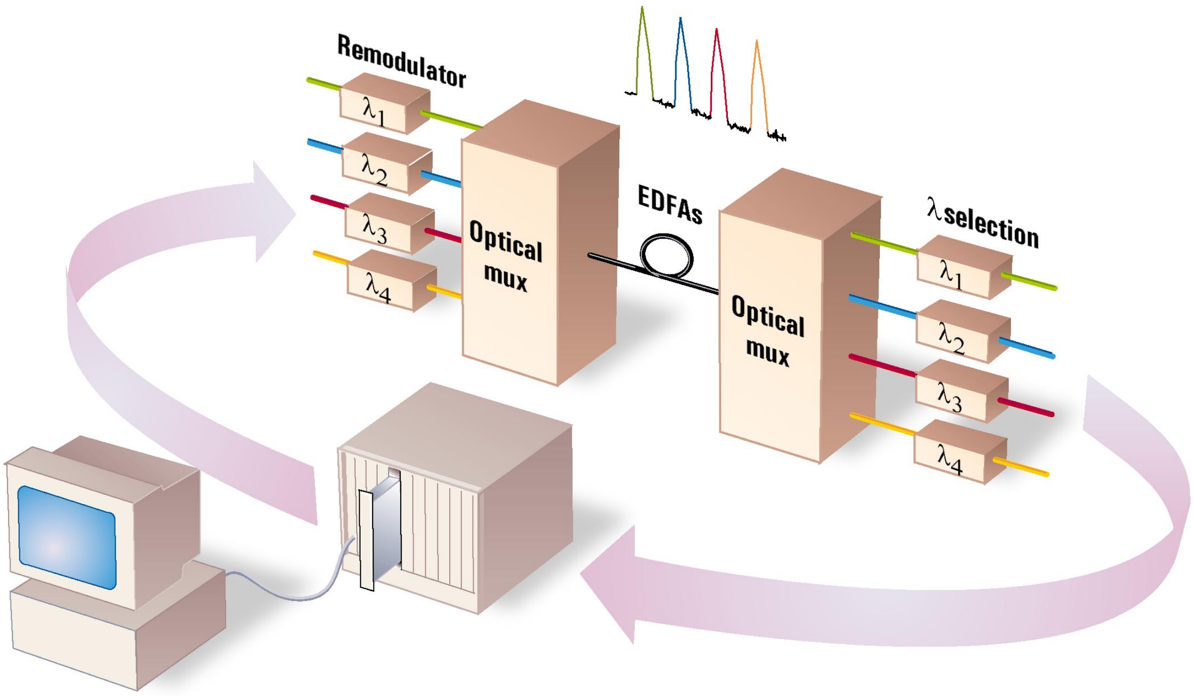
Introduction to BER testing of WDM systems

Application note 1299



Wavelength division multiplexing (WDM) is a new and exciting technology for migrating the core optical transmission network to higher bandwidths. The ability to transfer multiple optical carriers over the same span of fiber promises almost unlimited bandwidth.

However, the ultimate test for any transmission medium is its bit error ratio (BER) performance.

How WDM overlays onto the network

If a network hotspot produces capacity shortfall problems, network operators can now opt to deploy a WDM system to quickly expand capacity on existing fiber links. For example, WDM equipment has already been deployed to multiply the capacity of existing STM-16/OC-48 links—by combining and carrying up to 16 STM-16/OC-48 signals along the existing fiber path[†]. At the same time, upgrading of the existing STM-16/OC-48 line terminal mux to WDM operation is also readily achieved, providing increased bandwidth while retaining existing tributary access and connections. The operation of a WDM system can best be explained by looking at the sub-system level.

Figure 1. Simplified WDM system configuration.

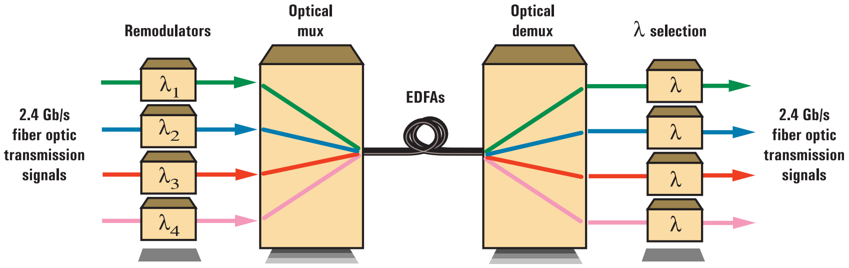
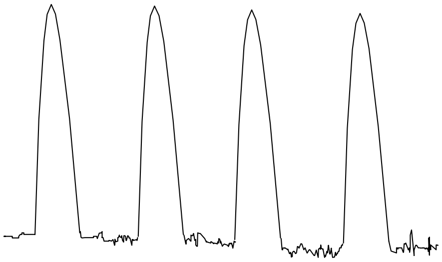


Figure 2. Example output spectrum for four 2.4 Gb/s laser sources.



