HEWLETT PACKARD

Application Note 270-2

AUTOMATED NOISE SIDEBAND MEASUREMENTS USING THE HP 8568A SPECTRUM ANALYZER

This application note describes an HP-IB controlled spectrum analyzer based system which directly measures USB noise sidebands of sources at frequencies up to 1500 MHz. The superior RF performance of the Hewlett-Packard 8568A Spectrum Analyzer combined with the speed and data handling capabilities of the Hewlett-Packard 9825A Computing Controller permits rapid measurement of noise sideband spectral densities to − 110 dBc/Hz at offsets ⩾ to 500 Hz. Measurements at offsets as close in as 50 Hz are possible.

MEASURING NOISE WITH A SPECTRUM ANALYZER

Accurate measurement of the frequency domain noise sidebands of a source can often be made with no more hardware than a spectrum analyzer with the signal connected directly to the input as shown in Figure 1. This simple system provides a solution for general purpose measurements of SSB noise RF power spectral density, $S(f)_{RF}$.

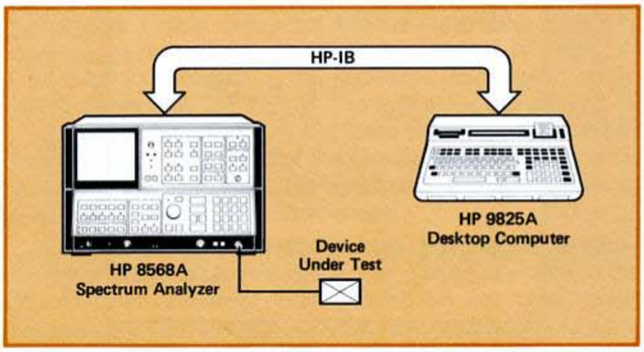


Figure 1. Measurement setup.

Two problems which must be considered when measuring noise sidebands with a spectrum analyzer are discriminating between AM noise and phase noise, and measuring noise close (1 Hz to 1 kHz) to the carrier.

A spectrum analyzer cannot distinguish AM noise from phase noise and instead measures the sum of the two, $S(f)_{RF}$. Noise sidebands of many sources, however, are mainly phase noise sidebands, so measuring the total noise with a spectrum analyzer closely approximates a true measurement of phase noise, L(f). Unless the measurement requires considerable dynamic range at very small frequency offsets, the extra complexity of reference oscillators, phase shifters, mixers and phase detectors characteristic of other measurement systems can be avoided. In those instances where the phase noise and the AM noise must be analyzed separately, other techniques employing hardware such as modulation analyzers are recommended.

Spectrum analyzer resolution of noise sidebands close to the carrier usually degrades as the carrier frequency increases due to instability of the analyzer's local oscillators. This often prevents the use of narrow IF resolution bandwidths in high frequency spectrum analyzers, or at best limits their effectiveness if they are used at all. Because of this, direct measurement of noise sidebands with a spectrum analyzer has generally been limited to low frequencies where good analyzer stability could be achieved and narrow IF bandwidths implemented. At high RF and microwave frequencies down conversion to a low IF frequency (or DC) has been used to permit close-in analysis with a low frequency spectrum or wave analyzer.

The exceptional stability and spectral purity of the Hewlett-Packard 8568A Spectrum Analyzer allows measurement of noise sideband densities approaching − 100 dBc/Hz at a 500 Hz offset from a 1 GHz carrier frequency. Measurements as close-in as 50 Hz are possible. Synthesizer-like tuning accuracy permits automation of the measurement using a Hewlett-Packard 9825A Computing Controller to add the benefits of speed, ease of measurement, and data formatting. With the USB Noise Measurement Program, the system described in this application note automatically measures USB total noise density on signals in the − 10 dBm to + 20 dBm amplitude range (optimum), at frequencies between 100 kHz and 1500 MHz. Figure 2 shows the noise sideband amplitude and frequency offset measurement ranges.

