROUTINE FLOW CHART

```
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$="DD 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 N=0 THEN 290
260 FOR I=1 TO N
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 ! GET RESPONSES
1110 N=0
1120 GOSUB 1400 ! CHECK CMD DONE AND OUTPUT READY BITS
1130 IF BIT (S9,7)=0 THEN 1150
1140 N=N+1 @ ENTER A9;A(N)
1150 IF BIT (S9,0)=0 THEN 1120
1160 RETURN

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

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

```
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: cmd 7,CHAR (24);rdb(A) -> S
46: cmd 7, char(95)&char(25)
47: ret
```

```
10 ! HP9826, 9816, OR 9836 SIMPLE STATIC INTERFACE
11 PRINT CHR$(12)
20 DIM A(4096)

100 INPUT "ENTER DEVICE GPIB ADDRESS: ",A9
110 A9=A9+700
120 CLEAR A9
130 PRINT CHR$(12)
140 PRINT "DEVICE MUST BE SET FOR CR/LF TERMINATOR."
150 PRINT " "
160 C$="DD 10"
170 GOSUB 1000

200 ! MAIN LOOP
210 LINPUT "ENTER COMMAND: ",C$
211 PRINT "ENTER COMMAND: ";C$
220 GOSUB 1200 ! SEND COMMAND AND GET RESPONSES IF ANY
230 IF BIT (S9,1)=0 THEN 250
240 PRINT "COMMAND ERROR";CHR$(7)
250 ! PRINT RESPONSES
260 IF N=0 THEN 291
270 FOR I=1 to N
280 PRINT "RESPONSE #";I;" = ";A(I)
290 NEXT I
291 PRINT CHR$(10)
300 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;C$
1040 RETURN

1100 ! GET RESPONSES
1101 N=0
1120 GOSUB 1400 ! CHECK CMD DONE AND OUTPUT READY BITS
1130 IF BIT (S9,7)=0 THEN 1160
1140 N=N+1
1150 ENTER A9;A(N)
1160 IF BIT (S9,0)=0 THEN 1120
1170 RETURN

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

1400 ! DO A SERIAL POLL (A9)
1410 S9=SPOLL(A9)
1420 RETURN
1430 END
```

```
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$="DD 10" ! FOR 5205/6 ONLY, LINE 150 C$="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 N=0 THEN 300
260 FOR I=1 TO N
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 N=0
1120 GOSUB 1400 ! CHECK CMD DONE AND OUTPUT READY BITS
1130 IF ((S9 DIV 128) MOD 2) = 0 THEN 1150
1140 N=N+1
1145 ENTER A9;A(N)
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 SENDBUS 7;95,24,64+A9 ! UNTALK,SPE,TALK
1420 S9=READBIN(A9)
1430 SENDBUS 7;95,25 ! UNTALK,SPD
1440 RETURN
```

APPENDIX C
RS232C INTERFACE

C.1 INTRODUCTION

RS232C is an industry standard *serial* data communications interface. It is widely used for communications between digital devices such as computers, terminals, printers, and telephone links. RS232C is capable of bidirectional data transfer between digital devices.

Both devices must be equipped with an RS232C interface for data transfer. Virtually every modern computer has RS232C capability as standard or optional equipment. RS232C interfacing specifies data transfer as a stream of serial characters. Usually ASCII (American Standard Code for Information Interchange) coding, which defines each character as a specific set of seven bits, is used. For example, the character sequence "−0.200V" is seven characters long. The RS232C circuit translates each of the seven characters into the proper bit sequence and transmits each character sequentially to the receiving device.

The RS232C Standard specifies many parameters, such as voltage (logic) levels, transfer rates, etc. for data transfer. However, some parameters have optional values that are user-selectable. *The user must be aware of these parameters, since all parameters must be the same on both devices for proper communication.*

The user-selectable RS232C parameters are baud rate, word length, parity, and stop-bit configuration. These four parameters must be selected to be exactly the same on both devices. Some of the parameters may be fixed by one of the devices, in which case the other device must be configured to match the fixed parameters.

If the devices are transferring data back and forth, some method of determining the readiness of the receiving device is needed, especially for rapid data transfer. "Handshaking" is a term used to describe this function. As explained in Subsection C.4, a more detailed general discussion of RS232C, the RS232C handshake system was designed for a specific limited application, and is not well suited to general interface use. As a result, RS232C communications are particularly prone to handshake problems.

C.2 RS232C AS IMPLEMENTED IN THE 5207/8

C.2A INTRODUCTION

A key difference between GPIB and RS232C communications as implemented in the 5207/8 has to do with the concept of LOCAL versus REMOTE, that is, control via a front panel or by remote messages applied to an Interface port, neither of which can be simultaneously active. LOCAL versus REMOTE operation is a GPIB concept only and does not apply to the RS232C port. The RS232C port is always active. In principle, if GPIB control line $\overline{REN}$ is asserted, one could use both the GPIB and RS232C ports simultaneously (not recommended). There is no logic in the Model 5207/8 to arbitrate between RS232C and GPIB communications.