Laser sources and remodulators

The transmitter of a WDM system produces laser signals at specific wavelengths and with a nominal spectral line spacing between them (Figure 2). Frequency separation is carried out using laser sources of specific frequencies, or using parallel 1550 nm laser sources with a remodulator to obtain the required frequencies. Laser sources are usually distributed feedback (DFB) lasers, typically working in the range 1530 to 1565 nm[‡]. They offer good stability and a narrow spectral width which is a pre-requisite for dense-WDM (DWDM), where the spectral line spacing can be as narrow as 0.8 nm.

If the WDM system is deployed within existing STM-16/OC-48 fiber links then the remodulator also accepts the existing 1550 nm signal and remodulates it to the chosen WDM wavelength, ready for the wavelength multiplexing process.

Optical multiplexer

The multiplexer (mux) couples together different wavelengths then combines them for transmission into a single mode fiber—maintaining the wavelength integrity of each optical carrier.

Fiber path and EDFAs

If an optical link is short, the transmission path will consist of nothing more than optical fiber. If the path is longer, say 50 to 100 km, then erbium doped fiber amplifiers (EDFAs) are used for pre- and post-amplification. Where longer links are deployed, over 100 km, then EDFAs are also used as intermediate amplifiers.

Optical demultiplexer and wavelength selection

The receive side employs a demultiplexer (demux) or decoupler to distribute the optical signal to the wavelength selectors. These devices define the optical bandwidth to recover the original tributary and remove unwanted components.

[†] *Schemes are proposed carrying up to 32 STM-16/OC-48 signals.*

[‡] *Currently, ITU-T draft recommendations O.mcs specify 43 WDM wavelengths.*

Impairments affecting WDM system performance

This application note focuses on the requirement for BER testing a WDM system. There are several potential sources of impairments associated with WDM components and optical fiber links. The main impairments that affect BER performance are listed below.

Amplifier spontaneous emissions from EDFAs
An accumulation of naturally occurring emissions that may cause a reduction in overall signal-to-noise ratio.

Gain flatness of EDFAs
A measure of how flat the optical spectrum remains after passing through the amplifier. Ideally all wavelengths in the WDM signal are amplified equally. Non-linearity needs to be compensated for, because ultimately it could lead to channel failure.

Gain competition in EDFAs
This is associated with the allocation of power to channels. Each EDFA has a defined amount of optical power available for amplifying incoming signals. Increasing the bandwidth of the amplifier adds more channels but leads to an overall reduction of power in existing channels.

Intrinsic and timing jitter
Jitter is the phase variation of a signal from its correct position in time. It can accumulate in a transmission network, leading to errors. The remodulation stage of a WDM system employs a clock recovery and re-clocking stage which can contribute to jitter on an incoming signal.

Dispersion
The characteristics of a fiber can cause wavelengths to propagate at different velocities through the fiber. This leads to pulse broadening and, ultimately, pulse merging which results in errors on the receiver detection circuit.

Crosstalk between adjacent channels
This is the interaction between adjacent channels in a WDM line signal. Because of the closeness of channel spacing, the contents of one channel can cause interference in an adjacent channel, introducing errors at the receiver after demultiplexing and channel selection.

Four wave mixing
This occurs if components of existing optical signals combine to produce a new optical signal at a new wavelength.

Simulated Brillouin scattering and Raman scattering
A description of the interaction between the optical signal and acoustic waves in the fiber, and between the optical signal and the fiber.

As any of these impairments could adversely affect the future fail-safe operation of the network, they need to be evaluated properly and corrected when implementing a WDM system design. For parametric measurements such as power level and optical spectrum checks use a wavelength meter and an optical spectrum analyzer.

For information on diagnosing individual WDM impairments, refer to the DWDM Components Test Guide 5965-3124E.