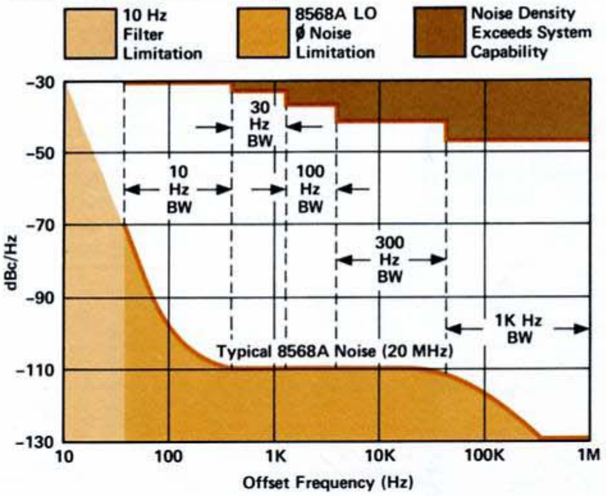


Figure 2. Noise sideband measurement window.

As an additional feature a routine identifies discrete sidebands (i.e. modulation, hum) and displays their true amplitude instead of integrating them with the adjacent distributed noise and normalizing to a 1 Hz noise power bandwidth. The measurement range for discrete sidebands is shown in Figure 3. The USB Noise Program will also compute the integrated rms noise to carrier power ratio in a user specified bandwidth, residual FM, and phase jitter based on measured noise data. The results of a typical measurement are shown in Figure 4.

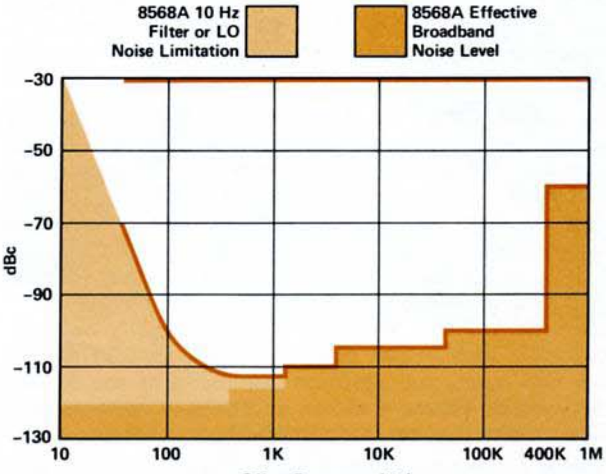
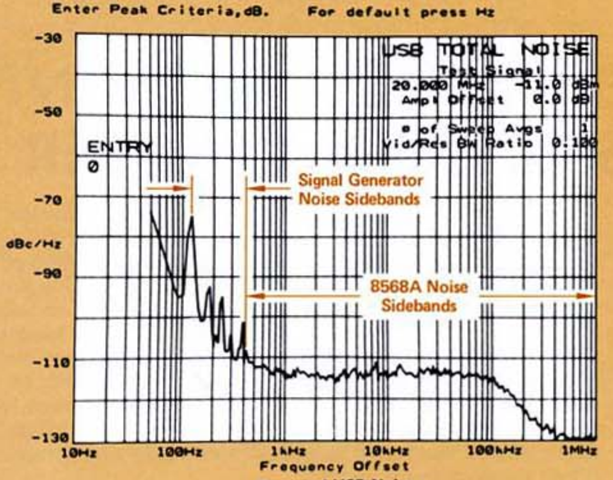
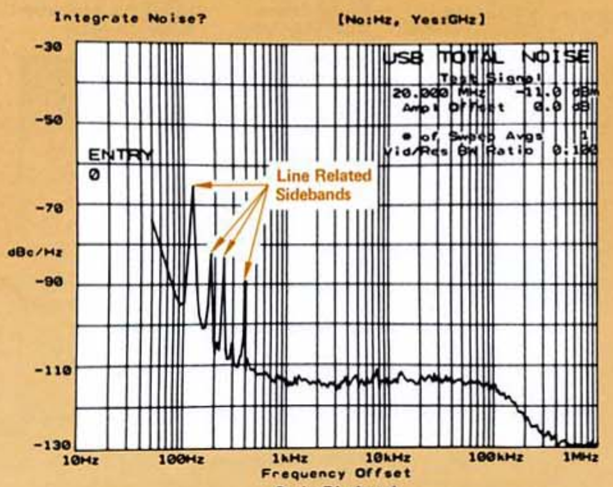