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, all discussed in the following paragraphs.

C.2B RS232C USER-SETTABLE PARAMETERS

INTRODUCTION

The RS232C Parameters are set from the front panel. Function 3, invoked by pressing LOCAL and REFERENCE, is used to set the baud rate. Function 4, invoked by pressing LOCAL and PHASE, is used to set the other RS232C parameters. Note that these are double-key functions; each is invoked by pressing LOCAL and, while it is held in, pressing either REFERENCE or PHASE, according to the desired function. When any one of these special functions are invoked, F# is displayed for about one second and then the parameter value is displayed. At the same time, all of the other LED's on the panel extinguish to indicate that the 5207/8 is not in a normal mode of operation. The parameter value is incremented or decremented using the UP-ARROW (↑) and DOWN-ARROW (↓) keys respectively. Each time a new value is set, it is immediately adopted and an asterisk is transmitted to the RS232C port. Another special function may be invoked via the appropriate double-key sequence. Normal lock-in operation can be re- established by pressing any key other than UP-ARROW (↑), DOWN-ARROW (↓), or LOCAL. A detailed description of how Functions 3 and 4 are used follows.

FUNCTION 3 (BAUD RATE)

This function allows the RS232C baud rate to be directly set to any of the following values. When setting the baud rate, either the "Hz" or "kHz" LED will be lighted as appropriate for the selected rate. The default selection is 9600 baud.

BAUD RATES

110	2400
300	4800
600	9600
1200	19200

FUNCTION 4 (OTHER RS232C PARAMETERS)

The displayed parameter value is the decimal equivalent of a five-bit binary number in which each bit controls a different parameter. The range for the parameter is 0 to 31. The coding for each bit is as follows.

BIT		MEANING
0	0 = ODD PARITY;	1 = EVEN PARITY
1	0 = ONE STOP BIT;	1 = TWO STOP BITS
2	0 = SEVEN DATA BITS;	1 = EIGHT DATA BITS
3	0 = ECHO OFF	1 = ECHO ON
4	0 = XON/XOFF PROTOCOL;	1 = CLEAR TO SEND PROTOCOL

The default value for the parameter is "9" (EVEN PARITY, ONE STOP BIT, SEVEN DATA BITS, ECHO ON, and XON/OFF PROTOCOL).

Note the following:

(1) If seven-bit data is selected, parity is automatically enabled.

(2) If eight-bit data is selected, parity is automatially disabled.

(3) If XON/XOFF protocol is selected, asserting the CLEAR TO SEND input will *NOT* halt transmission.

(4) If CLEAR-TO-SEND protocol is selected, XON/XOFF protocol should not be attempted. *IT WILL NOT WORK PROPERLY.*

(5) If CLEAR-TO-SEND protocol is selected and CLEAR-TO-SEND is asserted, one or two more characters may be sent before transmission is halted.

The various RS232C parameters are discussed in more detail in the following paragraphs.

PARITY

The user cannot directly select PARITY ON or PARITY OFF. If seven-bit data is selected, the PARITY is always ON. If eight-bit data is selected, it is always OFF. If ON, there is a choice of ODD or EVEN parity. 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 "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 5207/8 generates the parity bit, if selected, it does not itself detect the incoming parity information.

STOP BITS

Either one or two stop bits can be selected. Two stop bits gives more reliable communications at high baud rates.

CHARACTER LENGTH

A character length of either seven bits or eight bits can be selected. Most communications are in ASCII, a seven-bit code. If "8" is selected, the 5207/8 will always send a "0" as the eighth (MSB) bit when transmitting ASCII codes.

ECHO

Gives the user the choice of echo or no-echo operation. If echo is selected, each character received via the RS232C port will be echoed back to the character source. The RS232C echo is normally used only when the 5207/8 is connected to a CRT terminal. **NOTE:** Do not confuse this function with the GPIB TEST ECHO described in Appendix A.

TRANSMISSION CONTROL (PROTOCOL)

The user has the choice of CLEAR-TO-SEND or XON/XOFF control of RS232C data tranmission from the 5207/8 to the host computer. If CLEAR-TO-SEND is selected, this line must be asserted before the 5207/8 will transmit. (If CTS is left unconnected, it will float to the "asserted" state.) If the line is deasserted when data transmission is underway, it will halt the transmission after another one or two characters. The host computer's software must expect these characters.

If XON/XOFF control is selected, the "characters" XOFF (CONTROL S; ASCII decimal 19) and XON (CONTROL Q; ASCII decimal 17) are used to control RS232C data transmission. XOFF will prevent RS232C (only) transmissions. If applied during a transmission, the transmission will halt. However, the host computer must be ready to accept a couple more characters after it transmits XOFF. XOFF does not prevent characters from being echoed if the ECHO mode is ON. Transmission resumes when XON (CONTROL Q) is applied.

