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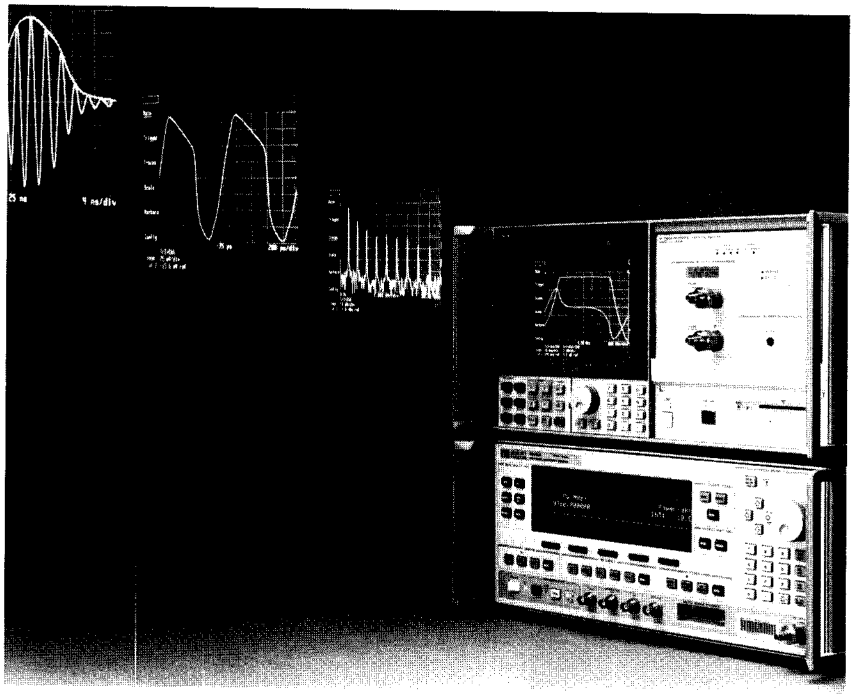
# The Microwave Transition Analyzer: A Versatile Measurement Set for Bench and Test

## Product Note 70820-1

**HP 71500A/70820A**
**Product Note Series**

*dc - 40 GHz*
*2 channels*

*Frequency and Power*
*Vector Voltage*
*Network Analysis*
*Power Sweeps*
*Sampled Spectrum Analysis*
*Array Processing*



This product note shows how to make some common measurements with the HP 70820A.
It also discusses the HP 70820A's performance in these measurements and gives a brief theory of operation.

# Product Note 70820-1

## HP 70820A Microwave Transition Analyzer: A Versatile Measurement Set for Bench and Test

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# Introduction
## The Versatile Test Instrument

When space is at a premium, automatic test systems require small, versatile instruments. For these systems, the HP 70820A microwave transition analyzer offers a wide variety of measurement capabilities in a small package.

The same capabilities also make the HP 70820A a valuable instrument for all-day, every-day bench use. For example, you could perform a time-domain measurement of an amplifier's output waveform and harmonic levels, followed by a frequency-domain measurement of its 3 dB bandwidth, and then a power-sweep measurement to determine its 1 dB compression point -- all with a single instrument.

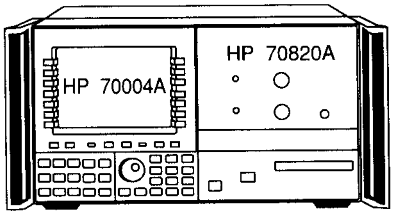


**Figure 1. The HP 71500A system consists of the HP 70820A microwave transition analyzer module and the HP 70004A color display and mainframe.**

### Description of Product Note

This product note begins with an overview of the measurement capabilities in the HP 70820A. Then, the note describes capabilities, limitations, and specifications for selected measurements made using the instrument. Next, discussions of the array processing capabilities, and theory of operation of the HP 70820A are presented. Those measurements not covered in detail here are discussed in other notes in the Product Note 70820 series. As the HP 70820A microwave transition analyzer is unique among instruments, comparisons are made to instruments traditionally used to perform each of the measurement examples.

Since this is a lengthy product note, you are encouraged to skip to those sections of most interest. Each section is self contained.

### The HP 70820A Microwave Transition Analyzer

The HP 70820A is a two channel, dc to 40 GHz, sampler-based instrument that accomplishes CW and pulsed-RF measurements such as frequency, power, peak power, gain, phase, and time interval, as well as displays time waveforms. The microwave transition analyzer internally triggers on the input to either channel from DC to 40 GHz. Its wide bandwidth measures and displays periodic pulses with rise times as fast as 10 picoseconds. The digital-signal-processing capabilities of the HP 70820A also are available for array processing of user-supplied data.

### Instrument Configuration

The HP 70820A microwave transition analyzer module is packaged in a 4/8-wide module as a part of the HP 70000 modular measurement system. The HP 71500A microwave transition analyzer system is a combination of the HP 70820A module and the HP 70004A color display and mainframe, as shown in figure 1. Of course, the HP 70820A module is also compatible with all other HP 70000 modular measurement system mainframes and displays. For automatic test systems where no display is required, the HP 70820A can be used in an HP 70001A system mainframe without a display.

## Source Compatibility For Device Testing

In addition to operating as a stand-alone instrument for signal testing, the HP 71500A can be combined with a synthesized source, allowing a wide range of device measurements. For optimum measurement performance, the microwave transition analyzer controls the frequency and power level of signals from the signal source. The analyzer can control a wide variety of synthesized sources over either its private HP-IB bus or the MSIB bus. Appendix A contains a list of these sources. Figure 2 shows a typical system configuration.

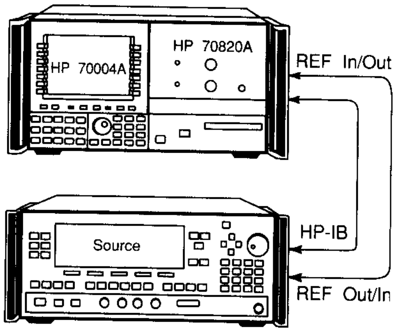


**Figure 2. Typical system configuration for device testing includes the HP 71500A and a synthesized source. Note the HP-IB and reference connections.**

# Chapter 1

## Overview of HP 70820A Measurement Capabilities

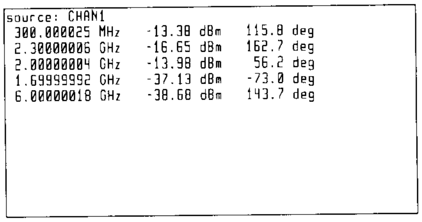
This chapter provides an overview of the measurement capabilities of the HP 70820A. Those capabilities followed by a diamond (♦) are discussed in detail in later chapters. Those capabilities not detailed in this product note are discussed in other titles in the Product Note 70820 series. A list of these product notes and other HP 70820A literature is contained in section 1.2 of this note.

### 1.1 Measurement Overview

**Frequency and Power of CW Signals ♦**

The HP 70820A measures and displays the frequency and magnitude of the largest signals at the input.

- Frequency (0.01 ppm accuracy) and power
- 500 Hz to 40 GHz
- Up to five signals and their harmonics
- Instantaneous phase of multiple signals



```
source: CHAN1
 300.000025 MHz   -13.38 dBm   115.8 deg
 2.30000006 GHz   -16.65 dBm   162.7 deg
 2.00000004 GHz   -13.98 dBm    56.2 deg
 1.69999992 GHz   -37.13 dBm   -73.0 deg
 6.00000018 GHz   -38.68 dBm   143.7 deg
```

**Figure 3. Frequency and power of the five largest IF responses of a mixer, including instantaneous phase of each signal simultaneously.**

**Carrier Frequency of Pulsed-RF Signals**

- Carrier frequency (± 1 kHz)
- For pulses > 1 μs wide

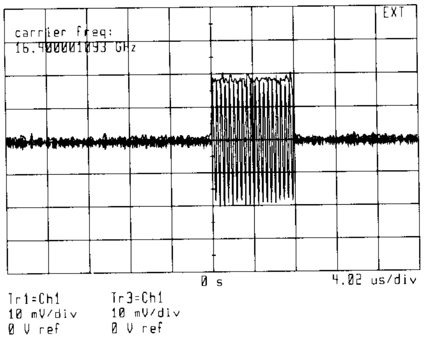
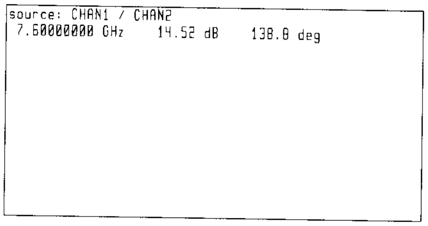


**Figure 4. A measurement of a 16.4 GHz carrier frequency on a pulsed-RF signal.**

## 40 GHz Vector-Voltage Measurements ♦

The HP 70820A identifies the frequency of an input signal and then measures the gain and phase relationship between channel 1 and channel 2. This measurement mode is useful for IF phase matching of multi-channel receivers and interferometers

- Measures signal frequency
- Two-channel gain
- Two-channel phase
- 500 Hz to 40 GHz input frequency range
- 50 ohm inputs



```
source: CHAN1 / CHAN2
 7.60000000 GHz    14.52 dB    138.8 deg
```

**Figure 5. Measurement of gain and phase of FET amplifier at 7.6 GHz. Signal frequency is also measured.**

## Network Analysis ♦

The HP 70820A, in conjunction with a synthesized source, accomplishes vector network-analysis measurements on CW (10 Hz to 40 GHz) or pulsed-RF signals (500 kHz to 40 GHz). Normalization can be used to correct for frequency-response errors.

- CW or pulsed-RF stimulus
- Transmission or reflection
- Normalization capability
- Harmonic and offset sweeps for CW measurements
- -110 dBm typical noise level at 10 GHz with 10 Hz noise filter bandwidth

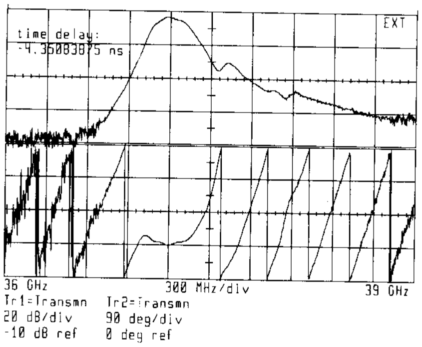


**Figure 6. Normalized transmission measurement of bandpass-filter gain and phase from 36 GHz to 39 GHz.**

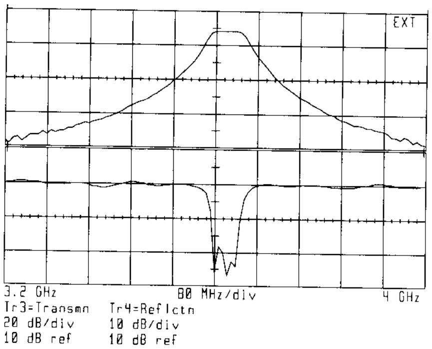


**Figure 7. Simultaneous measurement of insertion loss and return loss of a 3.6 GHz bandpass filter.**

## Power Sweeps ♦

The HP 70820A, in conjunction with a synthesized source, accomplishes gain and phase measurements of devices as a function of the input power level. The frequency range for CW signals is 10 Hz to 40 GHz, and the frequency range for pulsed-RF signals is 500 kHz to 40 GHz.

- CW or pulsed-RF stimulus
- Power out versus power in
- Normalization capability
- Harmonic- and offset-sweep capability (CW measurements only) for frequency multipliers, receivers, and many other devices.

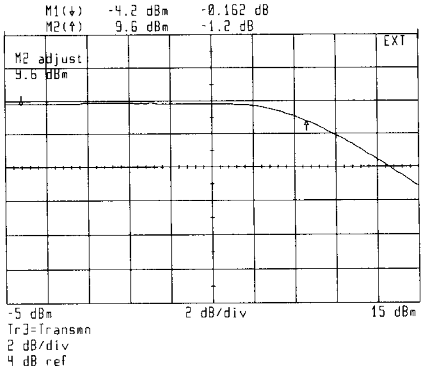


**Figure 8. Normalized measurement of the 1 dB compression point of a limiter.**

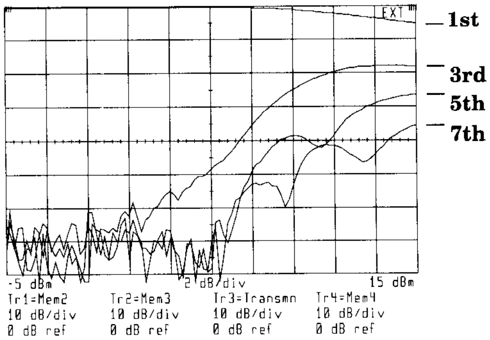


**Figure 9. Measurement of output power from the limiter versus input power level for the fundamental and 3rd, 5th, and 7th harmonics. Each is normalized by the input power level.**

## Accurate Delta-Time Measurements

Accurate measurements of the time between two events can be performed, either on a single channel or from one channel to a second channel. Accuracy requires a stable signal source, which shares a common time base with the HP 70820A, to stimulate the device under test.

- 1 picosecond accuracy at ≤ 100 ps/division
- 50 femtosecond resolution at 5 ps per division

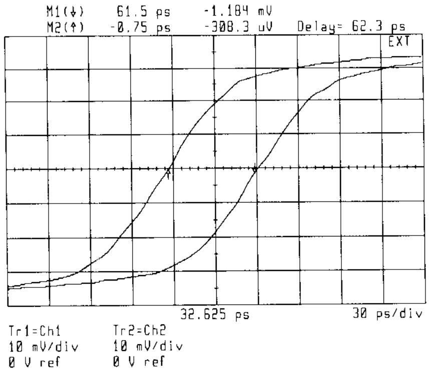


**Figure 10. 2 channel delay measurement of 62.3 picoseconds.**

## Microwave Time-Domain Analysis

The HP 70820A measures and displays the time waveform of repetitive signals from 0 to 40 GHz. An FFT provides the magnitude and frequency of the fundamental, as well as the relative magnitude and phase of the harmonics.