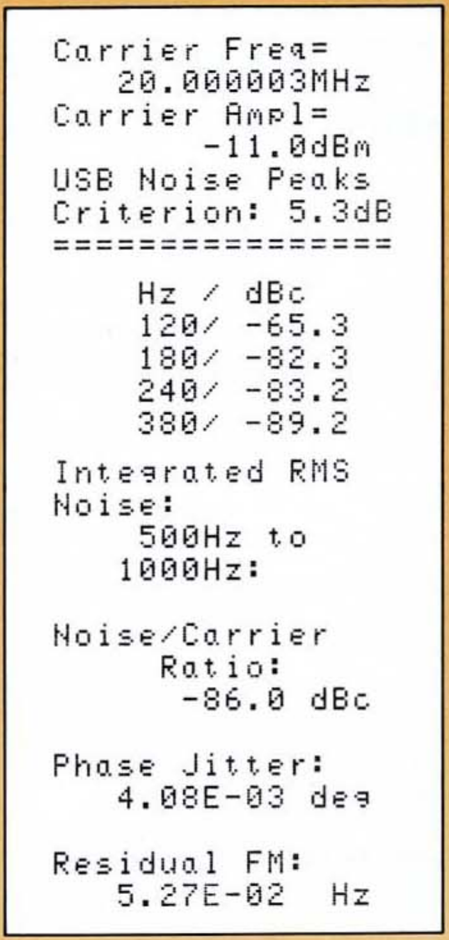
Figure 3. Discrete sideband measurement window.



Measured USB Noise



Peaks Displayed



```
Carrier Freq=
   20.000003MHz
Carrier Ampl=
        -11.0dBm
USB Noise Peaks
Criterion: 5.3dB
================

    Hz / dBc
    120/ -65.3
    180/ -82.3
    240/ -83.2
    380/ -89.2

Integrated RMS
Noise:
    500Hz to
   1000Hz:

Noise/Carrier
     Ratio:
      -86.0 dBc

Phase Jitter:
   4.08E-03 deg

Residual FM:
   5.27E-02  Hz
```

9825A Data Printout

Figure 4. USB noise measurement.

MAKING THE MEASUREMENT

The measurement is made by first counting the carrier frequency to 1 Hz resolution. Using a narrow resolution bandwidth (10 Hz to 1 kHz) eight sweeps are made and data is collected at offsets between 50 Hz and 1 MHz. By proper choice of the resolution bandwidths used, noise within the 50 Hz to 1 MHz offset can be characterized by data values spaced at approximately the 3 dB resolution bandwidth. This assures a reasonably continuous coverage of the noise sideband information.

The 8568A Spectrum Analyzer can measure carrier noise sidebands down to levels of −130 dBc/Hz at offsets greater than 500 kHz. To do this, however, the peak of the carrier must be driven offscreen by 20 dB to bring the low-level noise data onscreen. The noise data collected in each measurement resolution bandwidth is normalized to a 1 Hz noise power bandwidth by applying detector, logging, noise power bandwidth, and normalization corrections to the raw data. Noise sideband spectral density between −30 dBc/Hz and −130 dBc/Hz is then plotted on the 8568A CRT using the graphics capability of the 8568A/9825A system. Figure 4 shows an example measurement made on a signal generator at 20 MHz.

Typical measurement times vary between 3 and 20 minutes or more and depend primarily on the amount of noise data video smoothing desired. Smoothing is achieved by either analog video filtering in the spectrum analyzer or by digital averaging in the controller over repeated sweeps of the spectrum analyzer. Figure 4 was smoothed using video filtering and required three minutes to make the measurement. Video filtering achieves a given degree of smoothing in approximately half the time required by digital averaging, but requires longer sweep times. Long sweep times can lead to measurement errors due to drift of the source during the sweep. Digital averaging, on the other hand, reduces errors caused by signal drift by allowing the spectrum analyzer to retune to the source frequency before each sweep. Signal drift on the order of 50 Hz/minute to 100 Hz/minute can thus be accounted for. So while more sweeps are required for digitally averaged data (and a proportionally longer measurement time), a better close-in measurement on drifting signals can be made. Signals which have good long term stability can be measured using video filtering or digital averaging or both.

ANALYZING THE RESULTS

Once the measurement is made, some interpretation of the results is required to distinguish the signal's noise sidebands from the spectrum analyzer's noise sidebands, since the measurement is the sum of the two. Comparing the measurement to the system's limits enables you to make this differentiation. Figure 2 shows the upper and lower amplitude limits for measuring noise sideband spectral density with this system. An explanation of how the limits were derived is helpful.