C.2C WORD CONSTRUCTION

Between transmissions, the transmit data line rests at the low voltage level. Each transmission begins with a START bit, the leading edge of which is marked by the transmit line going to the positive voltage 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 for ASCII characters.

Negative true logic is used for data. A logic 1 is represented by a negative voltage between −3 V

and −25 V. A logic 0 is represented by a positive voltage in the range of +3 V to +25 V. **NOTE:** The specific devices used to implement RS232C communication in the 5207/8 are rated at ±12 V max. Do not exceed these levels.

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. The ASCII codes are listed in Appendix E.

The parity bit is followed by either one or two STOP bits, as selected. The STOP bits are at the negative voltage level. returning the line to the quiescent state. If the parity function is OFF (eight-bit data), 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.

C.2D PROMPTS AND COMMAND OVERRUNS

In RS232C communications, command overruns (sending a command while the 5207/8 is still busy executing the previous command) are prevented by using the prompt function provided. Assuming all RS232C parameters have been set properly, the host computer will receive a prompt character from the 5207/8 when it is ready for a new command. If the previously executed command generated no errors in the 5207/8 (Invalid Command, etc.), the prompt character will be an asterisk (*). If the previously executed command did generate an error in the 5207/8, the prompt is a question mark (?). The prompt is transmitted after power up and after completion of any command. By waiting for the prompt character, Command Overrun Errors will be avoided.

C.2E TERMINATOR

When two RS232C compatible devices are communicating, their protocol requirements may well be such as to require no special terminator considerations. More frequently, however, one device or the other will have specific terminator requirements that will have to be observed for proper operation.

If the 5207/8 is communicating with an external computer via the RS232C port, the choice of terminator is critical. The terminator is the character that marks the end of each transmission from the Model 5207/8 to the external computer or from the external computer to the Model 5207/8. The terminator MUST BE SELECTED ACCORDING TO THE REQUIREMENTS OF THE HOST COMPUTER. Failure to satisfy this requirement is one of the most common causes of problems in establishing communications with an external computer via the RS232C port. NOTE THAT THE TERMINATOR SELECTION IS DONE WITH FUNCTION 2 AS DESCRIBED IN APPENDIX A. Either a Carriage Return <CR> or a Carriage Return followed by a Line Feed <CRLF> can be selected.

C.2F CABLE AND PINOUT

No serial interface cable is supplied with the 5207/8. Suitable cables and connectors are readily available from commercial sources. The RS232C pinout follows.

PIN	FUNCTION	COMMENT
1	Earth Ground	Ties the chassis of the 5207/8 to that of the Computer.
2	Transmit Data	The 5207/8 transmits on this line. It must connect to the computer connector pin that receives serial data.
3	Receive Data	The 5207/8 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 5207/8, that is, it is always at a positive logic level (+10 V). As a result, the computer continuously receives the message that the Model 5207/8 is ready to receive a character.
5	Clear to Send	The computer controls the 5207/8 via this line. To enable the 5207/8 to transmit, the line is placed at the positive logic level (+3 V to +12 V). To hold off transmission by the 5207/8, the line must be at the negative logic level (−3 V to −12 V). Once this line goes positive, data transfer, if initiated by an appropriate command, will proceed rapidly. This line is pulled up to +12 volts so that, if it is left unconnected, the 5207/8 is allowed unimpeded transmission.
6		Unused
7	Logic Ground	Data signal levels should be with reference to logic ground. The logic ground line of the 5207/8 should interconnect with the logic ground line of the computer.
8 to 25		Unused

C.2G RS232C SUMMARY

The preceding paragraphs contain all the information a user needs to know about the Serial Interface *per se*. To actually use the interface to control the 5207/8, the user will additionally have to understand and implement the appropriate user commands applied according to the requirements of the 5207/8 Interface Communications Protocol. The protocol is discussed in Appendix D. The device-dependent commands recognized by the 5207/8 are discussed in Section VI of this manual.

C.3 TROUBLESHOOTING RS232C COMMUNICATIONS PROBLEMS

(1) Check the wiring of the RS232 connector.

The Transmit Data line of one device must be connected to the Receive Data line of the other.

The Clear to Send Input line of each device must be connected to the other's Request to Send or to a voltage in the range of +5 V to +12 V. The Model 5207/8's Clear to Send is internally pulled up to +12 V and so may be left unconnected.

(2) Check that the following settings agree on both the 5207/8 and host computer.

BAUD rate.
Number of Character Bits in the Serial Data Word.
Logic state of the eighth character bit, if selected.
Parity Settings.
Number of Stop Bits.