Evaluating BER performance

Conclusive testing of BER performance (and other impairments) in a WDM system requires the duplication, as close as possible, of an in-service situation. Loading up the tributaries of a WDM system with dynamic, uncorrelated test signals gives a good simulation of live traffic. A typical test setup requires multiple 2.4 Gb/s optical sources of network quality, using DFB lasers or equivalent. Testing also requires wavelengths from the ITU-T WDM grid in order to mimic or test beyond system designs. An OC-48/STM-16 BER analyzer with SONET/SDH frame structures will simulate the traffic of a real network, and if it offers a modular, scaleable transmit/receive measurement capability would be ideal for WDM system testing.

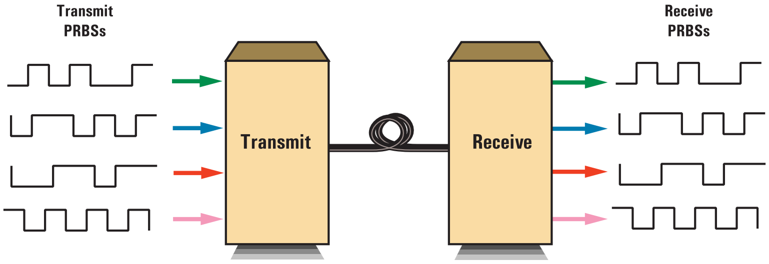


Figure 3. Ideally, BER performance checks on a WDM system would use uncorrelated, parallel PRBS test signals to verify transmission.

1. Tributary-side BER testing

Once assembled, WDM systems are usually 'soak tested'. That is, an end-to-end BER test is performed across all tributaries of the WDM system. Each tributary test is typically 3–4 hours duration due to the low residual BER levels of WDM systems.

Soak testing can be approached in a number of ways.

1. Using a single transmit/receive optical source with optical switches to test each tributary in turn.
2. Using an optical splitter on the transmit output of an optical source to load up all inputs of the WDM mux, then using an optical switch at the output for measuring BER on each receive tributary in turn.
3. Using mulitple transmit/receive optical sources to allow all inputs of the mux to be loaded and to allow simultaneous BER measurement on all receive tributaries.

Approach 1 may be sufficient for a functional test of a proven design, but testing each tributary in turn is inefficient. This approach often results in a trade-off on the amount of time spent measuring each tributary—in order to reduce overall test time. Simply expressed, we can say that . . .

Overall test time = number of WDM channels × BER test time per channel

A further limitation is that loading each tributary in turn may not produce or detect the impairments described in the previous section. Any BER estimate from this approach may therefore be unreliable. If there is any instability in the system design then this approach is not recommended.

Approach 2 may also result in a trade-off in test time, but removes the need for optical switching on the transmit side and allows all tributaries to be loaded. Most of the WDM impairments will emerge in this configuration. However, as the tributary test signals are identical, this approach is less likely to highlight crosstalk problems. In general, this BER estimate will be a good approximation.

Approach 3 offers the best solution, in terms of both test time and thoroughness of test. Having independent optical sources means that the test signals are uncorrelated across the WDM tributary inputs. The multiple receive capability allows tributary BER measurements to be made in parallel, reducing overall test time significantly and providing a more accurate means of identifying problem tributaries by cross correlation of BER performance.