- Pre-trigger data can be viewed
- 5 ps/division to 100 s/division time scale
- Internal triggering to 40 GHz
- Phase triggering for low-level signals
- Magnitude and phase of harmonics
- Up to 16 harmonics listed

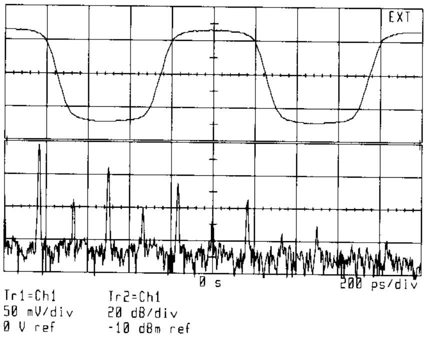
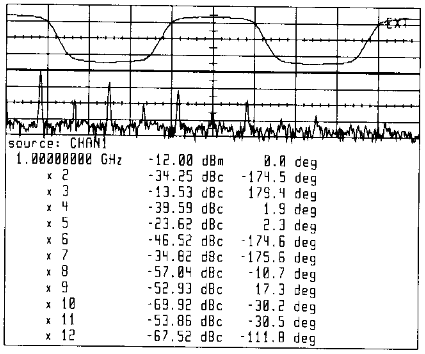


**Figure 11. 1 GHz sine wave compressed by a microwave limiter, viewed in time and frequency domains.**



```
source: CHAN1
 1.00000000 GHz   -12.00 dBm     0.0 deg
       x 2        -34.25 dBc  -174.5 deg
       x 3        -13.53 dBc   179.4 deg
       x 4        -39.59 dBc     1.9 deg
       x 5        -23.62 dBc     2.3 deg
       x 6        -46.52 dBc  -174.6 deg
       x 7        -34.82 dBc  -175.6 deg
       x 8        -57.04 dBc   -10.7 deg
       x 9        -52.93 dBc    17.3 deg
       x 10       -69.92 dBc   -30.2 deg
       x 11       -53.86 dBc   -30.5 deg
       x 12       -67.52 dBc  -111.8 deg
```

**Figure 12. Tabular listing includes fundamental frequency and power of the limiter's output as well as the relative magnitudes and phases of the harmonics.**

## Single-Shot Measurements

Non-periodic signals from dc to 40 GHz with bandwidths less than 10 MHz can be captured.

- 10 MHz maximum bandwidth
- Carrier frequencies from 0 to 40 GHz
- Pre-trigger data can be viewed
- Pulse envelopes mathematically reconstructed

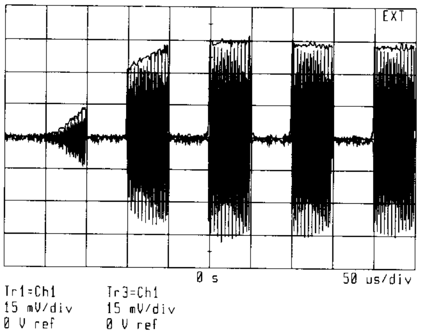


**Figure 13. Single-shot mode catches turn-on characteristics of pulse modulator.**

## Fast Pulsed-RF Components: Magnitude

The HP 70820A characterizes fast pulsed-RF components in stimulus/response measurements.

- Rise times as fast as 10 ps
- Pulse widths as narrow as 100 ps
- Internal pulse generator with 100 ns resolution
- Removes video feedthrough
- Pulse envelopes mathematically reconstructed

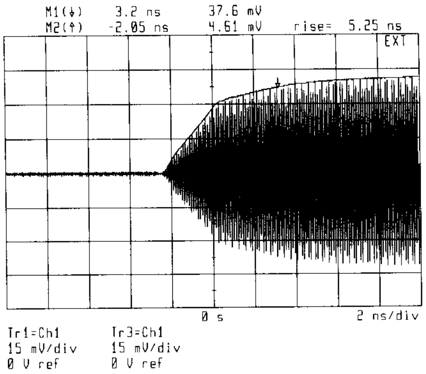


**Figure 14. Magnitude of rising edge of pulsed RF signal with 5.25 ns rise time.**

## Fast Pulsed-RF Components: Phase

The phase of the carrier through the pulse can be measured relative to a CW or pulsed-RF reference. Also possible are single-channel phase measurements relative to the internal reference of the HP 70820A.

- Two-channel phase
- Single channel phase

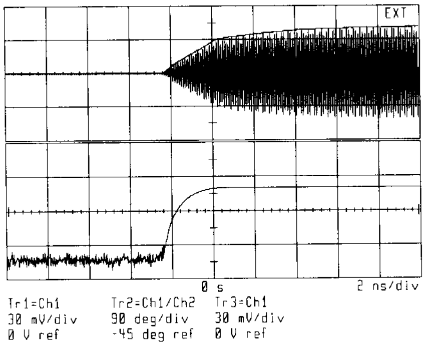


**Figure 15. Phase through pulsed-RF modulator, at the rising edge of above pulse, relative to unmodulated carrier.**

## Peak-Power Measurements

- Pulse widths > 1 μs (single shot)
- Pulse widths > 1 ns (if PRF can be controlled)
- Summation technique used

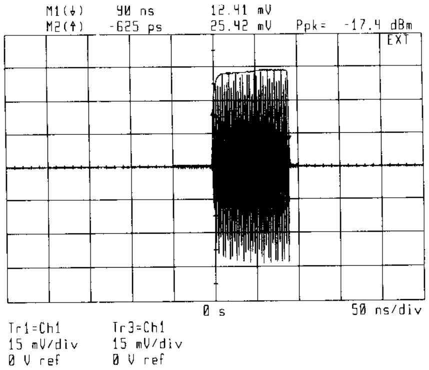


**Figure 16. Peak-power measurement of a 90 ns pulsed RF signal.**

## Sampled Spectrum Analysis ♦

The HP 70820A functions as an unpreselected, sampling-based, single-shot spectrum analyzer from 0 to 40 GHz. Maximum span is approximately 10 MHz for most center frequencies.

- 0 to 40 GHz input frequency range
- noise floor typically -75 dBm at 1 GHz, can be reduced further with zoom transform
- Frequency spans up to 10 MHz
- Phase of spectral components

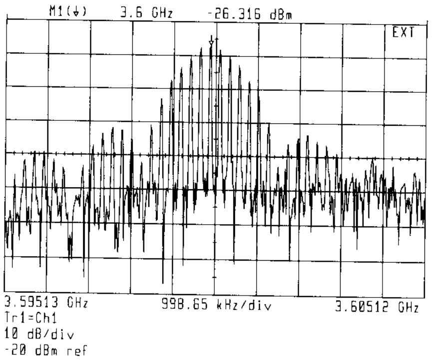


**Figure 17. Spectrum of 3.6 GHz pulsed-RF signal with 230 kHz pulse repetition frequency.**

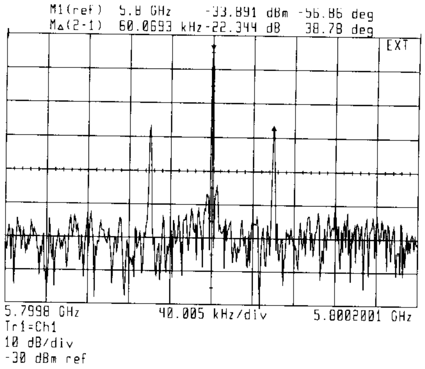
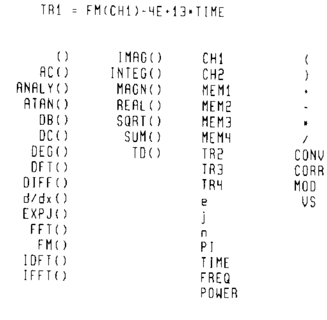


**Figure 18. Spectrum of 5.8 GHz narrowband FM signal. Markers show that carrier power is -33.9 dBm, modulation frequency is 60 kHz, sideband level is -22.3 dBc, and the instantaneous phase difference between the upper sideband and the carrier is 38.8 degrees.**

## Array Processing ♦

The digital-signal-processing capabilities of the HP 70820A are accessible for use over the HP-IB or MSIB buses.

- 32 to 1,024 complex point trace lengths
- 32-bit block, floating-point processing with 24 bit mantissa



```
TR1 = FM(CH1)-4E+13*TIME

       ()    IMAG()   CH1      (
     AC()   INTEG()   CH2      )
  ANALY()    MAGN()   MEM1     +
   ATAN()    REAL()   MEM2     -
     DB()    SQRT()   MEM3     *
     DC()     SUM()   MEM4     /
    DEG()      TD()   TR2     CONV
    DFT()             TR3     CORR
   DIFF()             TR4     MOD
   d/dx()             e        VS
   EXPJ()             j
    FFT()             n
     FM()             PI
   IDFT()             TIME
   IFFT()             FREQ
                      POWER
```

**Figure 19. Listing of available functions that can be performed on records up to 1,024 points long. These functions are also available from the front panel for trace definitions.**

## 1.2 List of HP 70820A Literature Series

### Color Brochure

"HP 71500A Microwave Transition Analyzer"

Lit # 5091-0791

### Product Notes:

"The Microwave Transition Analyzer: A Versatile Measurement Set for Bench and Test" for general measurement applications.

Lit # 5952-2543

"The Microwave Transition Analyzer: Measure 25 ps Transitions on Switched and Pulsed Microwave Component Testing" for switched and pulsed-RF magnitude measurements.

Lit # 5952-2546

"The Microwave Transition Analyzer: Picosecond Delta Time Accuracy" for high accuracy delta-time measurements

Lit # 5952-2545

### Technical Data Sheet:

"HP 71500A Microwave Transition Analyzer System
HP 70820A Microwave Transition Analyzer Module"
specifications and ordering information

Lit # 5091-0792

### MMS Catalog:

"Modular Measurement System" catalog.
Details on the complete HP 70000 product line Lit # 5952-2170

### Videos:

Videos are available that show the unprecedented performance of the microwave transition analyzer:

| | |
|---|---|
| "Microwave Design in Radar and Communications" | 90454T |
| "Switched and Pulsed-RF Component Testing" | 90453T |

# Chapter 2

## Basic Measurement Information

This chapter contains useful information for performing the measurement examples contained in the chapters that follow.

### 2.1 HP 71500A Key Locations

In the measurement examples, various keys are referred to for use. Figure 20 shows the location of these keys. Measurement functions in the HP 70820A are controlled using the softkeys along the sides of the display. The measurement functions are divided into twelve categories, or "menus." The softkeys along the left hand side of the display are used to select each menu. Two pages of menus are available, and the bottom softkey on the left side is used to change from one page, or level, to the other.

The softkeys along the right side of the display contain functions that depend on the menu selected. When a menu has more than seven associated functions, the bottom softkey on the right side is used to change from one level of softkeys to the next. When a softkey is labeled with upper-case characters, pressing it will execute a function. When a softkey is labeled with lower-case characters, pressing it will bring up a sub-level of softkeys, still on the right side of the display.

To simplify measurements, commonly used functions are also available using the hardkeys located on the panel below the display and to the left. Numeric keys, up/down arrows, and the rotary pulse generator (RPG) are located below the display and to the right.

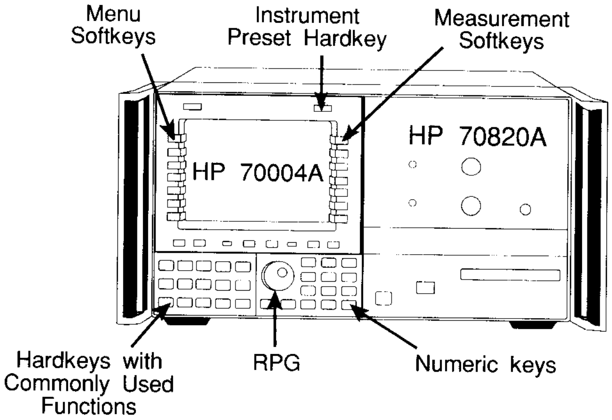


Figure 20. HP 71500A key locations.

### 2.2 HP 70820A Pre-defined States

The HP 70820A contains pre-defined instrument states, which simplify many of the measurements in this product note. Found under the **States** menu, the main function of the pre-defined states is to specify such things as trace definitions, sweep types, trigger settings, etc. All functions controlled by pre-defined states are also available from the front panel using the softkeys.

# Chapter 3
## Frequency and Power Measurements

Both the frequency and power of input signals from 500 Hz to 40 GHz can be measured using the HP 70820A. The power of signals at frequencies less than 500 Hz can be measured if the user enters the precise frequency.

The frequency and power of up to five signals can be measured simultaneously. This capability would be useful, for example, in measuring the output of a mixer, which contains multiple signals. For each signal, the HP 70820A can also measure the power level and phase of each of its harmonics.

Measurement examples follow that show how to configure and use the HP 70820A for CW frequency, power, and harmonic measurements of single and multi-tone signals. Frequency measurements of pulsed-RF signals are discussed in other titles of the Product Note 70820 series. Following the CW measurement examples is a discussion of measurement specifications and limitations, and a comparison is made between the HP 70820A and instruments traditionally used to perform these measurements.

### 3.1 CW Measurement Example: Oscillator Frequency, Power and Harmonics

#### Measurement Setup and Results

The measurement setup for frequency and power measurements is shown in figure 21. The signal to be measured is connected to channel 1 for this illustration, although channel 2 could also be used.

- Connect signal under test to CH1 input.

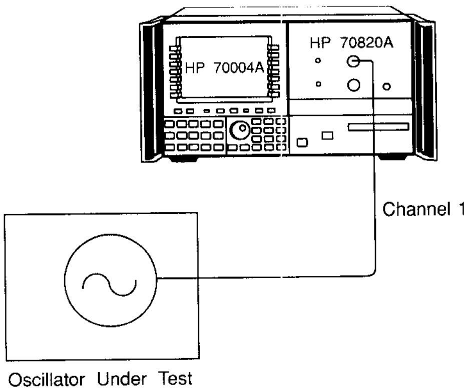
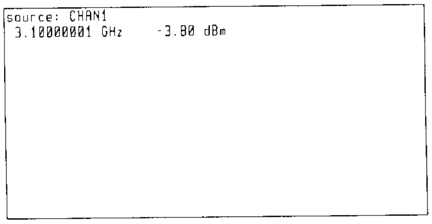


**Figure 21. Measurement setup for frequency and power measurements.**



```
source: CHAN1
 3.10000001 GHz     -3.80 dBm
```

**Figure 22. Display of the frequency and power out of a 3.1 GHz oscillator.**

Figure 22 shows the results of the oscillator measurement. The display shows that the oscillator frequency is 3.1 GHz and the output power level is -3.8 dBm.

**Measurement Procedure**
Having set up the equipment as shown in figure 21, activate the frequency-and-power mode of operation by executing the following keystrokes:

- **States** menu ; **FREQ & POWER**.

The display now appears as in figure 22. In this mode of operation, the HP 70820A determines the frequency of the incoming signal at channel 1 and then measures the power level of that signal. During these measurements, the HP 70820A tracks the signal at channel 1 because it is defined to be the trigger input. When the HP 70820A detects a change in frequency, it measures the new frequency and continues with the measurement. If a signal source is configured to be controlled by the HP 70820A, the signal track function turns off automatically (when FREQ & POWER is pressed) since the frequency is known.

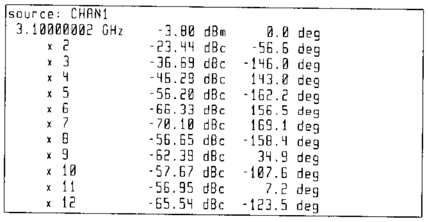
## Additional Capabilities

### *Harmonic measurements*

Measure the harmonic content of the signal under test by using the following additional keystrokes:

- **Table** menu ; **signal list** (second level)
- **INCLUDE HARMONICS** (until underlined)
- **prev menu**
- **# of HARMNCS** ; **16** ; **ENTER**
- **show MAG I PHA** until both MAG and PHA are underlined.