Measurement Limits

For the five IF bandwidths used in this measurement, combined noise power bandwidth corrections (including detector and logging corrections) and bandwidth normalization factors amount to between – 7 and – 27 dB typically[1]. Applying the correction factors to the bandwidths used in the measurement gives the system limitation curves in Figure 2. The dark brown upper boundary line represents the maximum noise power density (dBm/Hz) that can be measured by the analyzer without driving the trace offscreen during measurement. This line is determined by adding the – 7 dB to – 27 dB adjustments to the – 20 dBc/10 Hz (– 30 dBc/Hz) reference level setting of the spectrum analyzer. The dark brown lower boundary line is defined by the largest of the analyzer's own LO noise, the broadband noise, or the 10 Hz IF filter skirt when measuring close in to the signal. Analyzer broadband noise lies below – 130 dBc/Hz for signals greater than – 10 dBm and therefore does not appear in Figure 2. The unshaded area of Figure 2 (offsets >50 Hz) represents the region over which noise is measured by the program.

The upper boundary and the analyzer's LO noise curve shown in Figure 2 do not vary with signal amplitude. Consequently signals less than – 10 dBm can be analyzed with the program, but the effect is to raise the analyzer's broadband noise level, which is independent of signal amplitude (for signals within the – 10 dBm to + 20 dBm optimum range). For signals with amplitudes of – 20 dBm or – 30 dBm for example, the system's broadband noise would appear on the Figure 2 graph at – 120 dBc/Hz or – 110 dBc/Hz respectively. But since this level is below the analyzer's LO noise (except at offsets greater than approximately 50 kHz), the analyzer's LO noise is still the limiting factor over most of the offset range.

Attempting to measure noise sidebands of an exceptionally pure signal at levels below the analyzer's own noise sidebands would reveal nothing about the test signal, since the analyzer displays the sum of the test signal and analyzer noise sidebands. Indeed, such a measurement would instead display the analyzer's local oscillator noise sidebands. This technique was used to generate the system noise sideband sensitivity photos shown in the Appendix. Any noise sideband measurements observed at least 10 dB above these levels and within the upper nine display divisions will be in error by less than 0.5 dB due to test signal and analyzer noise sideband powers adding. The Appendix shows typical 8568A LO sideband noise at 20 MHz, 500 MHz, 1000 MHz and 1500 MHz and should be used as a rough indication of the system's measurement limitations due to the analyzer's LO noise.

As an additional feature, this program permits separation of discrete sidebands which, when identified as such by the program, are displayed as discrete signals at their true amplitude instead of being integrated with adjacent noise and normalized to a 1 Hz noise power bandwidth.

Figure 3 displays the system's sensitivity limitations for detection of discrete sidebands. The parameters which affect the detection of these discrete sidebands are analyzer LO noise and offset frequency (which determines the IF resolution bandwidth and, therefore, sensitivity) as shown in Figure 3. The analyzer broadband noise floor, which increases with resolution bandwidth, limits the system sensitivity to discrete sidebands, especially when the wider resolution bandwidths are used at increased carrier offsets. At lesser offsets, the analyzer's own LO noise or IF filter skirt becomes the limitation. These considerations generate the sensitivity steps shown in Figure 3.

Note that signal level (for signals within the optimum range) does not affect the system's sensitivity to discrete sidebands. Although system measurement range would normally improve with increasing carrier level, this is offset by the autoranging of the 8568A's RF attenuator to prevent analyzer gain compression. The resultant system sensitivity is independent of carrier level at carrier levels greater than – 10 dBm and is defined by the dark brown line shown in Figure 3. Discrete sidebands observed at least 10 dB above this line will be in error by less than 0.5 dB due to the signal and analyzer noise powers adding. If a discrete sideband is suspected of being present and hidden below the analyzer's broadband noise, a manual search using a narow IF bandwidth may reveal its presence. Discrete sidebands masked by the 8568A LO noise or 10 Hz filter skirt cannot be retrieved.

Peak Search

A special problem arises in normalizing distributed noise power to an equivalent one Hertz noise power bandwidth. Discrete sidebands must be recognized and treated differently from random noise. An algorithm is used to seek out and identify discrete sidebands and to rescale their amplitudes, effectively removing them from the normalization.