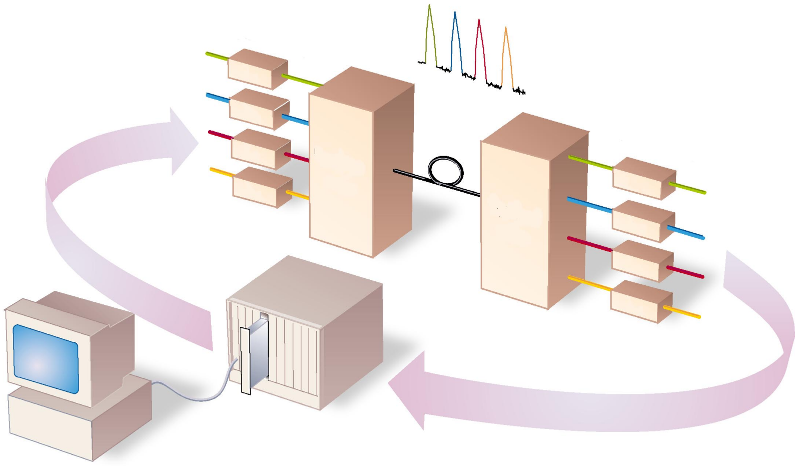
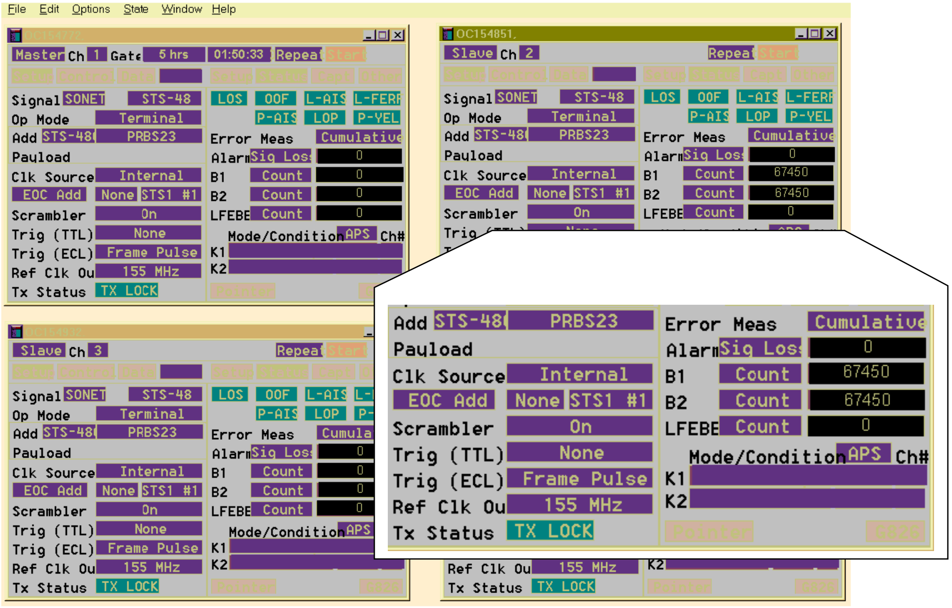


Figure 4. A modular, scaleable transmit/receive measurement capability is ideal for WDM system testing.



```
Master Ch 1 Gate 5 hrs 01:50:33 Repeat Start
Signal SONET STS-48          LOS OOF L-AIS L-FERF
Op Mode Terminal                 P-AIS LOP P-YEL
Add STS-48 PRBS23            Error Meas Cumulative
Payload                      Alarm Sig Loss   0
Clk Source Internal          B1 Count   0
EOC Add None STS1 #1         B2 Count   0
Scrambler On                 LFEBE Count   0
Trig (TTL) None              Mode/Condition APS Ch#
Trig (ECL) Frame Pulse       K1
Ref Clk Ou 155 MHz           K2
Tx Status TX LOCK
```

```
Slave Ch 2 Repeat Start
Signal SONET STS-48          LOS OOF L-AIS L-FERF
Op Mode Terminal                 P-AIS LOP P-YEL
Add STS-48 PRBS23            Error Meas Cumulative
Payload                      Alarm Sig Loss   0
Clk Source Internal          B1 Count   67450
EOC Add None STS1 #1         B2 Count   67450
Scrambler On                 LFEBE Count   0
Trig (TTL) None              Mode/Condition APS Ch#
Trig (ECL) Frame Pulse       K1
Ref Clk Ou 155 MHz           K2
Tx Status TX LOCK
```

```
Slave Ch 3 Repeat Start
Signal SONET STS-48          LOS OOF L-AIS L-
Op Mode Terminal                 P-AIS LOP P-
Add STS-48 PRBS23            Error Meas Cumula
Payload                      Alarm Sig Loss   0
Clk Source Internal          B1 Count   0
EOC Add None STS1 #1         B2 Count   0
Scrambler On                 LFEBE Count   0
Trig (TTL) None              Mode/Condition APS
Trig (ECL) Frame Pulse       K1
Ref Clk Ou 155 MHz           K2
Tx Status TX LOCK
```

Multiport configuration and parallel measurements allow easy cross-correlation of test results.