The HP 70820A now measures the fundamental and harmonics (up to the 16th) of the signal. For each harmonic measured, the power level and phase, relative to the fundamental, are displayed. The display appears as shown in figure 23. The highest harmonic shown is the 12th. In order to view the higher harmonics, use the **SCROLL TABLE** function under the Table menu. If the higher harmonics are not of interest, they need not be displayed. In order to display only the 2nd and 3rd harmonics press:

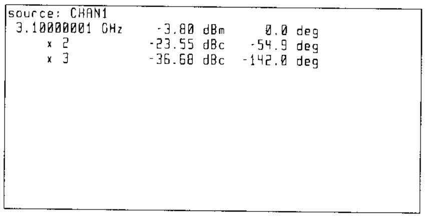


```
source: CHAN1
 3.10000002 GHz     -3.80 dBm     0.0 deg
      x 2          -23.44 dBc   -56.6 deg
      x 3          -36.69 dBc  -146.0 deg
      x 4          -46.29 dBc   143.0 deg
      x 5          -56.20 dBc  -162.2 deg
      x 6          -66.33 dBc   156.5 deg
      x 7          -70.10 dBc   169.1 deg
      x 8          -56.65 dBc  -158.4 deg
      x 9          -62.39 dBc    34.9 deg
      x 10         -57.67 dBc  -107.6 deg
      x 11         -56.95 dBc     7.2 deg
      x 12         -65.54 dBc  -123.5 deg
```

**Figure 23. Display of the frequency, power, and phase of a 3.1 GHz oscillator from the fundamental to the 12th harmonic.**

- **# of HARMNCS** ; **3** ; **ENTER**

The display now appears as in figure 24.



```
source: CHAN1
 3.10000001 GHz     -3.80 dBm     0.0 deg
      x 2          -23.55 dBc   -54.9 deg
      x 3          -36.68 dBc  -142.0 deg
```

**Figure 24. Display of the frequency, power, and phase of a 3.1 GHz oscillator from the fundamental to the 3rd harmonic.**

### *Traces, display*

Since the top portion of the display now is blank, it is available for traces. In addition to displaying the waveforms at the inputs, the top of the screen can be used to display a trace that is based on the information in the table. This time-domain waveform is displayed by defining trace 1 as **TABLE** and setting the trace 1 **display** to **ON** in the trace menu. With trace 1 displayed, the shape of the trace can be seen to change, for signals with large harmonic content, as the number of harmonics used in the table measurement is changed.

### *Reducing noise, increasing speed*

For measurements involving low signal levels or large amounts of noise on the signals, averaging can be used to reduce the variations between measurements. The **average** function is located under the Table menu and can be set from 1 to 1,024 averages.

The **filter** function, also under the Table menu, can be used to improve the resolution of frequency measurements. Because of the improved frequency resolution, use of this filter requires greater signal stability.

In applications where measurement speed is important and the frequency of the incoming signal is stable, the **sig trk** function can be turned off after the signal frequency has been determined. This prevents the HP 70820A from spending time checking the signal frequency.

## 3.2 Multi-Signal Measurement Example: Top Five Mixer Outputs

### Measurement Setup and Results

The measurement setup for a frequency and power measurement of a mixer's IF signal is shown in figure 25. The signal to be measured is connected to channel 1. The frequency and power of the five largest signals are measured and displayed.

- connect signal under test to CH1.

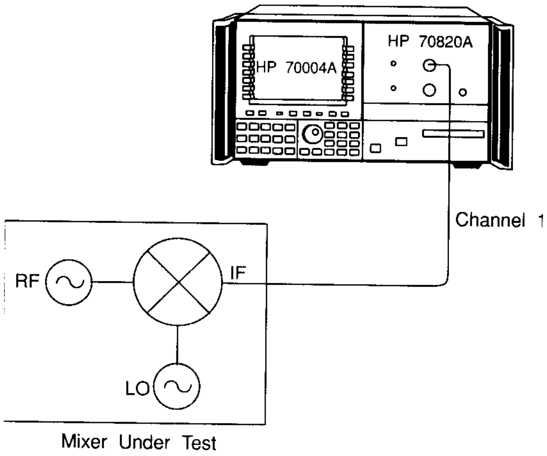
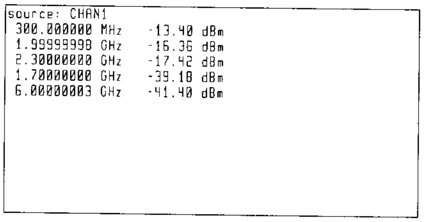


**Figure 25. Measurement setup for frequency and power measurement of IF output of a mixer.**

Figure 26 shows the results from the measurement of the IF signal of a mixer. For this measurement, the frequency of the local oscillator (LO) was 2.0 GHz and the RF frequency was 2.3 GHz. Both signals fed through to the mixer's output (IF). In addition to the LO (2.0 GHz) and RF (2.3 GHz) terms, the largest mixing products are the desired mixer IF output of 300 MHz (2.3 GHz - 2.0 GHz), a 2nd harmonic mixing term at 1.7 GHz (2 * 2.0 GHz - 2.3 GHz), and the 6.0 GHz 3rd harmonic of the 2.0 GHz LO.



```
source: CHAN1
 300.000000 MHz   -13.40 dBm
 1.99999998 GHz   -16.36 dBm
 2.30000000 GHz   -17.42 dBm
 1.70000000 GHz   -39.18 dBm
 6.00000003 GHz   -41.40 dBm
```

**Figure 26. Display of the frequency and power of the five largest IF responses of a mixer.**

### Measurement Procedure

For this measurement, the HP 70820A must be configured so that it does not control either source. This configuration allows the signal-track feature to determine the frequency of all signals of interest, not just the frequency of the configured source. See appendix A for source configuration information.

Using the setup shown in figure 25, activate the frequency and power mode of operation as follows:

- **States** menu ; **FREQ & POWER.**

In this mode, the HP 70820A determines the frequency of the largest incoming signal at channel 1 and then measures the power level of that signal. During these measurements, the HP 70820A tracks the signals at channel 1, the defined trigger input. When channel 1 detects a change in frequency, the new frequency is measured, and the HP 70820A continues with the measurements. In order to measure the five largest responses, press the following keys:

- **Table** menu
- **signals ONE | ALL** (2nd level) until ALL is underlined

The HP 70820A now identifies all signals, up to five, of sufficient amplitude ( > -40 dBm) and measures their frequencies from 500 Hz to 40 GHz. The display will now appear as in figure 26.

### Additional Capabilities

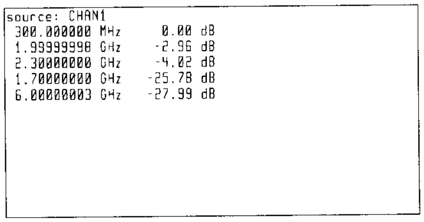
In addition to the capabilities described below, the features described in the previous oscillator measurement example (section 3.1) could also be used for this measurement. Refer to the oscillator measurement example for more information.

#### *Relative measurements*

The display in figure 26 shows the absolute power of the five IF-response signals identified by the HP 70820A. The power levels can also be shown relative to any one of the signals, as shown in figure 27. In this case, the displayed power levels are referenced to the desired mixer IF response of 300 MHz. This is accomplished by setting the **ABS | REL** key (under the Table menu) to **REL** and using the RPG or up and down arrows to select the desired reference signal.

#### *Harmonic measurements*

By selecting the **INCLUDE HARMONICS** function under **signal list** under the Table menu and setting the **# of HARMNCS** function greater than 1, the harmonics of each signal can be measured, as was done in section 3.1. If this were done on the signal shown in figures 26 and 27, the 6 GHz response would no longer appear as an independent signal but as a harmonic of the 2 GHz signal.



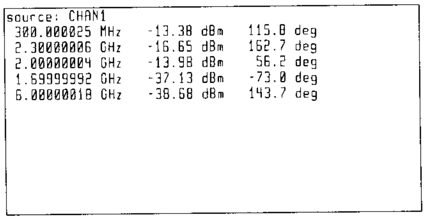
```
source: CHAN1
 300.000000 MHz     0.00 dB
 1.99999998 GHz    -2.96 dB
 2.30000000 GHz    -4.02 dB
 1.70000000 GHz   -25.78 dB
 6.00000003 GHz   -27.99 dB
```

**Figure 27. Display of the frequency and power, referenced to the desired IF response, of the five largest IF responses of a mixer.**

#### *Phase measurements*

The instantaneous phase of each of the five signals can be measured and displayed, as shown in figure 28. This is accomplished by setting the **MAG | PHA** key (under the Table menu) until both MAG and PHA are underlined. The displayed angles represent the phase, based on a cosine definition, of each signal, measured at the same time.

This feature can be used to characterize the phase through a mixer. The measurement requires that the **filter** is turned off and that the **INCLUDE HARMONICS** function is turned off (not underlined).



```
source: CHAN1
 300.000025 MHz   -13.38 dBm   115.8 deg
 2.30000006 GHz   -16.65 dBm   162.7 deg
 2.00000004 GHz   -13.98 dBm    56.2 deg
 1.69999992 GHz   -37.13 dBm   -73.0 deg
 6.00000018 GHz   -38.68 dBm   143.7 deg
```

**Figure 28. Display of the instantaneous phase of each signal at the same point in time, in addition to displaying the frequency and power.**

## 3.3 Applying the Specifications

The frequency accuracy of these frequency-and-power mode measurements is specified as Signal Track Frequency Accuracy in the section, "Signal Acquisition," of the HP 70820A specifications.

The amplitude accuracy of these measurements is a combination of the Absolute Amplitude RF Frequency Response, RF Corrections On, and the Amplitude Accuracy versus Input Power Level specifications, in addition to the effects of mismatch. If multiple signal measurements are made with the filter off, or if harmonics are being measured, then the IF Amplitude Flatness specification must also be included.

## 3.4 Limitations

In the frequency-and-power mode of operation, the HP 70820A is limited to measuring the five largest signals and their harmonics from 500 Hz to 40 GHz. The instrument typically requires signals greater than -50 dBm at 26 GHz for frequency measurements of unknown signals. Measuring multiple signals requires a minimum signal separation of 500 kHz.

Once the precise frequency has been determined by the HP 70820A, or entered by the user, the signal-track feature can be turned off and the power level can be measured to about 30 dB lower than the level required for acquiring the frequency.

## 3.5 Comparison to Other Instruments

### Microwave Frequency Counters

The HP 70820A provides a greater dynamic range than is available in most microwave frequency counters. Microwave frequency counters typically can measure higher-power (+7 dBm) signals than will the HP 70820A (0 dBm), but the HP 70820A is more sensitive (typically -50 dBm at 26 GHz) than are dedicated microwave counters (typically -30 dBm at 26 GHz).

Microwave frequency counters are more tolerant of frequency-modulated signals than is the HP 70820A. The HP 70820A can determine the frequency of signals, as long as the maximum peak-to-peak frequency deviation is less than either 100 kHz or twice the modulation rate, whichever is greater.

With a good time base, microwave frequency counters can achieve better frequency accuracy than does the HP 70820A. At microwave frequencies, the accuracy of counters is dominated by the product of the time-base error and the signal frequency. The accuracy of the HP 70820A in the frequency-and-power mode is typically equal to that same product plus 3.5 parts in $10^9$ times the input frequency (with the filter on). This additional term is equal to 140 Hz error at 40 GHz. The HP 70820A contains a high-stability, ovenized, 10 MHz time-base.

The HP 70820A is capable of simultaneously measuring the frequencies of five signals, while frequency counters are limited to measuring one signal. In addition, frequency counters do not have the capability to measure power or phase.

### Power Meters

With an internal power-reference signal, power meters provide better amplitude accuracy than does the HP 70820A. Power meters also measure the total power of a signal, while the HP 70820A is frequency selective. Frequency selectivity allows the HP 70820A to measure lower signal levels (typically -85 dBm for a known signal frequency) than is possible using a power meter, in addition to the ability to measure frequency and phase. Power meters require multiple sensors to cover a wide range of frequencies and power levels, while the HP 70820A needs no sensors.

The HP 70820A has internal amplitude corrections, allowing the accuracy of a power meter to be transferred to an HP 70820A.

### Spectrum Analyzers

The amplitude and frequency accuracy of the HP 70820A typically exceeds that of microwave spectrum analyzers, although some spectrum analyzers have built-in frequency counters. The HP 70820A is similar to spectrum analyzers in that it is frequency selective and can measure multiple signals at the same time. While spectrum analyzers can display a large number of responses over a broad frequency range, the HP 70820A, in frequency-and-power mode, is limited to reporting the five largest signals and their harmonics. Spectrum analyzers tend to have greater sensitivity than does the HP 70820A. Unlike the HP 70820A, spectrum analyzers do not measure phase.

# Chapter 4
## Vector Voltage Measurements

Upon determining the frequency of the input signal, the HP 70820A measures the gain and phase relationships between channel 1 and channel 2. In addition to frequency, gain and phase, the power level at either channel can also be displayed.

Vector voltage measurements differ from swept network-analysis measurements in that the measurement occurs at a single frequency and it is not required that the source be either referenced to or controlled by the HP 70820A. In the vector-voltage mode of operation, the signal source can be part of the device under test, and the frequency of the input signal can be between 500 Hz and 40 GHz.

The measurement examples that follow show how to use the HP 70820A for transmission and phase-matching measurements. Reflection measurements can also be performed using the setup shown for vector network-analysis reflection measurements. Following the measurement examples is a discussion of measurement specifications and limitations, and a comparison is made between the HP 70820A and dedicated vector voltmeters.

### 4.1 Transmission Measurement Example: FET Amplifier Gain and Phase

#### Measurement Setup and Results

Figure 29 shows the measurement setup for vector voltage transmission measurements. This configuration can be used for measuring the gain, insertion loss, or phase shift of two-port devices at a single frequency.

- Connect source output to power splitter input
- Connect one output of power splitter to input of DUT
- Connect output of device under test (DUT) to CH1 input
- Connect other output of power splitter to CH2 input

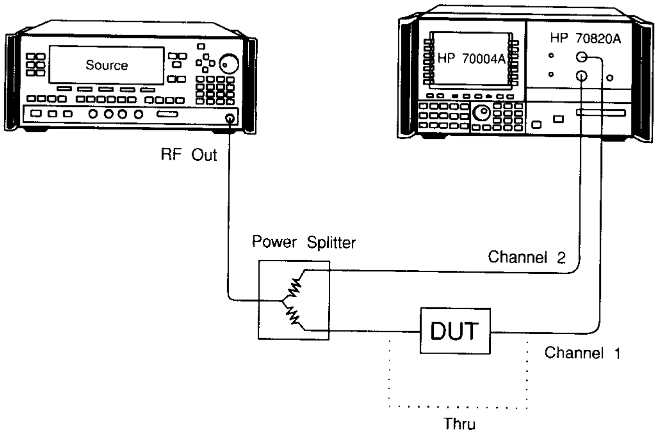
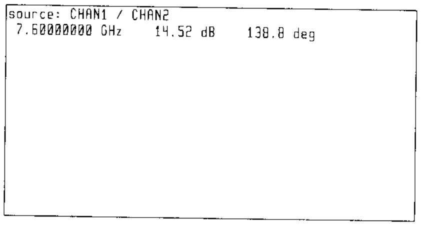


**Figure 29. Measurement setup for vector-voltage transmission measurement.**



```
source: CHAN1 / CHAN2
 7.60000000 GHz     14.52 dB     138.8 deg
```

**Figure 30. Display of the gain and phase of a three-stage FET amplifier. The signal frequency is also measured and displayed.**

Figure 30 shows the results from the measurement of a three-stage FET amplifier. The display shows that the signal frequency is 7.6 GHz, the gain of the amplifier is 14.5 dB, and the phase shift is 138.8 degrees.