(3) Check that the host and 5207/8 agree on the terminator character, either <CR> or <CRLF>. The terminator set at the 5207/8 should be that of the host computer.

(4) Avoid command overruns; make the host wait for the RS232C prompt character before sending a new command.

(5) Check that there are no timing problems. Two different timing problems are commonly encountered when RS232C is used to interface a host computer to a device. Both are associated with responses from the device to the host.

First, when the host sends a command to the device, the host must be ready to accept the response from the device before the device sends the first character of the response. There are three methods for solving this problem. The host's program can be written to have a fast turnaround from the portion that sends the command to the portion that receives the response. This is not always possible with a slow, high-level language. It may work at low baud rates, but it is not a guaranteed solution. Alternatively, the host can use its Request to Send line to inhibit the device's Clear to Send line until the host is ready to receive the device's output. Finally, the host can be programmed to accept the device's output stream under interrupt control. This is a reliable method but it requires intimate knowledge of the host computer's hardware and assembly language.

Second, once the device's output stream starts, the host must be able to accept characters as fast as the device can send them. This can be assured by selecting a very low baud rate. In order to allow data transfer at high baud rates, it may be necessary to code the host's input routine in assembly language. Whether in high level or assembly language, the host's program should accept the entire output stream of the device in a tight loop.

It is advisable to start out at a very low baud rate such as 300 baud. Once the host's program is seen to be working, the baud rate can be raised as high as the host's software will allow. The data stream can be cut off by making the Clear-to-Send line negative or by applying X-OFF (CONTROL S), as selected by Function 4. If this is done, the Model 5207/8 will finish transmitting the character being processed at that instant, and possibly one more besides. Data transmission can be resumed by setting Clear to Send positive or by sending X-ON. As long as the computer's software anticipates that one or two more characters will be forthcoming, this is a perfectly legitimate means of controlling the data flow with a Model 5207/8. However, since this is definitely *NOT* in accordance with the RS232C Standard, users should not infer that RS232C communications with other devices can be controlled in this way.

(6) In the case of intractable problems, it might prove helpful to monitor the controller's output line with an oscilloscope. One effective approach to doing this is to program the controller to transmit the letter "U" (alternate 1's and 0's) in a repeating loop. If the scope is adjusted to trigger about ground on a positive transition and the X axis display is calibrated so that the time per division equals one bit period, the serial data can be easily examined and decoded. Any RS232C parameter discrepancies can then be determined and corrected. The output of the 5207/8 can be similarly checked by turning the RS232C Echo on and observing the 5207/8 echo the "U" from the host computer.

A logic bus analyzer, such as those manufactured by Hewlett Packard, Tektronix, or Interface Technology, may also prove useful.

One final note. If you find it necessary to change from the default settings of the computer to make it work with the 5207/8, be sure to bypass the computer's I/O re-initialization routines. They may restore the default values and so cause messages to be garbled.

C.4 HISTORY AND PROBLEMS OF RS232C

The remainder of this appendix consists of general discussion of the history and problems of RS232C. An understanding of this material is in no way essential to using the RS232C Interface. It is simply provided as a source of additional background for those who may be interested.

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 wide-

spread reliable electronic data communications via serial coding. With the development of computers, 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. 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 requirements for communications between a DTE (Data Terminal Equipment), typically a computer or a video terminal, and a DCE (Data Communications Equipment), a modem. 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. are frequently provided with "RS232C-compatible" serial data links. 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 frequently 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. Data received from the modem must 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 problem. 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 state 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. **NOTE:** As stated in C.3, RS232C data flow from the 5207/8 can be cut off by bringing Clear-to-Send to its negative state, or by applying X-OFF (CONTROL S). The 5207/8 will finish sending the character being processed, and possibly one more as well. If the host computer's software is prepared to handle these one or two additional characters, this is a perfectly legitimate way of controlling the data flow. Bear in mind, however, that controlling in this manner is not in accordance with the standard, and may not work for other RS232C compatible devices.

Another potential problem has its origin in the RS232C voltage levels. Because TTL is so ubiquitous in modern electronic designs, it is all too easy to assume that TTL devices and levels apply everywhere. However, RS232C was around long before TTL, and 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, designers cannot use TTL devices in implementing RS232C communications. **NOTE:** The particular devices used to implement RS232C communications in the 5207/8 cannot withstand voltages higher than ±12 V. BE CAREFUL.

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 lines idle at the negative logic level. As shown in Figure C-1, each transmission begins with a start bit, the leading edge of which is defined by the data line going positive (logic Ø). 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. RS232C allows 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 to mark the beginning of the subsequent communication. Most RS232C-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 expected.