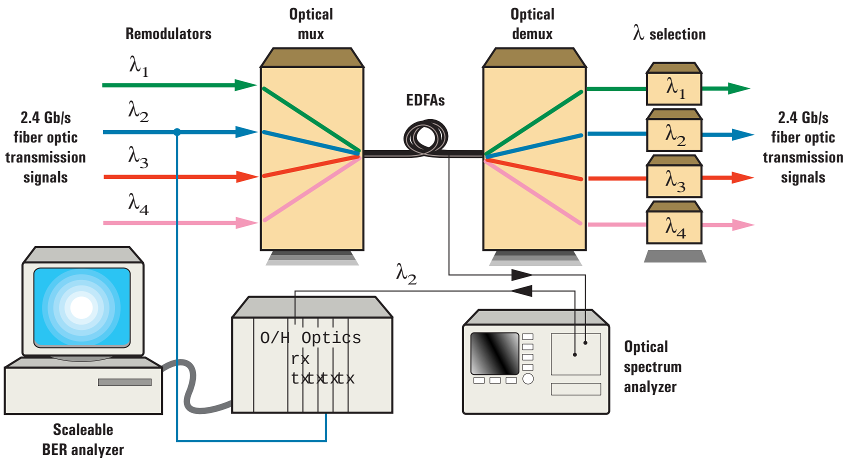
2. In-service BER testing

Accessing tributaries for test when the WDM system is carrying live traffic is impractical. Some network monitoring capability may be built into the WDM but it is yet unclear how comprehensive and informative this capability will become. In any case, because of system aging, in-service testing a WDM system requires measurements of both BER performance and optical parameters.

The present strategy for maintaining the performance of a WDM system relies on examination of the optical spectrum of the WDM signal to ensure optical wavelength and power levels are within established limits. These tests are completed using a waveform multimeter and perhaps an optical spectrum analyzer (OSA) for higher resolution measurements. These measurements are a good indication of system performance but not an absolute, quantifiable measure. This can only be achieved with a BER measurement and the challenge is how to access a channel within a WDM line signal to make BER testing possible.

Using an OSA with a monochromator allows individual tributaries to be isolated and dropped to a BER analyzer. The analyzer can then perform in-service B1 parity error measurements on the live signal. So BER performance can be checked for any change in channel performance detected by parametric testing.

Figure 5. The mono-chromator of an optical spectrum analyzer can act as a tunable optical preselector to drop a suspect channel to a BER analyzer.



Periodically checking in-service BER performance could be used as a vital pro-active measure, highlighting any degradation in quality of service (QoS) before it impacts the service user. Further, for long term monitoring, a maintenance strategy could specify that a WDM channel be allocated as a test channel. This test channel could be 'hard-wired' by the OSA to the BER analyzer, then be monitored continuously as a measure of overall system performance. This would achieve a time-stamped record of QoS with no impact on throughput of traffic. The test channel could be allocated from any one of the channels carried in the WDM system and could be switched periodically across the output stream to check for non-linearities in system performance.

For more information on creating a tunable SONET/SDH BERT for WDM line testing, refer to product note 5965-2741E.

3. BER testing and jitter

In SONET/SDH networks, jitter is a serious threat to quality of service. Controlling intrinsic jitter levels is a priority, and conformance testing of a SONET/SDH network usually includes some BER testing combined with jitter analysis. Later, when a network is operational, the level of jitter is monitored to ensure it remains inside ITU-T recommended levels. Because WDM is being overlaid onto the SONET/SDH infrastructure, it too must meet the current jitter requirements. The two key jitter measurements are jitter transfer and jitter tolerance.

Jitter transfer

This is a measure of jitter gain across any element or section of the network.

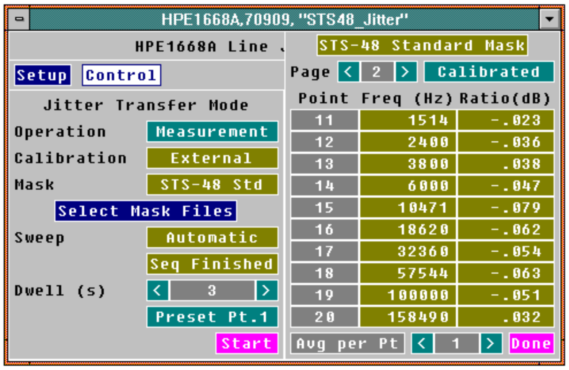
Jitter transfer (dB) = 20 log (Jitter out / Jitter in)

It is important to measure jitter transfer across a WDM system to ensure that there is no jitter contribution from the clock recovery stages present in the remodulators. Using a jitter analyzer with low intrinsic jitter performance is the most accurate method to measure the jitter contribution in a WDM system. Typically a test signal (as jitter free as possible) is applied to the input stage of the WDM remodulators and the jitter is measured on the output tributary of the demultiplexer.