**Measurement Procedure**

Using the setup shown in figure 29, activate the vector-voltage mode of operation in the HP 70820A by executing the following keystrokes:

- **States** menu ; **VECTOR VOLTAGE**.

In this mode, the HP 70820A determines the frequency of the incoming signal at channel 2 and then measures the ratio of the magnitude of the channel 1 signal to the channel 2 signal and the phase difference between the channel 1 signal and the channel 2 signal. The HP 70820A tracks the signal at channel 2 because it is defined to be the trigger input. When channel 2 detects a change in frequency, it measures the new frequency and continues with the measurements. If a signal source is configured to be controlled by the HP 70820A, the signal track function is turned off automatically (when VECTOR VOLTAGE is pressed) since the frequency is known).

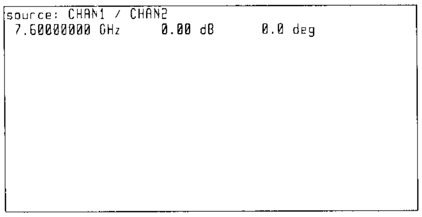
The measurement system should be normalized before a measurement of the device under test is performed.

- Remove the device under test
- Make thru connection as shown in figure 29 (dashed line)

This setup will be used as the zero-gain, zero-phase shift reference. Press the following keys to set the reference to zero:

- **Table** menu ; **delta** ; **SET REF**.

This sets the gain and phase readings to zero, as shown in figure 31. For noisy signals, averaging the normalization measurement before setting the reference can improve the measurement accuracy. Refer to the section that follows, "Additional Capabilities," for more information.



```
source: CHAN1 / CHAN2
 7.60000000 GHz      0.00 dB       0.0 deg
```

**Figure 31. Display of zero gain and zero phase after thru normalization for transmission measurement.**

- Reinsert DUT into measurement setup

Measurement results are displayed as shown in figure 30.

## Additional Capabilities

### *Traces, display*

The upper half of the screen can be used to display traces that correspond to the gain or phase of the device under test. These traces provide the operator with feedback during adjustment of the device under test. Normally, these traces are not displayed during vector-voltage operation. These waveforms are displayed by defining trace 1 as **TABLE** and setting the trace 1 **display** to **ON** in the Trace menu. Units used in the tabular display are dB for the ratio of the magnitudes of the signals and degrees for the phase. With a trace input defined to be **TABLE**, the trace display can be formatted as the **Real** part, the **Mag**nitude, the **Logmag**nitude, or the **Phase** of the complex ratio given in the table. The format is selected by using the **Format** function under the Traces menu. The easiest method for reading data from the trace is to use the **Markers**. The magnitude readout of the markers can be set to logarithmic or linear terms (independent of the trace format setting). The phase readout of the markers can be set to degrees or radians. These settings are accessed under the **readout** function of the marker menu.

### *Reducing noise, increasing speed*

The features presented in the "Reducing noise, increasing speed" section of chapter 3 can also be used for vector-voltage measurements. Refer to section 3.1 for more information.

### *Use of probes*

For devices without coaxial input and output ports, transmission measurements can be made using probes such as the HP 85024A high-frequency probes. Probe power ports, located in the HP 70820A next to the RF inputs, provide the power to operate the HP 85024A probes.

The normalization routine for this measurement requires probing the same signal (input or output) with the channel 1 and channel 2 probes and then selecting the **Set Ref** function. The channel 1 probe is then placed at the input and the channel 2 probe at the output of the device under test to perform the measurement.

The **single update** function, located under the Table menu, is a useful feature for making probe measurements. When the probes are placed correctly, the single update function can be executed and the measurement will be saved, allowing the probes to be removed from the measurement points. For absolute power measurements using probes, the **EXTERNL ATTEN** function located under **hardware** under the Scale menu can be used to compensate for probe attenuation factors.

## 4.2 Two-Channel Phase Comparison Example: Dual Synthesizer Phase Difference

The technique used for this measurement can be used for measuring the phase difference between many devices. For example, the technique could be used to measure the IF phase matching of multi-channel receivers or interferometers.

### Measurement Setup and Results

The setup for the dual-synthesizer phase-difference measurement is shown in figure 32. The HP 3326A is a two-channel synthesizer in which the phase relationship between the two outputs can be controlled. The frequency of the HP 3326A is set to 10 MHz, and the outputs are used as the 10 MHz reference oscillators for the two microwave synthesizers, which are set at the same frequency. By adjusting the phase difference of the HP 3326A outputs, the phase relationship between the two microwave synthesizers can be adjusted.

- Connect HP 3326A output A to REF IN of source #1
- Connect HP 3326A output B to REF in of source #2
- Connect source #1 RF output to CH1 input
- Connect source #2 RF output to CH2 input.

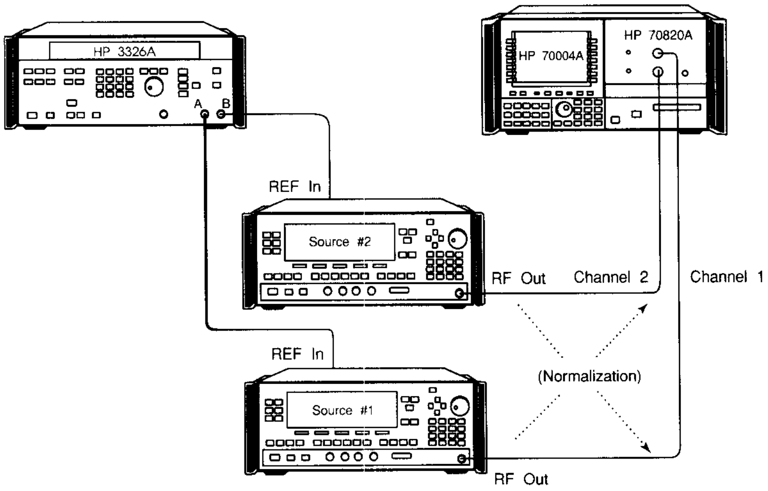
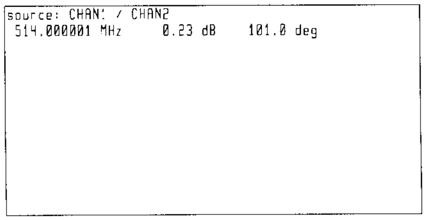


Figure 32. Measurement setup for dual-synthesizer phase matching.



```
source: CHAN1 / CHAN2
 514.000001 MHz     0.23 dB    101.0 deg
```

Figure 33. Display of differences of phase and magnitude in microwave synthesizers.

Figure 33 shows the measurement results. The two 514 MHz signals are 101 degrees out of phase. The phase difference between the HP 3326A outputs can be adjusted, either manually or with an external controller, until the desired phase relationship between the microwave signals is achieved. Although this measurement example concentrates on the phase matching of these sources, this measurement can also be used for the amplitude matching of the sources.

**Measurement Procedure**
Using the configuration shown in figure 32, activate the vector voltage mode of operation in the HP 70820 by executing the following keystrokes:

- **States** menu ; **VECTOR VOLTAGE**

In this mode, the HP 70820A determines the frequency of the incoming signal at channel 2 and then measures the phase ratio of the channel 1 signal to the channel 2 signal. The HP 70820A tracks the signal at channel 2 because it is defined to be the trigger input. Upon detecting a change in frequency, the HP 70820A will measure the new frequency and continue with the measurements. If a signal source is configured to be controlled by the HP 70820A, the signal-track function will be turned off automatically (when VECTOR VOLTAGE is pressed) since the frequency is known.

After the HP 70820A determines the frequency of the signals, it displays the magnitude and phase differences, as shown in figure 33.

For improved accuracy, the path length differences from the desired measurement point (phase reference plane) to the HP 70820A inputs can be corrected.

Corrections are accomplished using the auto skew and channel 2 skew functions. These functions apply a time shift to the channel 2 signal. The auto skew function determines and applies the time shift necessary to set the measured phase difference between channel 1 and channel 2 to zero.

Activate the auto skew function with the following keystrokes:

- **Calib** menu ; **chan skew** ; **AUTO SKEW**

For this example, the function will return a channel 2 skew setting of -545.8 ps, which is equivalent to 101.0 degrees at 514 MHz, and the phase reading will be zero.

- Disconnect the cables at the phase reference plane
- Re-connect cables to the opposite channels

Set the channel 2 skew to zero by executing the following keystrokes:

- **CHAN2 SKEW** ; **0** ; **ps**

Ideally, the phase difference would now read -101.0 degrees, but due to path length differences it reads -105.0 degrees. Activate the auto skew function:

- **AUTO SKEW**

The result is 567.4 ps, and the phase reads 0 degrees. If the path lengths were identical, the two skew values would be the same. The actual path length difference is one half the difference of the magnitudes of the skew readings. For this example, the path length difference = (567.4 ps - 545.8 ps)/2 = 10.8 ps. This is entered by executing the following keystrokes:

- **CHAN2 SKEW** ; **10.8** ; **ps**

The HP 70820A display will now read out the corrected results (-103.0 degrees).

This correction procedure assumes that the path lengths were within one-half wavelength of each other. If they are, this skew value applies at all frequencies. If not, the value applies proper phase correction only at the frequency that these measurements were made.

In order to accurately correct for multi-wavelength path differences, the auto-skew routine should be used first on a low-frequency signal. The low-frequency signal must be selected to have a wavelength greater than twice the difference in the path length, allowing for an unambiguous path-length correction.

Each successive use of the auto-skew function is based on the previous setting. That is, the previous setting determines the nearest (to the last value) channel-skew value that will set the phase difference between the channels to zero. After the low-frequency adjustment has been made, the frequency should be increased and the auto-skew function repeated. This adds greater resolution to the first measurement. This process can be repeated, with increasing frequencies, to obtain the desired skew resolution.

### Additional Capabilities

The additional features of the HP 70820A in the vector voltage mode of operation that were discussed in section 4.1, "Transmission Measurement Example," also could be used for this measurement. Refer to section 4.1 for information on these features.

## 4.3 Applying the Specifications

The frequency accuracy of these table-mode measurements is specified as "Signal Track Frequency Accuracy," under "Signal Acquisition," in the HP 70820A specifications.

The amplitude accuracy of the normalized gain measurement includes the specification, "Amplitude Accuracy vs. Input Power Level," in addition to the effects of mismatches.

The accuracy of normalized phase measurements includes the specification, "Ratio Phase Accuracy vs Input Power Level," in addition to the effects of mismatches.

## 4.4 Limitations

The HP 70820A can accomplish vector-voltage measurements from 500 Hz to 40 GHz. In this mode of operation, the HP 70820A tracks the largest signal at the channel 2 input and typically requires signals greater than -50 dBm (at 26.5 GHz) to determine the frequency.

Once the precise frequency is determined, or entered by the user, the signal track feature can be turned off and the power level can be measured to about 30 dB lower than the level required for acquiring the frequency.

The HP 70820A can determine the frequency of signals having a limited amount of frequency modulation. The maximum peak-to-peak frequency deviation must be less than either 100 kHz or twice the modulation rate, whichever is greater.

## 4.5 Comparison with Vector Voltmeters

Vector voltmeters typically provide either 50 ohm inputs or high-impedance inputs. The HP 70820A offers 50 ohm inputs only, but high-impedance probes, such as the HP 85024A high-frequency probes, can be used with the HP 70820A to give it high impedance capability.

The HP 70820A has a greater frequency range than do vector voltmeters. Typically, a vector voltmeter may have a 50 ohm frequency range of 300 kHz to 2 GHz and a high impedance frequency range of 100 kHz to 1 GHz. The HP 70820A has a 50 ohm frequency range of 500 Hz to 40 GHz. With the HP 85024A high frequency probes, the high-impedance frequency range is 300 kHz to 3 GHz.

Vector voltmeters tend to have more display format options, especially for reflection measurements, than does the HP 70820A in the vector-voltmeter mode of operation.

Vector voltmeters typically lock onto the reference channel. They can then track changes in signal frequency within a certain range, real-time. Due to phase-lock-loop dynamic range, vector voltmeters have limited sensitivity on the reference channel (approximately -60 dBm at 1 GHz) compared to the measurement channel (approximately -90 dBm at 1 GHz).

The HP 70820A determines the frequency of the input signal by sampling it at a number of sampling frequencies and then calculating the input frequency based on the resulting IF frequencies. This process can be performed on the IF signal of either channel. When the HP 70820A monitors a signal of known frequency, the sensitivity of each channel is typically -85 dBm at 1 GHz (with no other signals present). With signal track on, the minimum signal power level required on the trigger input channel is typically -50 dBm.

Vector voltmeters and the HP 70820A have similar display update rates, typically 2 readings per second for the HP 70820A and 3 readings per second for the vector voltmeter. The vector voltmeter has a faster HP-IB transfer rate (approximately 12 readings per second compared to three readings per second for the HP 70820A).

For measurements where speed is a prime concern, the HP 70820A can achieve HP-IB transfer rates of approximately 14 readings per second for frequency-stable signals. This is accomplished by setting up a measurement of the channel 1 and channel 2 waveforms with a small number of points, such as 64, taking the FFT of each waveform, placing the markers on the peak of each FFT result, and using the delta-marker function to measure the magnitude and phase differences.

# Chapter 5
## Network Analysis Measurements

Combining the HP 70820A and a synthesized signal source allows vector network-analysis measurements to be performed. Transmission measurements, such as gain, phase, and delay, as well as reflection measurements, can be made with CW (10 Hz to 40 GHz) or pulsed-RF (500 kHz to 40 GHz) signals.

This chapter discusses vector and scalar network measurements performed using a CW stimulus. Network measurements using a pulsed-RF stimulus are discussed in other titles of the Product Note 70820 series.

These network measurements require a synthesized source that can be controlled by the HP 70820A via the HP-IB bus or the MSIB bus. Compatible sources are listed in appendix A. The frequency range of the measurement will be a function of both the source and the HP 70820A.

Normalization can be used to correct for frequency-response errors, but full vector error correction is not available. It is possible to develop a vector error-calibration procedure to be performed by a controller connected to the HP 70820A. The correction factors could then be downloaded into the HP 70820A and applied to the measured data. An example of a three-term vector reflection correction using the array processing capabilities of the HP 70820A is presented in section 8.3 of chapter 8, "Array processing."