The technique used is adapted from the 85860A subprogram entitled "*PEAKS."[2] Minima must be observed sufficiently far down (the "Peak Criterion") on both sides of the candidate peak, and that criterion must be satisfied within three data points (which are spaced at intervals approximately equal to the 3 dB resolution bandwidth[3]). See Figure 5. Maxima which do not form sufficiently localized peaks are interpreted as broadband noise and disqualified as a discrete signal. A peak which does meet the criterion is rescaled to reflect its true amplitude.

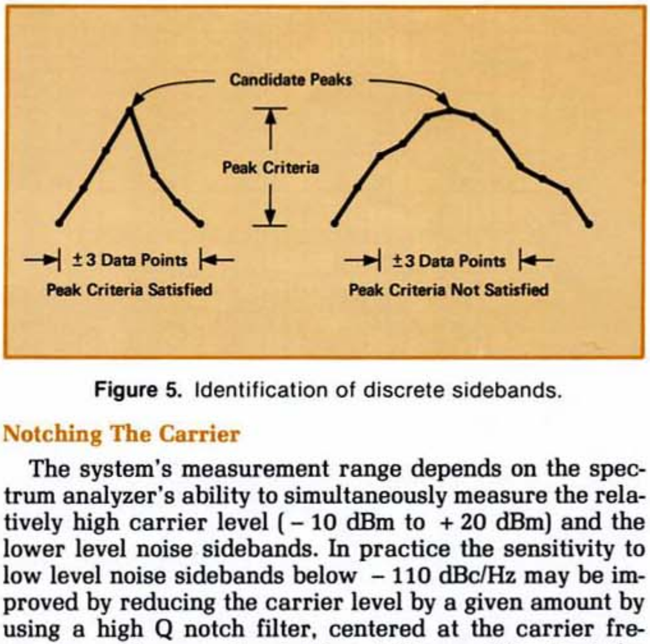


Figure 5. Identification of discrete sidebands.

Notching The Carrier

The system's measurement range depends on the spectrum analyzer's ability to simultaneously measure the relatively high carrier level (– 10 dBm to + 20 dBm) and the lower level noise sidebands. In practice the sensitivity to low level noise sidebands below – 110 dBc/Hz may be improved by reducing the carrier level by a given amount by using a high Q notch filter, centered at the carrier frequency, and measuring (with suitable amplification) the resultant. This effectively increases the measurement dynamic range by increasing the level of the sideband noise without exceeding the + 20 dBm system limit with the notched carrier. Altering the carrier level necessitates rescaling the amplitudes to allow for changes in the sideband/carrier amplitude ratio. The program's amplitude offset feature rescales and simplifies interpretation of the CRT displayed data.

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[1] HP Application Note 150-4 presents a discussion of bandwidth correction and normalization factors.

[2] 85860A is the HP 8581A Automatic Spectrum Analyzer Sample Program Pac software.

[3] At offset <400 kHz.

Noise Integration

Having obtained the distribution of noise $S(f)_{RF}$ as a function of offset frequency, the program calculates three measures of stability within a user specified bandwidth: noise to carrier ratio, phase jitter, and residual FM where

$$\text{noise/carrier ratio} = \frac{\int_{f1}^{f2} L(f)df}{\text{Carrier Power}} \ \text{dB}$$

$$\text{rms phase jitter} = \sqrt{2\int_{f1}^{f2} L(f)df} \ \text{radians}$$

and

$$\text{rms residual FM} = \sqrt{2\int_{f1}^{f2} L(f)f^2df} \ \text{Hz}$$

where it is assumed that AM noise is negligible and $L(f) \propto S_{RF}$.

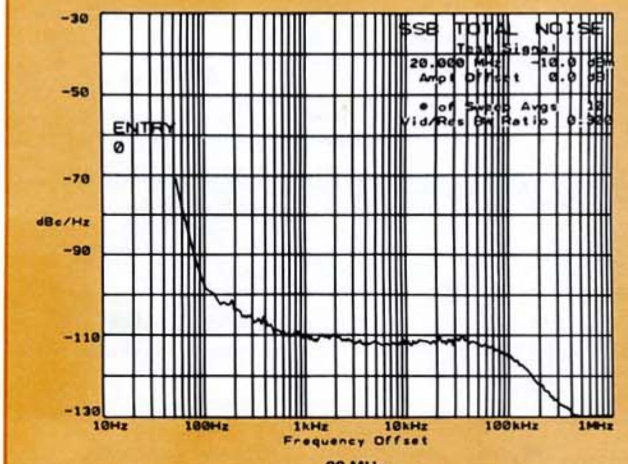
It should be noted that because phase information is not available this program does not integrate the power contained in any discrete signals such as modulation sidebands. Consequently the limits of integration, f1 and f2, must be chosen exclusive of discrete signals identified by the program.