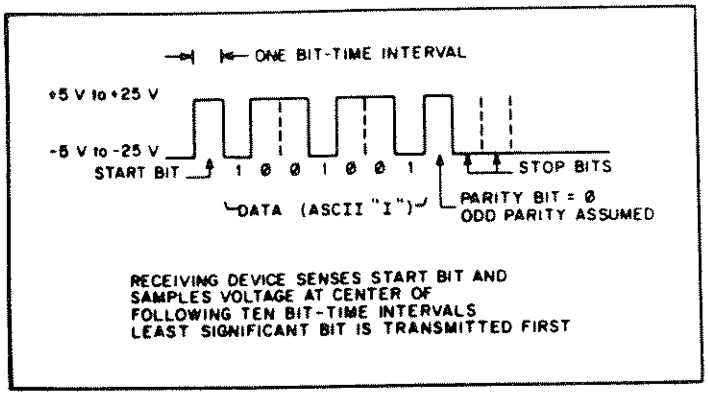


Figure C-1. TYPICAL RS232C DATA WORD

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 the standard from:

Electronic Industries Association
Engineering Department
2ØØ1 I Street, N.W.
Washington, DC

APPENDIX D
PROTOCOL AND INTERFACING

D.1 INTRODUCTION

This Appendix discusses the 5207/8 communications protocol together with considerations germane to establishing successful communications. Unless otherwise indicated, this information applies equally to both GPIB and RS232C communications.

D.2 COMMUNICATIONS PROTOCOL

INTRODUCTION

A transmission to the Model 5207/8 consists of a command followed by a space, a number or numbers 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 either initiates an action or is interpreted as a request to read the associated setting or status.

Each command consists of one or more uppercase letters. The letters are used to delineate the command and suggest the associated function. Where necessary, the letters are followed by one or more decimal numbers to complete the command. In the case of ON/OFF functions, "1" is used to denote ON and "0" to denote OFF.

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. With the exception of the minus sign and period, the Model 5207/8 will recognize any non-numeric printing character as a delimiter (use of comma or space as delimiter in transmissions from the host computer is recommended). This delimiter recognition is entirely independent of the DD command. The Model 5207/8 sends a comma as the delimiter unless the DD command is used to specify some other character. (**NOTE:** Most BASIC's, including APPLESOFT, will not accept the comma as a delimiter in input statements.)

Numbers are transmitted as ASCII decimal with the most significant digit transmitted first. No more than five leading blanks are permitted before a command or number sent to the 5207/8.

TERMINATOR

The terminator that follows each command message can be either a CARRIAGE RETURN or a CARRIAGE RETURN followed by a LINE FEED, as selected by Function 2 and explained in Appendix A. In communications with a computer, THE TERMINATOR MUST BE SET ACCORDING TO THE REQUIREMENTS OF THE HOST COMPUTER. If the computer is expecting a line feed and <CR> has been selected, the system will "hang" as the computer waits forever for the missing line feed. If the computer expects <CR> and <CRLF> is selected, the computer will respond to the carriage return in the <CRLF> sequence all right, but then will make the line feed the first character of the next command, probably with unexpected and undesired results.

COMPOUND COMMANDS

Several commands can be sent on one line by separating them with a semicolon. For example, the sequence:

S 9 <CR>
T 0,1 <CR>
X 0 <CR>
D 0 <CR>

could be transmitted as a single compound command with the sequence:

S 9;T 0,1;X 0;D 0 <CR>

However, if an error is detected at any point in the line, the rest of the command will be ignored. The size of the 5207/8's input buffer is 80 characters. Commands longer than 80 characters will be truncated at 80 characters. Similarly, the size of the 5207/8's output buffer is also 80 characters. Any compound command that generates more than 80 characters of output will cause data to be lost.

CONTROL CHARACTERS

Table D-1 lists the Control Characters to which the 5207/8 responds and describes the instrument's response. All other control characters are ignored. Control characters such as CONTROL R and CONTROL B must be sent by the host computer as single bytes without any terminator. The $\overline{\text{EOI}}$ line on the GPIB may be in either state when Control Characters are sent.

COMMUNICATIONS CONTROL

Commands cannot be transmitted to the 5207/8 while it is busy executing a previous command. Should a command be sent when the 5207/8 is busy, it will be ignored and a Command Overrun error will be generated. In GPIB communications, the Serial Poll function can be used to maintain orderly bus control. The Output Ready and Command Complete bits of the Serial Poll Status Byte are provided for this purpose. In RS232C communications, the 5207/8 sends a prompt to the host computer at powerup and after executing each command. This prompt can be used by the

host computer to prevent command overruns. Use of the Serial Poll Status Byte to control GPIB communications is discussed in Appendix A. Use of the RS232C prompt is discussed in Appendix C.

MODEL 5207/8 FRONT-PANEL INTERFACE INDICATORS

There are four LED interface indicators and a LOCAL key on the front panel of the Model 5207/8. The indicators give the interface status. The LOCAL key facilitates transfer from REMOTE to LOCAL (front-panel) operation. A more detailed discussion of each follows.