Any external hardware, such as couplers, splitters, and switches, required for a particular measurement must be provided by the user since no standard 40 GHz test sets presently are available for the HP 70820A.

In addition to standard scalar and vector measurements, the HP 70820A can be used to complete harmonic and offset sweeps with a CW stimulus. An example of this can be seen in section 5.4.

The following four measurement examples show how to use the HP 70820A for vector transmission measurements, vector reflection measurements, simultaneous scalar transmission and reflection measurements, and scalar harmonic-transmission measurements. Following these measurement examples is a discussion of the measurement specifications and limitations, and a comparison is made between the HP 70820A and network analyzers.

## 5.1 Transmission Measurement Example: Gain and Phase of 37 GHz Bandpass Filter

### Measurement Setup and Results

The measurement setup for vector transmission measurements is shown in figure 34. This configuration can be used for making vector and scalar transmission measurements using ratios.

- Connect source output to power-splitter input
- Connect one output of power splitter to input of DUT
- Connect output of DUT to CH1 input
- Connect other output of power splitter to CH2 input
- Connect 10 MHz reference output of synthesized source to 10 MHz reference input of HP 70820A
- Connect HP-IB on rear panel of HP 70820A to HP-IB on rear panel of source. (For MMS-based sources, this connection is via MSIB.)

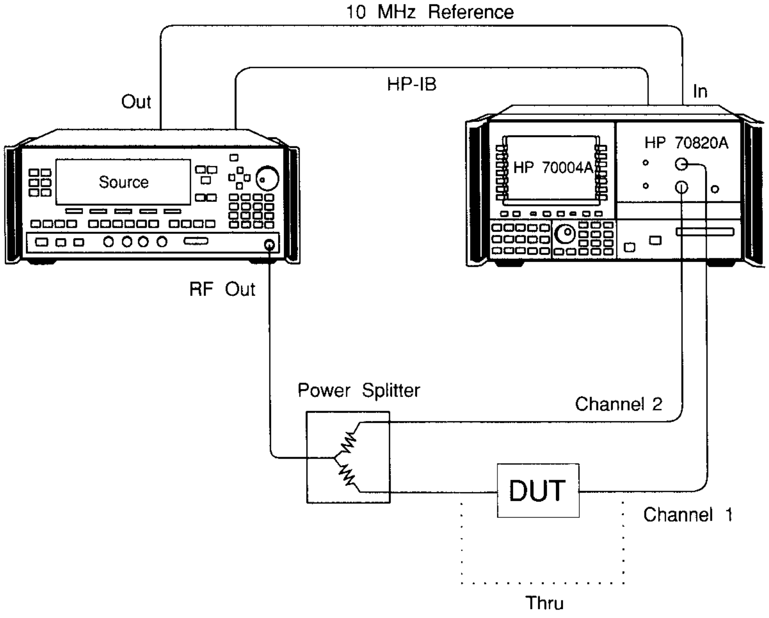


**Figure 34. Measurement setup for vector network-analysis transmission measurement.**

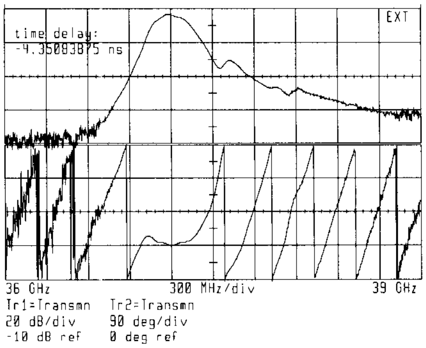


**Figure 35. Normalized transmission measurement of bandpass-filter gain and phase from 36 to 39 GHz.**

Figure 35 presents the measurement results from a 37 GHz bandpass filter. The upper trace, with a vertical scale of 20 dB per division, shows the insertion loss of the filter. The lower trace shows the phase through the filter, after time-delay compensation.

### Measurement Procedure

For this measurement, the HP 70820A must be configured to control the synthesized source. Appendix A presents the configuration procedure required to perform this measurement.

Using the setup shown in figure 34, activate the vector-network-analysis mode of operation by pressing the following softkeys:

- **States** menu ; **VECTOR NETWORK**

In the vector network-analysis mode of operation, the HP 70820A accomplishes stepped frequency-response measurements by controlling the source. The vector-network state defines trace 1 as channel 1/channel 2. Trace 2 is defined as trace 1 divided by a thru normalization trace that is to be stored in memory 1. Initially, only trace 1 is displayed, as memory 1 must be filled with data prior to displaying trace 2. The number of measurement points (frequencies) is automatically set to 101; however this may be changed to a maximum of 1,024. The start and stop frequencies, power level, and RF output on/off must be set for the measurement.

For this example, the frequency range to be measured is 36 to 39 GHz, and the desired source output power level is 0 dBm. Set these parameters as follows:

- (The HP 70820A is currently in the Main menu)
- **START** ; **36** ; **GHz**
- **STOP** ; **39** ; **GHz**
- **source POWER** ; **0** ; **dBm**
- Press **RF out ON | OFF** until ON is underlined

Set the number of trace points to 801, reduce the noise filter bandwidth, and activate the single sweep mode as follows:

- **CONFIG** menu ; **801** ; **ENTER**
- **MAIN** menu ; **NOISE FILTER** ; **100** ; **Hz**
- **Trigger** menu ; **SINGLE**

During the sweep, a diamond moves across the bottom of the display. This indicates the frequency of the source as it is stepped from the start frequency to the stop frequency. The display of the synthesizer is turned off during the sweep to speed up the measurement. Before performing a measurement of the device under test, the measurement system should be normalized.

- Remove the device under test
- Make thru connection as in Figure 34 (dashed line)

This setup will be used as the thru normalization for the transmission measurement. Take a single sweep and store it in memory 1 for normalization.

- **SINGLE** ; wait for the sweep to finish
- **Traces** menu (TR1 is active)
- **store trace** ; **TO MEM1**

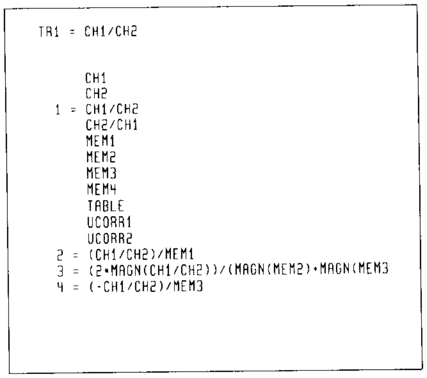
As stated above, trace 2 is defined as the normalized transmission. In order to display magnitude as one trace and phase as another, one more trace also will be defined as normalized transmission. Since the un-normalized transmission is no longer needed for this measurement, trace 1 will be re-defined to match the definition of trace 2. This is accomplished as follows:

- **input:**
- Scroll to **2 = (CH1/CH2)/MEM1** ; **RETURN** as shown in figure 36 (this will define trace 1 to be the same as trace 2).

Trace 1 should be formatted automatically as log magnitude. Format trace 2 as phase and display as follows:

- **select:** TR1 ; **TR2**
- Press **display ON | OFF** until ON is underlined
- **format** FRQ,LOG ; **PHASE** to set to phase

At this time, trace 1 should be 0 dB and trace 2 should be 0 degrees, as shown in figure 37. Now that the normalization trace has been saved, reinsert the device under test and take another measurement.



```
TR1 = CH1/CH2


        CH1
        CH2
    1 = CH1/CH2
        CH2/CH1
        MEM1
        MEM2
        MEM3
        MEM4
        TABLE
        UCORR1
        UCORR2
    2 = (CH1/CH2)/MEM1
    3 = (2*MAGN(CH1/CH2))/(MAGN(MEM2)+MAGN(MEM3
    4 = (-CH1/CH2)/MEM3
```

**Figure 36. Input menu showing predefined equations and trace definitions. Trace 1 is being defined.**

- Reinsert DUT into measurement setup

- **Trigger** menu ; **SINGLE**

Figure 38 shows the display of the insertion loss and phase through the filter, prior to compensation for path length. Set the trace scaling as appropriate for each trace using the following keystrokes:

- **Scale** menu
- Press **select:** TR2 ; **TRX** to activate desired trace
- Use **SCALE** and **REF LEV** functions to set the scale and reference level as appropriate

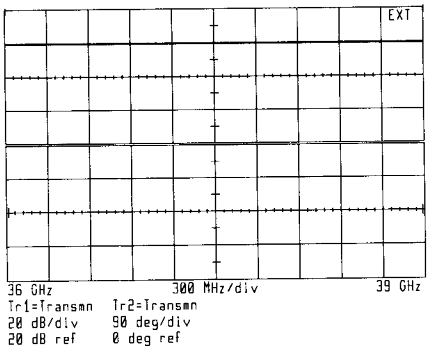


**Figure 37. Display of 0 dB gain and 0 degrees phase at transmission-measurement normalization.**

The time-delay function can be used to remove a fixed amount of delay, allowing the deviation from linear phase to be displayed. Since the path to channel 1 became longer after the normalization (due to the DUT), a negative amount of time delay must be added to compensate for the difference.

The auto-delay function provides a method of automatically compensating for the delay. This function can be executed for use on the entire phase trace, or for only a small portion by using the markers to set the window of operation. Devices such as cables, which have constant delay over frequency, are well suited for the auto-delay function without using markers. Devices having a changing delay as a function of frequency, such as filters, are well suited for the auto-delay function over a small frequency window, using markers. Place the markers on the phase trace and execute the auto-delay function as follows:

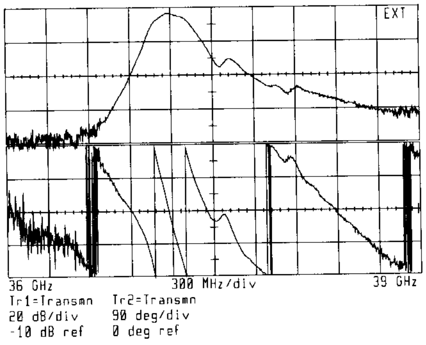


**Figure 38. Display of insertion loss and phase through the filter prior to compensating for the path length.**

- **Markers** menu
- **M1(↓)** until **TR2** is the selected trace
- Scroll until marker is at lower -6 dB frequency
- **M2(↑)** until **TR2** is the selected trace
- Scroll until marker is at upper -6 dB frequency
- **Scale** menu ; **select:** TRX ; **TR2**
- **AUTO DELAY** (on second level)

This flattens the windowed portion of the phase trace as much as possible with a single delay value applied to the whole trace. In order to determine how much delay has been compensated for, activate the time-delay function as follows:

- **TIME DELAY**

The results appear in figure 35. Note that a negative time delay means that delay had to be removed. (The channel 1 path was electrically longer than channel 2 path relative to the normalization lengths.)

## Additional Capabilities

### Group delay

Just as the time-delay function was used to obtain an average value of the delay over a certain frequency range, the group delay can be displayed as a function of frequency. By defining a trace to be **TD(TR1)**, group-delay measurements can be accomplished with the data that already has been taken. Figure 39 shows the display of trace 1 equal to the magnitude response (top) and trace 4 equal to the group delay of the filter as a function of frequency (bottom). For this figure, the phase trace (trace 2) was not displayed, and the **smoothing width** (located under avg,hld which is under the traces menu) was set to 5.

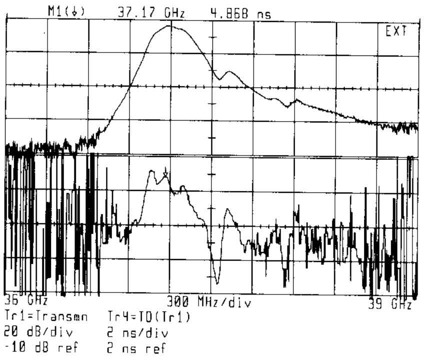


**Figure 39. Group-delay measurement (lower trace) of the 37 GHz bandpass filter**

### Reducing noise

In stepped frequency measurements, the noise-filter function (**NOISE FILTER**) located in the Main menu controls the bandwidth of the digital filtering occuring at each frequency point. The noise-filter bandwidth can be set from 10 Hz to 50 kHz. The narrower the filter, the more data points required at each frequency measured. As a result, lowering the noise-filter bandwidth can increase the measurement time. Small time penalties exist for filter bandwidths down to about 1 kHz.

Another method to reduce the noise on the measurement is to use the vector-averaging function (**VECTOR AVERAGE**), located under the avg,hld key, which is under the Traces menu. This function can be set to average from 1 to 1,024 traces. Since stable vector data is available, the vector-average function is preferred over format averaging. Vector averaging will work only for ratio measurements. In measurements where only the magnitude information is stable, such as non-ratio scalar measurements, format averaging should be used.

### Markers

The markers on either trace can be set to read just the trace data, magnitude or phase, or both the magnitude and phase information for traces formatted as magnitude, log magnitude, or phase. This is controlled using the **SCL | VEC** function located under the readout options key, which is under the Markers menu. In addition, the amplitude portion of the marker readout can be set to linear or logarithmic units, regardless of the trace format units, and the phase can be set to read out as degrees or radians. These functions are also controlled under readout options.

## 5.2 Reflection Measurement Example: $S_{11}$ of Wideband Amplifier

### Measurement Setup and Results

The measurement setup for vector reflection measurements is shown in figure 40. This configuration can be used for making vector and scalar reflection measurements using ratios.

- Connect source output to power-splitter input
- Connect one output of power splitter to CH2 input
- Connect other output of power splitter to non-coupled input of coupler
- Connect DUT input port to coupled input of coupler
- Connect coupled output of coupler to CH1 input
- Connect 10 MHz reference output of synthesized source to 10 MHz reference input of HP 70820A
- Connect HP-IB on rear panel of HP 70820A to HP-IB on rear panel of source (for MMS sources, this connection is via MSIB)
- Connect 50 ohm termination on DUT output port
- For highly reflective devices, an attenuator can be placed at the input to the DUT to reduce measurement errors. The attenuator can be normalized out as part of the setup.

Figure 41 shows the results of a 2 to 8 GHz vector reflection measurement performed on a wideband amplifier. The top trace is the return loss of the amplifier in dB, and the bottom trace is the reflection phase in degrees.