Jitter tolerance

This a measure of BER performance versus applied jitter. A jitter tolerance measurement is used to verify an interface can withstand defined jitter levels and perform error free. Typically the test signal is applied to the input stage of the WDM remodulators with defined levels of jitter at different frequencies, and the BER performance is measured on the output tributary of the demultiplexer. The jitter tolerance measurement masks have been defined by the ITU-T, and having a test set with these masks built-in makes measurements faster and simpler.

Having a jitter analyzer that displays the results in decibels (dB) will allow a quick comparison with the ITU-T jitter standards.



HPE1668A,70909, "STS48_Jitter"

HPE1668A Line

STS-48 Standard Mask

Page 2 Calibrated

Jitter Transfer Mode

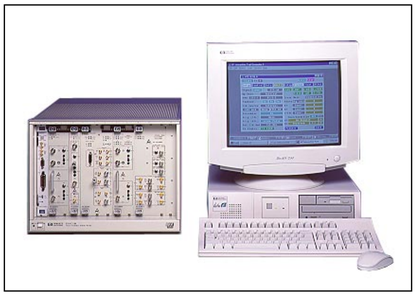
Operation: Measurement
Calibration: External
Mask: STS-48 Std
Sweep: Automatic
Seq Finished
Dwell (s): 3
Preset Pt.1

Point	Freq (Hz)	Ratio(dB)
11	1514	-.023
12	2400	-.036
13	3800	.038
14	6000	-.047
15	10471	-.079
16	18620	-.062
17	32360	-.054
18	57544	-.063
19	100000	-.051
20	158490	.032

Avg per Pt 1

For more information on jitter measurement techniques, refer to Application Note 1267 "Frequency-agile jitter measurement system" (5963-5353E).

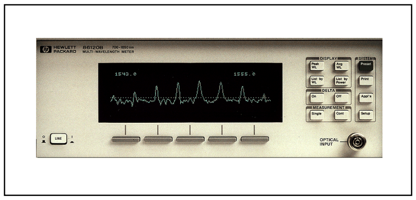
Sample WDM solutions from Hewlett-Packard



HP 75000 Series 90
modular telecom analyzer
A scaleable electrical/optical transmit and receive tester for SONET, SDH and WDM systems. Use for loading system inputs, and for BER and jitter measurements to SONET/SDH standards.

HP 37778A
STM-16/OC-48 test set
Comprehensive testing at 2.488 Gb/s, including BER and jitter analysis to SONET/SDH standards.

HP 71451B
optical spectrum analyzer
In addition to optical sources, this analyzer can characterize optical-to-optical devices such as couplers, filters, isolators, switches and WDM muxes.



HP 86120B
multi-wavelength meter
For 700 nm to 1650 nm. Offers fast measurement of wavelength, amplitude, drift and signal-to-noise ratios of up to 100 discrete laser lines.

For more information about Hewlett-Packard test & measurement products, applications, services, and for a current sales office listing, visit our web site, http://www.hp.com/go/tmdir. You can also contact one of the following centers and ask for a test and measurement sales representative.

United States:
Hewlett-Packard Company
Test and Measurement Call Center
P.O. Box 4026
Englewood, CO 80155-4026
1 800 452 4844

Canada:
Hewlett-Packard Canada Ltd.
5150 Spectrum Way
Mississauga, Ontario
L4W 5G1
(905) 206 4725

Europe:
Hewlett-Packard
European Marketing Centre
P. O. Box 999
1180 AZ Amstelveen
The Netherlands
(31 20) 547 9900

Japan:
Hewlett-Packard Japan Ltd.
Measurement Assistance Center
9-1, Takakura-Cho, Hachioji-Shi
Tokyo 192, Japan
Tel: (81) 426 56-7832
Fax: (81) 426 56-7840

Latin America:
Hewlett-Packard
Latin American Region Headquarters
5200 Blue Lagoon Drive
9th Floor
Miami, Florida 33126
USA
(305) 267 4245/4220
Fax: (305) 267-4288

Australia/New Zealand:
Hewlett-Packard Australia Ltd.
31-41 Joseph Street
Blackburn, Victoria 3130
Australia
Tel: 1 800 629 485 (Australia)
Tel: (0800) 738 378 (New Zealand)
Fax: (61 3) 9210 5489

Asia Pacific:
Hewlett-Packard Asia Pacific Ltd.
17-21/F Shell Tower, Times Square
1 Matheson Street, Causeway Bay
Hong Kong
Tel: (852) 2599 7777
Fax: (852) 2506 9285

Printed in USA
Data subject to change
5966-0911E 12/97