HP Programming Note 8568A/9825A-99, "Implementing AN 270-2 with the HP 8568A and HP 9825A" (5952-9351), discusses this program in more detail and is available free of charge. An annotated program listing is included to help you understand the details of programming the spectrum analyzer.

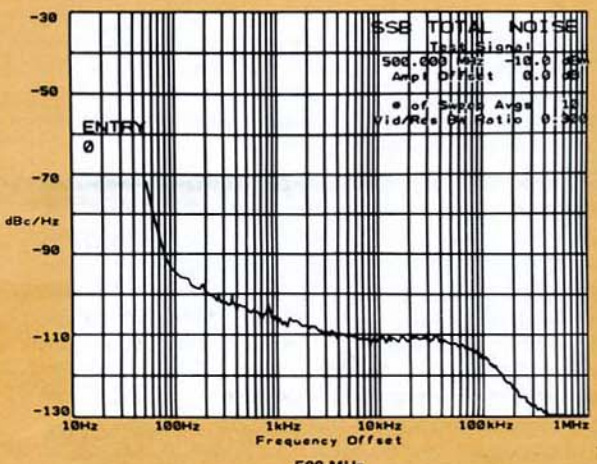
As an added convenience, a verified 9825A tape cassette of this application program is available at a nominal cost. The Programming Note and the program cassette (part number 08568-60120) may be obtained through your local Hewlett-Packard sales office.

Appendix

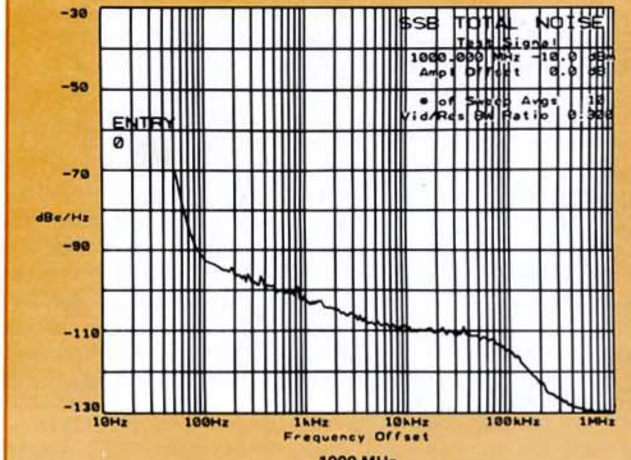
8568A Noise



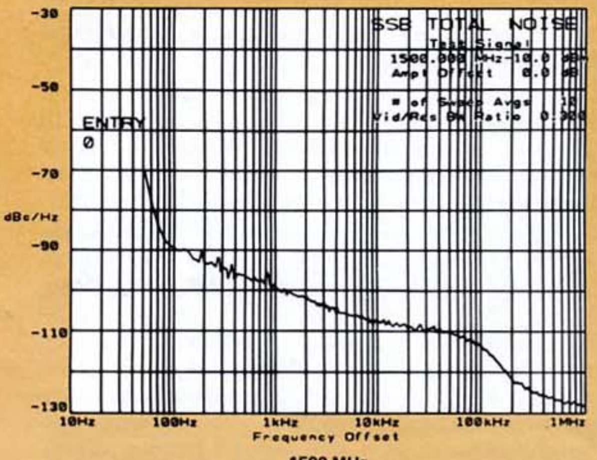
20 MHz



500 MHz



1000 MHz



1500 MHz

For more information, call your local HP Sales Office or nearest Regional Office: **Eastern** (201) 265-5000; **Midwestern** (312) 255-9800; **Southern** (404) 955-1500; **Western** (213) 970-7500; **Canadian** (416) 678-9430. Ask the operator for instrument sales. Or write Hewlett-Packard, 1501 Page Mill Road, Palo Alto, CA 94304. **In Europe:** Hewlett-Packard S.A., 7, rue du Bois-du-Lan, P.O. Box, CH 1217 Meyrin 2, Geneva, Switzerland. **In Japan:** Yokogawa-Hewlett-Packard Ltd., 29-21, Takaido-Higashi 3-chome, Suginami-ku, Tokyo 168.

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