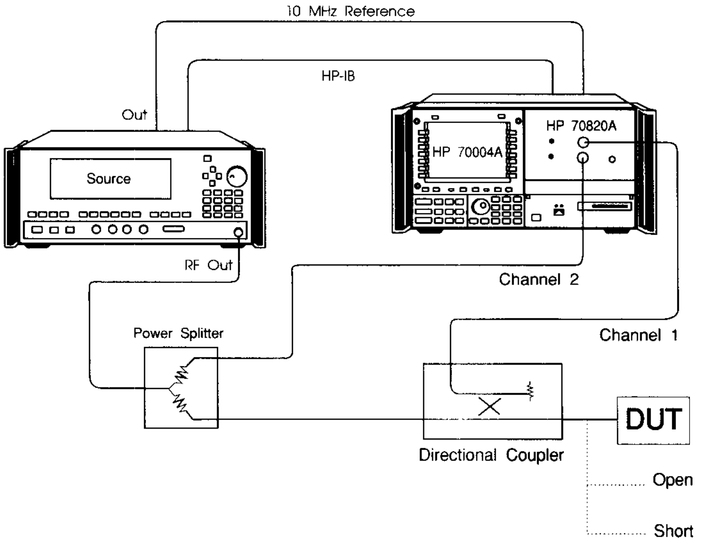


**Figure 40. Measurement setup for vector network-analysis reflection measurement.**

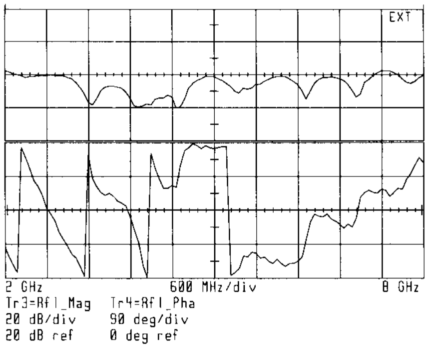


**Figure 41. Reflection measurement of wideband amplifier. The top trace is the return loss in dB, and the bottom trace is the phase in degrees.**

## Measurement Procedure

For this measurement, the HP 70820A must be configured to control the synthesized source. Appendix A presents the configuration procedure required to perform this measurement.

Using the setup shown in figure 40, activate the vector network-analysis mode of operation by pressing the following softkeys:

**States** menu ; **VECTOR NETWORK**

In the vector network-analysis mode of operation, the HP 70820A accomplishes stepped frequency-response measurements by controlling the source. The vector-network state defines trace 1 to be channel 1/channel 2. Trace 3 is defined to be trace 1 divided by an open/short average normalization. This is the normalization used by scalar network analyzers for reflection measurements. The open trace data is stored in memory 2, and the short trace data is stored in memory 3. This normalization applies only to the magnitude information; therefore, trace 3 should only be formatted as magnitude or log magnitude, not phase.

Trace 4 is defined to be the opposite of trace 1 divided by the short-trace data stored in memory 3. This short normalization is intended for the phase of the reflection. It could also be used for magnitude, but the normalization is not as accurate as that used for trace 3.

The phase of the open trace data is not used in either normalization because at high frequencies, opens have significant capacitance which changes the angle of their reflection coefficient. However, the capacitance does not affect the magnitude of the reflection. Low-frequency phase measurements could be normalized to an open by removing the "opposite of" from the trace 4 definition and using the memory that contains open data.

Initially, only trace 1 is displayed, as memories 2 and 3 must be filled with data prior to displaying trace 3 or 4. The number of measurement points (frequencies) is set to 101; however, this setting may be changed to a maximum of 1,024. The start and stop frequencies, power level, and RF-output on/off need to be set for the measurement. For this example, the frequency range to be measured extends from 2 to 8 GHz, and the desired source output power level is -10 dBm. Set these parameters as follows:

- (The HP 70820A is currently in the Main menu)
- **START** ; **2** ; **GHz**
- **STOP** ; **8** ; **GHz**
- **source POWER** ; **-10** ; **dBm**
- Press **RF out ON | OFF** until ON is underlined

Activate the single-sweep mode as follows:

- **Trigger** menu ; **SINGLE**

During the sweep, a diamond moves across the bottom of the display. This indicates the frequency of the source as it is stepped from the start frequency to the stop frequency. The display of the synthesizer is turned off during the sweep to speed up the measurement. Before performing a measurement of the device under test, the measurement system should be normalized.

- Remove the device under test
- Connect an open as in figure 40 (dashed line)

This setup will be used as the open normalization for the reflection measurement. Take a single sweep and store it in memory 2 for normalization.

- **SINGLE** ; wait for the sweep to finish
- **Traces** menu (TR1 is active)
- **store trace** ; **TO MEM2**

- Remove the open
- Connect a short as in figure 40 (dashed line)

This setup will be used as the short normalization for the reflection measurement. Take a single sweep and store it in memory 3 for normalization.

- **Trigger** menu ; **SINGLE** ; wait for the sweep to finish
- **Traces** menu (TR1 is active)
- **store trace** ; **TO MEM3**

As stated above, trace 3 is defined as the reflection magnitude normalized to an open/short average, and trace 4 is the reflection phase normalized to a short. Once the normalization data has been taken, these traces can be displayed. Since trace 1 is no longer needed for this measurement, turn off its display.

- (TR1 is active)
- **display ON | OFF** until OFF is underlined
- **select:** TR1 ; **TR3**
- **display ON | OFF** until ON is underlined
- **select:** TR3 ; **TR4**
- **display ON | OFF** until ON is underlined

Trace 3 should be formatted automatically as log magnitude, and trace 4 should be formatted automatically as phase.

Trace 3 now should be approximately 0 dB and trace 4 should be approximately 180 degrees. Due to the phase wrap-around from -180 degrees to +180 degrees, the display will appear as in figure 42. Trace 3 will not be exactly 0 dB, due to the method of normalization. With the normalization traces saved, reinsert the device under test and take another measurement.

- Reinsert DUT into measurement setup

- **Trigger** menu ; **SINGLE**

After the sweep has finished, the display should appear similar to figure 41. Figure 41 shows the magnitude (log) and phase of the reflection coefficient of the amplifier under test. Set the trace scaling as appropriate for each trace using the following keystrokes:

- **Scale** menu
- Press **select:** TR4 ; **TRX** to activate desired trace
- Use **SCALE** and **REF LEV** functions to set the scale and reference level as appropriate

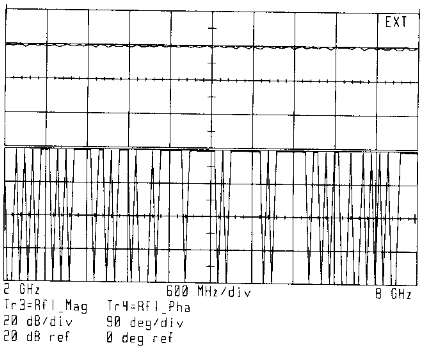


**Figure 42. Display of 0 dB magnitude and 180 degrees phase at reflection measurement normalization. Trace 4 appears as it does due to the phase wrap around from +180 degrees to -180 degrees.**

## Additional Capabilities

### Noise reduction, markers

The noise-reduction techniques and marker functions discussed in the vector transmission-measurement example of section 5.1 can be applied to this measurement with one exception. The magnitude-reflection trace (TR3) does not contain stable phase information; therefore, format averaging should be used on trace 3 instead of vector averaging. The **FORMAT AVERAGE** is located under the avg, hld key which is under the Traces menu. Vector averaging can still be used for trace 4 since it provides repeatable data for both magnitude and phase.

## 5.3 Scalar Measurement Example: Simultaneous Gain and Return Loss of 3.6 GHz BandpassFilter

### Measurement Setup and Results

The measurement setup for the simultaneous scalar measurement of transmission and reflection is shown in figure 43. This configuration can be used for making scalar network measurements without ratios. Scalar measurements with ratios tend to be more accurate, and they are made using the vector network state and configurations as discussed in the previous two measurement examples. The advantage of the measurements made without ratios is that transmission and reflection can be measured simultaneously. This setup can also be used for harmonic and offset sweeps, as measurements using ratios are not possible due to the difference in input and output frequencies.

- Connect source output to non-coupled input of coupler
- Connect DUT input port to coupled input of coupler
- Connect DUT output to CH1 input for transmission measurement
- Connect coupled output of coupler to CH2 input for return loss measurement
- Connect 10 MHz reference output of synthesized source to 10 MHz reference input of HP 70820A
- Connect HP-IB on rear panel of HP 70820A to HP-IB on rear panel of source. (For MMS-based sources, this connection is via MSIB.)

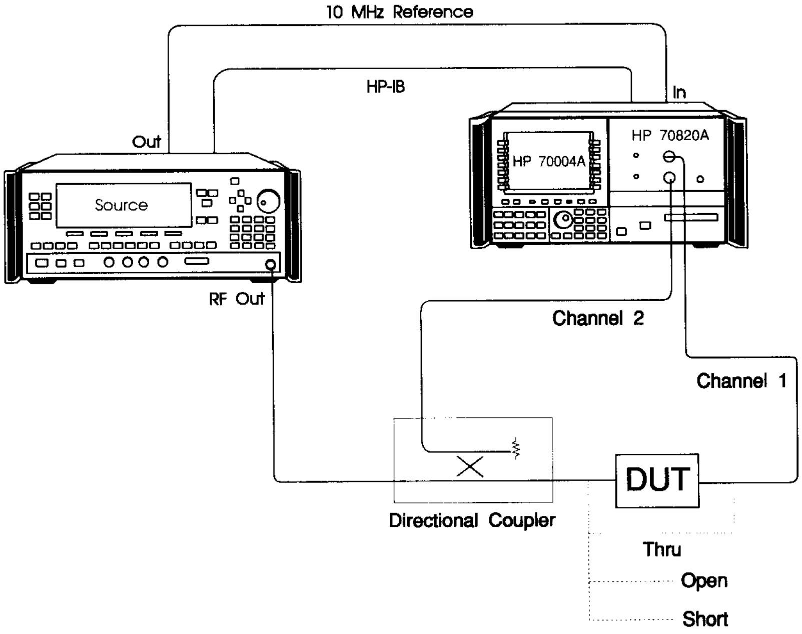


Figure 43. Measurement setup for simultaneous measurement of insertion loss and return loss of a filter.

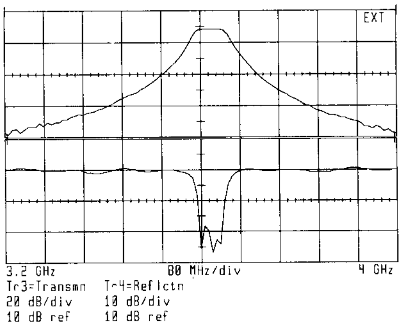


Figure 44. Measurement of insertion loss and return loss of a 3.6 GHz bandpass filter.

Figure 44 shows the results from the measurement of a 3.6 GHz bandpass filter. The upper trace is the insertion loss of the filter, with a vertical scale of 20 dB per division. The lower trace is the return loss, with a vertical scale of 10 dB per division.

**Measurement Procedure**

For this measurement, the HP 70820A must be configured to control the synthesized source. Appendix A presents the configuration procedure required to perform this measurement.

Using the setup shown in figure 43, activate the scalar-network-analysis mode of operation by pressing the following keys:

- **States** menu ; **SCALAR NETWORK**

In the scalar network-analysis mode of operation, the HP 70820A accomplishes stepped frequency-response measurements by controlling the source. The scalar-network state defines trace 1 as channel 1 and trace 2 as channel 2. Trace 3 is defined as channel 1 divided by a thru normalization trace that is stored in memory 1. Trace 4 is defined as channel 2 divided by an open/short average normalization. The open trace data is stored in memory 2, and the short trace data is stored in memory 3.

Initially, only trace 1 and trace 2 are displayed, as memory 1 must be filled before trace 3 can be displayed, and memories 2 and 3 must be filled before trace 4 can be displayed. The only differences between the vector-network and scalar-network auto-states are the trace definitions and the marker readout format (scalar or vector).

The number of measurement points (frequencies) is set to 101; however, this setting may be changed to a maximum of 1,024. The start and stop frequencies, power level, and RF output on/off need to be set for the measurement. For this example, the frequency range to be measured is 3.2 GHz to 4.0 GHz, and the desired source output power level is -5 dBm. Set these parameters as follows:

- (The HP 70820A is currently in the Main menu)
- **START** ; **3.2** ; **GHz**
- **STOP** ; **4** ; **GHz**
- **source POWER** ; **-5 dBm**
- Press **RF out ON | OFF** until ON is underlined

Activate the single sweep mode as follows:

- **Trigger** menu ; **SINGLE**

During the sweep, a diamond moves across the bottom of the display, indicating the frequency of the source as it is stepped from the start frequency to the stop frequency. The display of the synthesizer is turned off during the sweep to speed up the measurement. Before performing a measurement of the device under test, the measurement system should be normalized. Three normalization measurements are required: thru, open, and short.

- Remove the device under test
- Make thru connection as in figure 43 (dashed line)

This setup will be used as the thru normalization for the transmission measurement. Take a single sweep, and store it in memory 1 for normalization.

- **SINGLE** ; wait for the sweep to finish
- **Traces** menu (TR1 is active)
- **store trace** ; **TO MEM1**

- Disconnect the thru connection
- Connect an open as shown in figure 43 (dashed line)

This setup will be used as the open normalization for the reflection measurement. Take a single sweep, and store it in memory 2 for normalization.

- **Trigger** menu ; **SINGLE** ; wait for sweep to finish
- **Traces** menu ; **select:** TR1 ; **TR2**
- **store trace** ; **TO MEM2**

- Remove the open
- Connect a short as in figure 43 (dashed line)

This setup will be used as the short normalization for the reflection measurement. Take a single sweep, and store it in memory 3 for normalization.

- **Trigger** menu ; **SINGLE**
- **Traces** menu (TR2 is active)
- **store trace** ; **TO MEM3**

As stated above, trace 3 is defined as the transmission magnitude normalized to a thru measurement, and trace 4 is defined as the reflection magnitude normalized to an open/short average. Now that the normalization data has been obtained, these traces can be displayed. Since they are no longer needed for this measurement, turn off the display of trace 1 and trace 2.

- (TR2 is active)
- **display ON | OFF** until OFF is underlined (TR2)
- **select:** TR2 ; **TR1**
- **display ON | OFF** until OFF is underlined (TR1)
- **select:** TR1 ; **TR3**
- **display ON | OFF** until ON is underlined (TR3)
- **select:** TR3 ; **TR4**
- **display ON | OFF** until ON is underlined (TR4)

Trace 3 and trace 4 are automatically formatted as log magnitude. Trace 4 should now be at about 0 dB, and trace 3 will have a very low value (such as -100 dBm), since the last measurement was made with no signal at the channel 1 input. With the normalization traces saved, reinsert the device under test and take another measurement.

- Reconnect DUT into measurement setup
  - **Trigger** menu ; **SINGLE**

After the sweep has finished, set the trace scaling as appropriate for each trace using the following keystrokes:

- **Scale** menu
- **select:** TR4 ; then **TRX** to activate desired trace
- Use **SCALE** and **REF LEV** functions to set the scale and reference level as appropriate

Figure 44 presents the results from the measurement of the band-pass filter.

## Additional Capabilities

### Noise reduction, markers

The noise-reduction techniques and marker functions discussed in the vector-transmission measurement example can be applied to this measurement with one exception. Trace 3 and trace 4 do not contain stable phase information; therefore, format averaging should be used instead of vector averaging. The **FORMAT AVERAGE** is located under the avg,hld key which is under the Traces menu.