(1) TALK: This indicator lights when the 5207/8 has output ready to be sent to the host computer. It goes out when the 5207/8 has finished sending this output. The TALK indicator does NOT signal that the host computer has transmitted a TALK message. Rather it indicates that the Model 5207/8 has more output to dump before the command is completed.

(2) LISTEN: This indicator lights when the 5207/8 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 5207/8 is expecting more input before the current command is fully defined.

ASCII CODE	NAME	ACTION
13	<CR>	Starts interpretation of the command if <CR> has been selected as the terminator.
10	<LF>	Starts interpretation of the command if <CRLF> has been selected as the terminator. If <CRLF> has not been selected, the Model 5207/8 reconfigures itself to accept <CRLF> and interpretation of the command begins anyway.
3	CONTROL C	RESTART: Action is the same as for power-up restart.
2	CONTROL B	ABORT: Terminates the execution of a multiple command on completion of the individual command currently being carried out. Also terminates any command in its output phase.
18	CONTROL R	REPEAT: Causes execution of the previous command to be repeated.
19	CONTROL S	X-OFF: Prevents instrument from transmitting via the RS232C port (only). The host computer must be ready to accept a couple of characters after it transmits X-OFF. Does not prevent characters from being echoed if the ECHO mode is ON. Transmission resumes when X-ON (CONTROL Q) is applied.
17	CONTROL Q	X-ON: Once RS232C transmission has been halted by X-OFF, transmission can be resumed by applying CONTROL Q (X-ON).

Table D-1. CONTROL CHARACTERS RECOGNIZED BY 5207/8

(3) SRQ: This indicator lights when an event occurs that causes the 5207/8 to assert SRQ (make a service request). It remains lighted until the controller (host computer) has completed a serial poll of the 5207/8.

(4) REMOTE: This indicator lights when REMOTE operation has been established (REN asserted and LISTEN address applied). It remains lighted until LOCAL (front panel) control is restored. LOCAL can be restored by cycling the power, deasserting REN, pressing the LOCAL pushbutton (providing LLO message has not been applied), or applying the GTL message.

(5) LOCAL KEY: This key transfers the 5207/8 from REMOTE to LOCAL control if the LLO (LOCAL LOCKOUT) message has not been applied. It is effective even if REN is asserted. However, if REN continues to be asserted, the 5207/8 will return to REMOTE control if the unit's LISTEN address is applied.

NOTE: LOCAL versus REMOTE is a GPIB consideration only. The RS232C port is always active.

D.3 INTERFACING TO A HOST COMPUTER

INTRODUCTION

Successful interfacing between the 5207/8 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 much of this uncertainty.

A suggested approach to establishing successful communications follows.

(1A) GPIB INTERFACE:

(a) MODEL 5207/8 ONLY: Assert the REN line on the GPIB and send the 5207/8 LISTEN Address. The front-panel REMOTE indicator should light. If it doesn't, either the address is wrong or there is a problem with the 5207/8, computer, or interconnecting cable.

(b) Execute a GPIB Serial Poll of the 5207/8 from the host computer and see if the expected response is sent. A serial poll is the simplest possible data transfer and does not involve the 5207/8's microprocessor. If the serial poll status byte can be read successfully, it indicates that the 5207/8's GPIB address is configured properly and that the 5207/8 is able to transmit and receive bytes.

(1B) RS232C INTERFACE:

Determine whether the computer receives the RS232 prompt (asterisk) when the 5207/8 is first turned on. Assuming the baud rate, number of stop bits, and parity-bit configuration of the 5207/8 and the host computer are compatible, the 5207/8 will transmit a prompt when it is ready to receive a command. The prompt is transmitted after power-up, and after completion of any command. The prompt is provided to facilitate orderly data and command flow when controlling the system via an RS232C Interface. The prompt is normally an asterisk. If the command generates an error condition, the prompt is a question mark.

(2) Send the instrument a simple command that requires a number response. The ID command, for example, should cause the 5207/8 to respond with either "5207" or "5208", whichever applies. This test demonstrates whether bi-directional data transfer is possible.

If this step is successful, it confirms that the terminator character has been properly specified. 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.

(3) At this point it is often useful to know whether the host computer can receive a response consisting of more than one number. The O command, for example, should cause two numbers to be returned.

If the interface passes the test in (2) but fails the test in (3), it is possible that the host computer will not accept the comma as a delimiter between numbers (some BASIC's will not accept comma delimiter on input statements). This delimiter can be changed to an acceptable character, such as a space, with the DD command.

(4) 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. The Simple Static Interface and Device Driver Routines discussed in Appendix B can frequently be used to good advantage in establishing communications. Implementations of these routines for several common computers are provided.