## 5.4 Harmonic Sweep Measurement Example: Fundamental and Harmonic Output Powers of Frequency Doubler

### Measurement Setup and Results

The measurement setup for determining the fundamental and harmonic output powers of a frequency doubler is shown in figure 45. The configuration is the same as for a single-channel magnitude measurement. The available sweep options allow for harmonic, sub-harmonic, and offset sweeps, as well as for all their combinations. These sweep options allow testing of frequency multipliers and frequency translation devices. The test capabilities are implemented by setting the source to one frequency and tuning the HP 70820A to receive a signal at another frequency. Two-channel measurements can also be performed using the harmonic and offset capabilities, as long as the two signals input to the HP 70820A are at the same frequency.

- Connect source output to device under test input
- Connect DUT output to 20 dB pad because of high power levels. The measurement setup allows the effect of the 20 dB pad to be removed through normalization.
- Connect 20 dB pad output to CH1 input
- Connect 10 MHz reference output of synthesized source to 10 MHz reference input of HP 70820A
- Connect HP-IB on rear panel of HP 70820A to HP-IB on rear panel of source. (For MMS sources, this connection is via MSIB.)

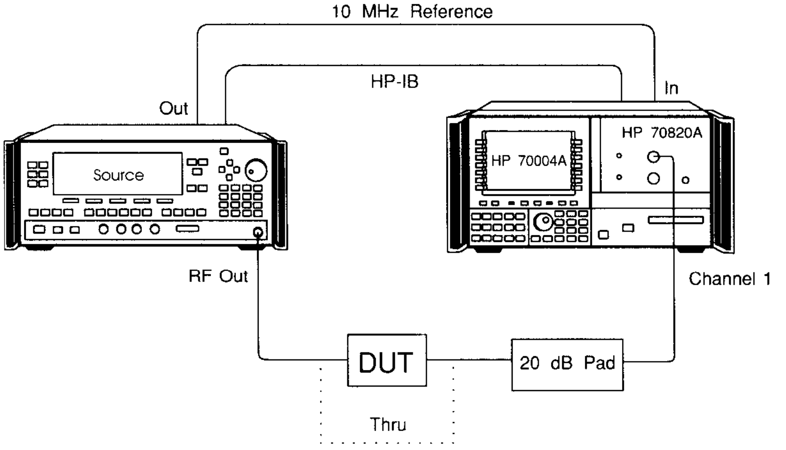


**Figure 45. Measurement setup for harmonic sweep measurement of microwave frequency doubler.**

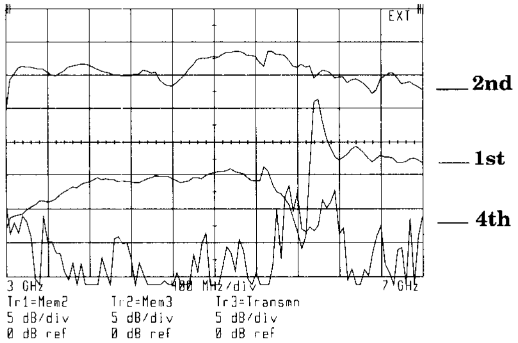


**Figure 46. Harmonic measurement of microwave frequency doubler. The three traces are 2nd-harmonic, fundamental, and 4th-harmonic output power. Each is normalized to the input power level.**

Figure 46 shows results from measurements, taken from 3 GHz to 7 GHz, of a microwave frequency doubler. The upper trace shows the 2nd-harmonic output power relative to the fundamental input power. The middle trace shows the fundamental output power relative to the fundamental input power. The lower trace shows the 4th-harmonic output power relative to the fundamental input power. Each trace is scaled at 5 dB per division and has a reference level of 0 dB at the top of the screen.

By using the same scaling, the relative power levels of the different outputs can be compared to one another, as well as relative to the input power. Considerable fundamental feedthrough can be seen at 6 GHz. Notice that the frequency readout at the bottom of the screen is based on the active trace.

**Measurement Procedure**
For harmonic sweep measurements, the HP 70820A must be configured to control the synthesized source. Appendix A describes the configuration for performing this measurement.

Using the setup shown in figure 45, activate the scalar analysis mode of operation by pressing the following keys:

- **States** menu ; **SCALAR NETWORK**

In this mode of operation, the HP 70820A accomplishes stepped frequency-response measurements by controlling the source. The scalar-network state defines trace 1 as channel 1 and trace 3 as channel 1 divided by a thru normalization trace that will be stored in memory 1. The predefined equations for trace 2 and trace 4 are not used during this measurement. The trace 2 display is turned off.

As measurements of the various harmonics are completed, results are stored in memories and then displayed. Before displaying the normalized trace 3, memory 1 must be filled. In this measurement, memory 1 will be filled with input data taken from 3 GHz to 7 GHz. This data will be used as the normalization trace for all the harmonic measurements, even though the start and stop frequencies are changed. Measurement of the ratio of the output harmonic power to the input fundamental power therefore is made possible.

For this example, the number of measurement points (frequencies) is set to 101; however, this number may be changed to a maximum of 1,024. The start and stop frequencies, power level, and RF output on/off need to be set for the measurement. For this example, the frequency range to be measured is 3 GHz to 7 GHz, and the desired source output power level is +10 dBm. Set these parameters as follows:

- (Main menu is active currently) • **START** ; **3** ; **GHz**
- **STOP** ; **7** ; **GHz**
- **source POWER** ; **10** ; **dBm**
- Press **RF out ON | OFF** until ON is underlined

Activate the single sweep mode as follows:

- **Trigger** menu ; **SINGLE**

Since channel 2 will not be used during this measurement, turn off the trace 2 display.

- **Traces** menu ; **select:** TR1 ; **TR2**
- Press **display ON | OFF** until OFF is underlined

During the sweep, a diamond moves across the bottom of the display, indicating the frequency of the source as it is stepped from the start frequency to the stop frequency. The display of the synthesizer is turned off during the sweep to speed up the measurement. Before performing a measurement of the device under test, the measurement system should be normalized.

- Remove the device under test
- Make thru connection as shown in figure 45 (dashed line)

This measurement setup will be used for thru normalization, at the fundamental frequency, for the transmission measurement. Take a single sweep and store it in memory 1 for normalization.

- **Trigger** menu ; **SINGLE** ; wait for the sweep to finish
- **Traces** menu ; **select:** TR2 ; **TR1**
- **store trace** ; **TO MEM1**

Trace 3 is defined as the channel 1 data normalized by memory 1. Now that memory 1 has been filled, trace 3 can be displayed. Turn off the display of the data that is not normalized, trace 1, as it is no longer needed.

- (TR1 is active)
- Press **display ON | OFF** until OFF is underlined
- Press **select:** TR1 ; **TR3**
- Press **display ON | OFF** until ON is underlined

Since memory 1 data now is equal to channel 1 data, the value of trace 3 is 0 dB. Reinsert the device into the measurement setup and take another measurement.

- Reconnect DUT into measurement setup
  - **Trigger** menu
  - **SINGLE** ; wait for the sweep to update

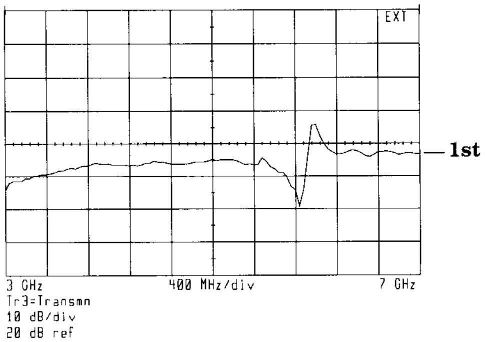


**Figure 47. Insertion loss of the fundamental frequency through the frequency doubler.**

Shown is the fundamental "gain" of the frequency doubler, approximately -25 dB, as shown in figure 47. Store this trace in memory 2 and display as trace 1:

- **Traces** menu (TR3 is active)
- **store trace** ; **TO MEM2**
- **select:** TR3 ; **TR1**

- **input:** CH1 ; **MEMx** ; **MEM2**

Trace 1 and trace 3 now are displayed. Set the HP 70820A to measure the 2nd harmonic of the source frequency, take another measurement, and display trace 3 as 2nd-harmonic data.

- **Main** menu ; **sweep options** (second level)
- **f mult numer** ; **2** ; **ENTER**
- **Trigger** menu ; **SINGLE** ; wait for the sweep to finish

In order to compare the power levels, set the scaling to the same level on the two traces. A reference level of 0 dB and a scale factor of 5 dB per division are appropriate for this measurement. Set these as follows:

- **Scale** menu (TR1 and SCALE are active) ; **5** ; **dB**
- press **REF LEV | POS** until LEV is underlined ; **0** ; **dB**
- **select:** TR1 ; **TR3** (REF LEV is active) ; **0** ; **dB**
- **SCALE** ; **5** ; **dB**

The display now appears as shown in figure 48. The upper trace is the 2nd-harmonic output power, and the lower trace is the fundamental output power; both are shown relative to the fundamental input power. Note that the frequency annotation at the bottom of the display is based on the active trace. With the fundamental trace active, the frequency span is listed as 3 GHz to 7 GHz. With the 2nd harmonic trace active, the frequency span is listed as 6 GHz to 14 GHz. When the 4th-harmonic trace, which is taken next, is active, the frequency span will be listed as 12 GHz to 28 GHz.

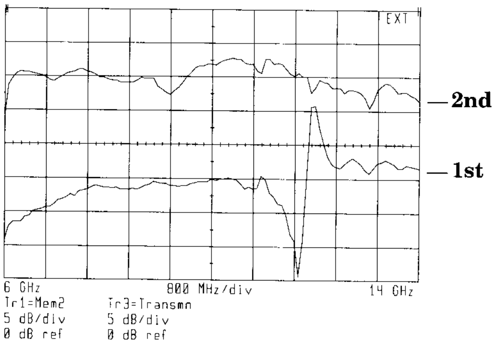


**Figure 48. Harmonic measurement of microwave frequency doubler. The two traces are the 2nd-harmonic and fundamental output power. Each is normalized to the input power level.**

Knowing the output power level of harmonics other than the fundamental and second may be important, also. For the device used for this example, the 4th harmonic is the next largest. Before measuring this, store the 2nd harmonic data into memory 3 and display it as trace 2 as follows:

- **Traces** menu ; (TR3 is active)
- **store trace** ; **TO MEM3**
- **select:** TR3 ; **TR2** ; **input:** CH2 ; **MEMx** ; **MEM3**

The screen now is split, with odd numbered traces in the upper half of the screen and even numbered traces in the lower half. For this measurement, comparisons of different measurements are easier if all are displayed on a single screen. Turn off the split screen feature as follows:

- **Config** menu ; **split:** AUTO ; **OFF**

Scale trace 2 with the same scale factors as the other two traces:

- **Scale** menu (TR2 and SCALE are active) ; **5** ; **dB**
- Press **REF LEV | POS** until LEV is underlined ; **0** ; **dB**

Trace 2 will not be visible now because it is hidden by trace 3. The HP 70820A can be set to measure the 4th harmonic output.

- **Main** menu ; **sweep options** (second level)
- **f mult numer** ; **4** ; **ENTER**
- **Trigger** menu ; **SINGLE**

After the sweep is updated, the markers can be used. Place marker 1 on the 2nd-harmonic trace (trace 2) at the frequency at which the fundamental feedthrough occurs. Place marker 2 on the fundamental trace at the same frequency (6 GHz).

- **Markers** menu ; **M1(↓)** until on TR2
- Place at point of interest: **12** ; **GHz**
- **M2(↑)** until on TR1
- Place at point of interest: **6** ; **GHz**

Figure 49 shows this display. Note that each marker reads out the frequency at that point of the trace on which it has been placed. The fundamental power level out of the device is almost as high as the 2nd-harmonic output power level at this frequency. The fundamental and 2nd-harmonic output power levels are about 10 dB to 14 dB lower than the input power level. In order to read out the exact difference, set the markers to the delta-marker mode:

- **delta (2-1) ON|OFF** until ON is underlined

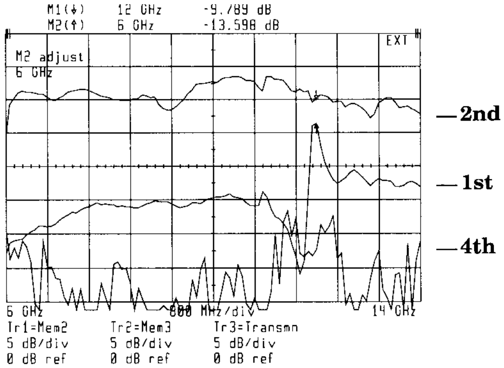


**Figure 49. Harmonic measurement of microwave doubler with markers placed on the fundamental and 2nd-harmonic traces. Each marker reads out frequency based on the trace on which it is placed.**

Figure 50 shows the harmonic measurement using the delta markers. The difference between the two signals is about 3.8 dB at an input frequency of 6 GHz.

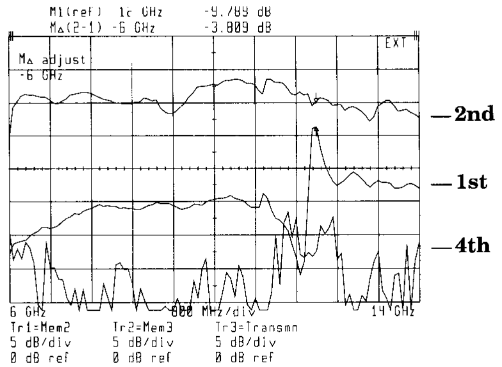


**Figure 50. Harmonic measurement of microwave doubler using the delta markers.**

### Additional Capabilities

### Harmonics, sub-harmonics, and offsets

In this measurement example, the harmonic measurement capability was used to measure the 2nd and 4th harmonics of a signal. Other frequencies related to the source frequency of the form $f_{measured} = (m/n) * f_{source} + f_{offset}$ can be used. In this mode of operation, the synthesized source frequency range is determined by the start and stop frequencies entered under the Main menu. The frequency-multiplier numerator, frequency-multiplier denominator, and frequency-offset functions, located under sweep options within the Main menu, control the frequency that the HP 70820A is tuned to receive.

### Noise reduction, markers

The noise-reduction techniques and marker functions discussed in the vector-transmission measurement example (section 5.1) can be applied to this measurement, with one exception. Traces of harmonic-sweep measurements do not contain stable phase information; therefore, format averaging should be used instead of vector averaging. The **FORMAT AVERAGE** function is located under the avg, hld key within the Traces menu.

## 5.5 Applying the Specifications

The amplitude accuracy of the normalized frequency-response measurements includes the specification for “Amplitude Accuracy vs. Input Power Level,” in addition to system errors due to coupler directivity, source match, and load match. The system frequency-response errors are removed by the normalizations.

For harmonic sweeps, specifications for “Absolute Amplitude RF Frequency Response, RF Corrections On,” “Harmonic Distortion,” and system frequency response errors also contribute to the measurement uncertainty. These contributions occur because the normalization data is obtained at a different frequency than is the harmonic data.