It is essential that the host computer only send a command to the 5207/8 when the 5207/8 has finished processing the previous command. In GPIB communications this is done by checking the COMMAND DONE bit of the 5207/8's Serial Poll byte as described in Appendix A. In RS232C communications, it is accomplished by always waiting for the prompt (asterisk) that the 5207/8 transmits when it ready for a command. **NOTE:** If the 5207/8 detects an error condition, the prompt is a question mark.

(5) A useful exercise at this point is to write a simple program that displays and updates the status of the 5207/8. Once this is accomplished, the resulting program structure can be used for reliable sequencing and monitoring of the 5207/8.

(6) 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.

The important point of this hierarchical process of bringing the 5207/8 up on a host computer is that, if a problem occurs at any step, the user can go back to the previous step and figure out what caused the new problem to occur.

D.4 DEFINITIONS

DEVICE	Apparatus (in this case the Model 5207 or Model 5208) 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.

D.5 EXAMPLES

The following examples illustrate some commands and responses. These examples assume that <CR> is an acceptable terminator for the host computer. (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.

APPENDIX E
ASCII CHARACTER CODES

BINARY	DECIMAL	HEX	CHARACTER	WHAT TO TYPE
0000000	0	00	NULL	CONTROL @
0000001	1	01	SOH	CONTROL A
0000010	2	02	STX	CONTROL B
0000011	3	03	ETX	CONTROL C
0000100	4	04	ET	CONTROL D
0000101	5	05	ENQ	CONTROL E
0000110	6	06	ACK	CONTROL F
0000111	7	07	BEL	CONTROL G
0001000	8	08	BS	CONTROL H
0001001	9	09	HT	CONTROL I
0001010	10	0A	LF	CONTROL J
0001011	11	0B	VT	CONTROL K
0001100	12	0C	FF	CONTROL L
0001101	13	0D	CR	CONTROL M or RETURN
0001110	14	0E	SO	CONTROL N
0001111	15	0F	SI	CONTROL O
0010000	16	10	DLE	CONTROL P
0010001	17	11	DC1	CONTROL Q
0010010	18	12	DC2	CONTROL R
0010011	19	13	DC3	CONTROL S
0010100	20	14	DC4	CONTROL T
0010101	21	15	NAK	CONTROL U
0010110	22	16	SYN	CONTROL V
0010111	23	17	ETB	CONTROL W
0011000	24	18	CAN	CONTROL X
0011001	25	19	EM	CONTROL Y
0011010	26	1A	SUB	CONTROL Z
0011011	27	1B	ESCAPE	ESC
0011100	28	1C	FS	CONTROL \
0011101	29	1D	GS	CONTROL]
0011110	30	1E	RS	CONTROL ↑
0011111	31	1F	US	CONTROL _
0100000	32	20	SPACE	SPACE
0100001	33	21	!	!
0100010	34	22	"	"
0100011	35	23	#	#
0100100	36	24	$	$
0100101	37	25	%	%
0100110	38	26	&	&
0100111	39	27	'	'
0101000	40	28	(	(
0101001	41	29	)	)
0101010	42	2A	*	*
0101011	43	2B	+	+
0101100	44	2C	,	,
0101101	45	2D	-	-
0101110	46	2E	.	.
0101111	47	2F	/	/
0110000	48	30	0	0
0110001	49	31	1	1
0110010	50	32	2	2
0110011	51	33	3	3
0110100	52	34	4	4
0110101	53	35	5	5
0110110	54	36	6	6
0110111	55	37	7	7
0111000	56	38	8	8
0111001	57	39	9	9
0111010	58	3A	:	:
0111011	59	3B	;	;
0111100	60	3C	<	<
0111101	61	3D	=	=
0111110	62	3E	>	>
0111111	63	3F	?	?
1000000	64	40	@	@
1000001	65	41	A	A
1000010	66	42	B	B
1000011	67	43	C	C
1000100	68	44	D	D
1000101	69	45	E	E
1000110	70	46	F	F
1000111	71	47	G	G
1001000	72	48	H	H
1001001	73	49	I	I
1001010	74	4A	J	J
1001011	75	4B	K	K
1001100	76	4C	L	L
1001101	77	4D	M	M
1001110	78	4E	N	N
1001111	79	4F	O	O
1010000	80	50	P	P
1010001	81	51	Q	Q
1010010	82	52	R	R
1010011	83	53	S	S
1010100	84	54	T	T
1010101	85	55	U	U
1010110	86	56	V	V
1010111	87	57	W	W
1011000	88	58	X	X
1011001	89	59	Y	Y
1011010	90	5A	Z	Z
1011011	91	5B	[	[
1011100	92	5C	\	\
1011101	93	5D	]	]
1011110	94	5E	↑	↑
1011111	95	5F	_	_
1100000	96	60	‘	‘
1100001	97	61	a	a
1100010	98	62	b	b
1100011	99	63	c	c
1100100	100	64	d	d
1100101	101	65	e	e
1100110	102	66	f	f
1100111	103	67	g	g
1101000	104	68	h	h
1101001	105	69	i	i
1101010	106	6A	j	j
1101011	107	6B	k	k
1101100	108	6C	l	l
1101101	109	6D	m	m
1101110	110	6E	n	n
1101111	111	6F	o	o
1110000	112	70	p	p
1110001	113	71	q	q
1110010	114	72	r	r
1110011	115	73	s	s
1110100	116	74	t	t
1110101	117	75	u	u
1110110	118	76	v	v
1110111	119	77	w	w
1111000	120	78	x	x
1111001	121	79	y	y
1111010	122	7A	z	z
1111011	123	7B	{	{
1111100	124	7C	|	|
1111101	125	7D	}	}
1111110	126	7E	~	~
1111111	127	7F	RUBOUT	

CONTROL CHARACTER
ALTERNATE CODE NAMES

CHAR-ACTER	MEANING
NUL	NULL, CTRL SHIFT P, TAPE LEADER
SOH	START OF HEADER, SOM
STX	START OF TEXT, EOA
ETX	ENX OF TEXT, EOM
EOT	END OF TRANSMISSION, END
ENQ	ENQUIRY, WRU, WHO ARE YOU
ACK	ACKNOWLEDGE, RU, ARE YOU
BEL	BELL
BS	BACKSPACE, FE0
HT	HORIZONTAL TAB, TAB
LF	LINE FEED, NEW LINE, NL
VT	VERTICAL TAB, VTAB
FF	FORM FEED, FORM, PAGE
CR	CARRIAGE RETURN, EOL
SO	SHIFT OUT, RED SHIFT
SI	SHIFT IN, BLACK SHIFT
DLE	DATA LINK ESCAPE, DC0
DC1	XON, READER ON
DC2	TAPE, PUNCH ON
DC3	XOFF, READER OFF
DC4	TAPE, PUNCH OFF
NAK	NEGATIVE ACKNOWLEDGE, ERR
SYN	SYNCHRONOUS IDLE, SYNC
ETB	END OF TEXT BUFFER, LEM
CAN	CANCEL, CANCL
EM	END OF MEDIUM
SUB	SUBSTITUTE
ESC	ESCAPE, PREFIX
FS	FILE SEPARATOR
GS	GROUP SEPARATOR
RS	RECORD SEPARATOR
US	UNIT SEPARATOR

APPENDIX F
M5207/8 NUMBER CONVERSION FORMULAE

COMMAND		
S #	T1 = # − [INT(#/3) * 3] + 1 IF T1 = 1 THEN T1 = 5 IF T1 = 3 THEN T1 = 1 V = [10↑ − INT(#/3)] * T1	(TO SENSITIVITY) (IN VOLTS)
	# = INT[ABS(3.0 * LOG(V) − 2.4)]	(TO INTEGER)
O #1,#2	IF #2 = 2 THEN #2 = − 1 O = (#1 * #2) / 10	(TO OFFSET INT) (% FULL SCALE)
	#1 = ABS (O * 10) #2 = 1 IF O < 0 THEN #2 = 2	(TO INTEGER)
J #1,#2	F = #1 * [10↑(2 − #2)]	(TO FREQUENCY IN HERTZ)
	#2 = 5 − INT[LOG(F) + 1)] IF #2 < 0 THEN #2 = 0 #1 = INT[F * 10↑)#2 − 2)]	(TO INTEGER)
P #1,#2	P = (#1 * 90) + .025 * (#2 − 200)	(TO PHASE IN DEGREES)
	#1 = INT(P/90) #2 = (40 * P) − (3600 * #1) + 200	(TO INTEGER)
T #1,#2	T = 10↑[2 − INT(#1/2)] IF #1 < > [INT(#1/2) * 2] THEN T = T * .3	(TO TIME CONSTANT IN SECS)
	#1 = 4 − [2 * INT(LOG(T))] IF LOG(T) < > INT[LOG(T)] THEN #1 = #1 − 1	(TO INTEGER)
	DB = 12 − (6 * #2)	(TO DB/OCTAVE)
	#2 = 1 − INT[(DB/12)]	(TO INTEGER)
G #	G = # / 1638	(TO GAIN FACTOR)
	# = INT(1638 / G)	(TO INTEGER)
Q1	V = (# / 2000) * SENSITIVITY	(CHANNEL 1 = X OR R)
Q2	V = (# / 2000) * SENSITIVITY	(CHANNEL 2 = Y)
Q1	LOGR = # / 20	(CHANNEL 1 = LOGR)
Q2	THETA = # / 10	(CHANNEL 2 = THETA)
Q3	V = # / 2000	(FOR 10 VOLT FULL SCALE) (AUXILIARY INPUT)

NOTES:
and #1 and #2 represent integer parameters for M5207/8 commands.
V represents volts.
T1 is a temporary variable.
Logs are to the base 10.