The phase accuracy of the normalized frequency-response measurements includes the specification for “Ratio Phase Accuracy vs. Input Power Level,” in addition to the system errors due to coupler directivity, source match, and load match. The system frequency-response errors are removed by the normalizations.

## 5.6 Limitations

The HP 70820A can accomplish stepped frequency-response measurements from 10 Hz to 40 GHz within the limitations of the synthesized source. The operating amplitude range at the inputs to the HP 70820A is from 0 dBm to a typical noise floor of -110 dBm at 10 GHz with a 10 Hz noise filter. For harmonic measurements, the harmonic distortion of the HP 70820A, as well as the harmonic output of the synthesized source, limit the dynamic range. Harmonic distortion in the HP 70820A is typically lower than -50 dBc for signals at frequencies greater than 10 MHz.

The requirement that the source be controlled by the HP 70820A limits which sources can be used. Appendix A lists compatible sources. A custom source driver can be loaded into the HP 70820A over the bus. The driver allows HP-IB commands for sources not listed in appendix A to be input, which allows their use with the HP 70820A.

One limitation exists regarding the measurement of frequency-translation devices, such as mixers and receivers: The output should be filtered. Without mixer IF filtering, the numerous mixing products produced in a wideband mixer may be converted by the input sampler of the HP 70820A to the same IF frequency as the desired component, resulting in measurement errors.

Normalization can correct for frequency-response errors, but full vector error correction is not available. Any external hardware, such as couplers, splitters, and switches, that are required for a particular measurement must be provided by the user, since no standard 40 GHz test sets are available for the HP 70820A at this writing.

## 5.7 Comparison with Network Analyzers

### Scalar Network Analyzers

Scalar network analyzers usually use broadband detectors, which accept the full frequency spectrum of the input signal. The advantages of using broadband detectors are reduced cost, compared to narrowband detection, and the ability to measure the conversion loss of frequency-translation devices and frequency multipliers. The disadvantages of broadband detection are a higher noise level and the lack of harmonic rejection.

The HP 70820A combines the benefits of low noise level and harmonic rejection of narrowband detection with the ability to measure the conversion loss of frequency-translation devices and frequency multipliers. The noise level of the HP 70820A at 10 GHz is typically less than -110 dBm with a 10 Hz noise-filter bandwidth. In comparison, a typical noise level for a scalar network analyzer is -60 dBm for measurements at the same frequency.

The HP 70820A and scalar network analyzers use similar methods of error correction. Both use thru normalizations for transmission measurements and open/short averaging for reflection measurements.

Scalar network analyzers are compatible with sweep oscillators and synthesized sweepers, while the HP 70820A requires a synthesized sweeper for the source.

In general, dedicated scalar network analyzers have a faster update rate, allowing fast feedback during adjustments to the device under test. The update rate of the HP 70820A varies greatly in the scalar-network-analyzer mode, depending on the number of points and the noise-filter bandwidth, but a typical sweep time is about 10 seconds for a 100 point trace with a 1 kHz noise-filter bandwidth.

### Vector Network Analyzers

The HP 70820A and vector network analyzers use narrowband detection techniques. Advantages of narrowband detection are reduced noise, improved accuracy, and greater dynamic range.

Vector network analyzers tune to the input frequency by phase locking to a signal provided at the reference input. The HP 70820A does not require a reference channel because the analyzer does not lock to a signal to accomplish the measurement. The HP 70820A tunes accurately to the input frequency by using a synthesized source with a shared time base. As a result, the HP 70820A accomplishes stepped frequency measurements rather than swept frequency measurements.

One advantage of not having a reference channel is that the HP 70820A can characterize non-linear devices. As shown in section 5-4, the harmonic-sweep measurement example, the HP 70820A can set the source to one frequency and tune to receive another. This capability allows for the scalar measurement of the output of frequency multipliers and frequency translation devices, either in absolute power, or power normalized to the input power level.

Many vector network analyzers have test sets available that separate the various signals for measurement. All external hardware, including signal separation devices, must be provided by the HP 70820A user, as no standard 40 GHz test sets are available for the HP 70820A at this writing.

Vector network analyzers often have multiple-term vector error correction for reducing the complex measurement uncertainties that result from factors such as coupler directivity, source match, load match, and system frequency response. The error correction available with the HP 70820A is limited to frequency-response normalizations. More elaborate error-calibration procedures can be developed using a controller with the HP 70820A. The correction factors could be downloaded into the HP 70820A and applied to the measured data. See section 8.3 of the chapter on array processing for an example of a user-developed procedure for three-term vector error correction in reflection measurements.

In general, dedicated vector network analyzers have a faster update rate than does the HP 70820A. The faster rate allows fast feedback during adjustments to the device under test. The update rate of the HP 70820A in vector network-analysis mode varies widely, depending on the number of points and the noise filter bandwidth. A typical sweep time is about 10 seconds for a 100 point trace with a 1 kHz noise-filter bandwidth. Vector network analyzers also tend to have more display format options, such as polar plots, than does the HP 70820A.

# Chapter 6
# Power Sweep Measurements

Combining the HP 70820A and a synthesized signal source allows scalar and vector power sweep measurements to be performed at frequencies from 10 Hz to 40 GHz.

Power-sweep measurements with the HP 70820A are performed exactly as are the network-analysis measurements that were discussed in chapter 5, except that the frequency is held constant, and the power is stepped over a specified range.

In the power-sweep mode, the HP 70820A has the same basic capabilities and limitations as it has in the network-analysis mode.

The measurement example that follows illustrates how to measure the 1 dB compression point of a microwave limiter, as well as how to measure the harmonic output of that limiter as it begins to compress the input signal. The same measurements also could be performed on an amplifier to determine its compression point and harmonic distortion. These measurements are performed as non-ratioed, scalar measurements. The non-harmonic measurements illustrated in this example could be performed as ratioed scalar or vector measurements using the vector transmission measurement setup. Following the example are discussions of the measurement specifications and limitations, and a comparison is made to the power sweep capability of network analyzers.

## 6.1 Compression and Harmonic Measurement: 1 dB Compression Point and Harmonic Output of Limiter

The measurement setup for scalar power-sweep measurements is shown in figure 51. The 20 dB attenuator is used in this measurement to allow enough power to be delivered to the limiter to cause compression, but not overdrive the input of the HP 70820A. The 20 dB attenuator is part of the test system, and it will be normalized out.

This configuration can be used for making non-ratioed scalar power sweeps. For ratioed scalar or vector power sweeps, refer to the setups shown in chapter 5, which covers network analysis.

- Connect source output to limiter (DUT) input
- Connect output of limiter to 20 dB pad
- Connect output of 20 dB pad to CH1 input
- Connect 10 MHz reference output of synthesized source to 10 MHz reference input of HP 70820A
- Connect HP-IB on rear panel of HP 70820A to HP-IB on rear panel of source (for MMS sources, this connection is via MSIB)

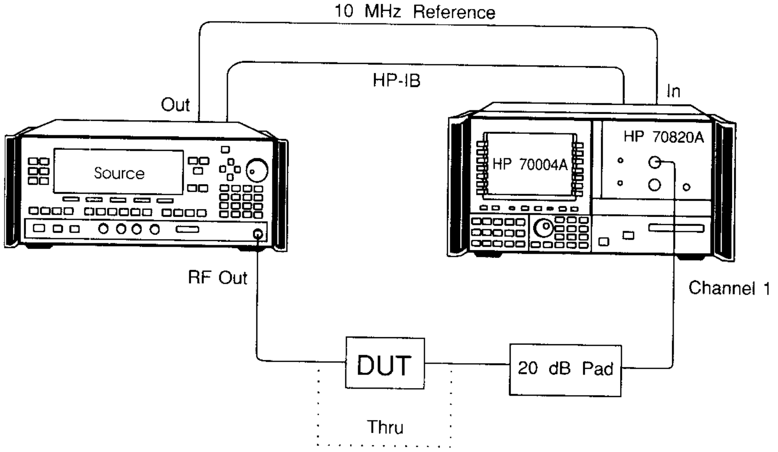


**Figure 51. Measurement setup for scalar power-sweep measurement of limiter.**

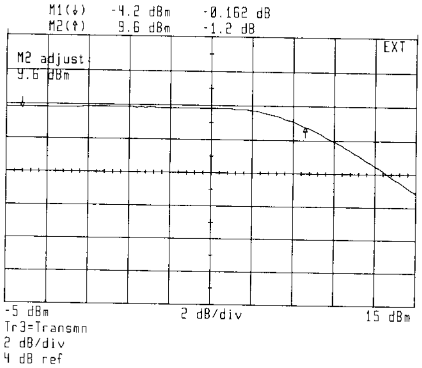


**Figure 52. Measurement of the 1 dB compression point of a limiter.**

Figure 52 shows the results of the measurement of the 1 dB compression point of a limiter. The input power to the limiter was stepped from -5 dBm to +15 dBm. For this measurement, the source frequency is 1 GHz. The trace indicates the insertion loss of the limiter. Marker 1 shows insertion loss (0.162 dB) of the limiter before it begins to limit. Marker 2 is placed at the point where the loss is 1 dB greater than the normal insertion loss of the device. This point occurs at an input power level of +9.6 dBm

Figure 53 shows the measurement results of the harmonic output of the limiter. Each trace is the output power of the limiter, at one frequency, normalized to the input power at the fundamental frequency (1 GHz). As the device limits the signal, the odd harmonics become larger than the even harmonics. The odd harmonics are displayed in the figure. The top trace (TR1) shows fundamental frequency output, the second-highest trace (TR2) displays the 3rd-harmonic output, the third-highest trace (TR4) shows the 5th-harmonic output, and the bottom trace (TR3) shows the 7th-harmonic output. As expected, as the limiter begins to compress the input signal, the harmonic content of the output signal begins to rise; as the input power increases, the output begins more and more to resemble a square wave.

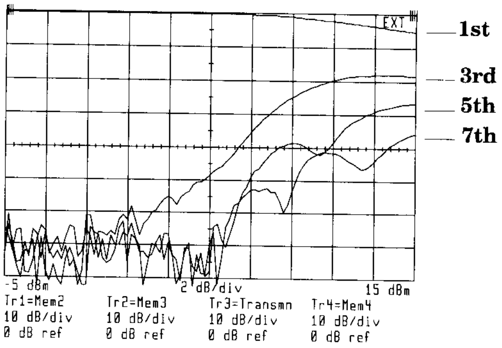


**Figure 53. Measurement of the fundamental and 3rd, 5th, and 7th harmonic power levels out of the limiter, normalized to the input power level.**

### Measurement Procedure

For scalar power-sweep measurements, the HP 70820A must be configured to control the synthesized source. Appendix A presents the configuration procedure required to perform this measurement.

Using the setup shown in figure 51, activate the scalar network analysis mode of operation as follows:

- **States** menu ; **SCALAR NETWORK**

The SCALAR NETWORK state is used to take advantage of its predefined trace definitions, although the measurement could be done just as easily without this predefined state. In the scalar-network mode of operation, the HP 70820A accomplishes stepped frequency response measurements by controlling the source. Trace 1 is defined as channel 1, trace 2 is defined as channel 2, trace 3 is defined as channel 1/memory 1 for normalized transmission measurements, and trace 4 is defined for normalized reflection measurements. Trace definitions 2 and 4 will not be used for this measurement. The number of measurement points is set to 101, but this setting may be changed to a maximum of 1,024. Initially, the log magnitude of channel 1 and channel 2 are displayed. Since channel 2 is not used for this measurement, it can be turned off.

The type of sweep must be changed from frequency to power, and the start and stop power levels, source frequency, and RF output on/off must be set for this measurement as follows:

- (the HP 70820A is currently in the Main menu)
- **Sweep:** FREQ ; **POWER**
- **START** ; **-5** ; **dBm**
- **STOP** ; **15** ; **dBm**
- **source FREQ** ; **1** ; **GHz**
- **RF out ON | OFF** until ON is underlined

Activate the single sweep mode as follows:

- **Trigger** menu ; **SINGLE**

During the sweep, a diamond moves across the bottom of the display, indicating the power level of the source as it is stepped from the start power to the stop power. The display of the synthesizer is turned off during the sweep to speed up the measurement. After the sweep is completed, trace 1 and trace 2 will be displayed. Turn off trace 2, as it is not needed.

- **Traces** menu ; **select:** TR1 ; **TR2**
- **display ON | OFF** until OFF is underlined

Trace 1 shows the output power of the limiter minus 20 dB, due to the attenuator. The input power is stepped over a 20 dB range (-5 to +15 dBm), resulting in an x-axis scaling of 2 dB per division. By scaling the vertical display of trace 1 at 2 dB per division, the trace will have a slope of 1:1 where the device is linear. Scale the trace as follows:

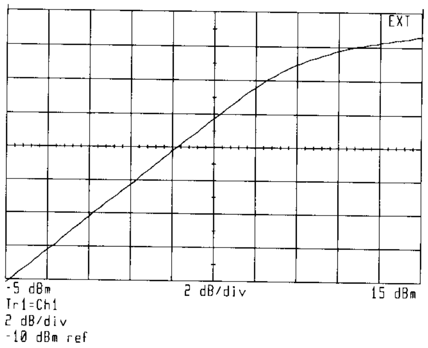
- **Scale** menu ; **select:** TR2 ; **TR1** ; **2** ; **dB**
- Set ref lev to show data, in this case -10 dBm
- **REF LEV | POS** until LEV is underlined ; **-10** ; **dBm**

The display now appears as in figure 54. Note that the slope is 1:1 before the limiter goes into compression and that the output power flattens out once the limiter has begun to compress. Before making measurements, normalize the measurement system.

- Remove the device under test
- Make thru connection as in figure 51 (dashed line)

This setup will be used as the thru normalization for the transmission measurements that follow. Take a single sweep and store it into memory 1.

- **Trigger** menu ; **SINGLE** ; wait for sweep to finish
- **Traces** menu (TR1 is active)
- **store trace** ; **TO MEM1**



**54. Measurement of the output power of a limiter, attenuated by 20 dB, with the input stepped from -5 to +15 dBm. At low power levels, the input and output power levels increase at the same rate. At high input-power levels, the output power level is limited.**

Reset the reference level to show the normalization data. In this case, a reference level of -8 dBm is appropriate. The display is scaled at 2 dB per division along each axis. As a result, the trace has a 1:1 slope. Some data is not shown on the screen because there are 10 divisions horizontally and eight divisions vertically. After resetting the reference level, the display will appear as in figure 55.

- **Scale** menu (REF LEV is active) ; **-8** ; **dBm**

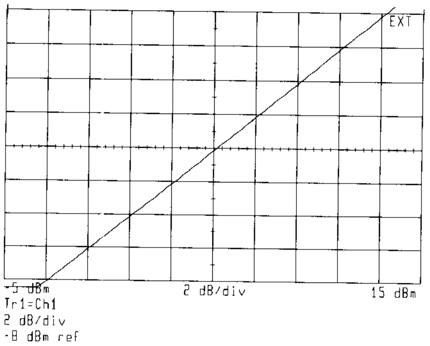


**Figure 55. Thru-normalization trace to be used for transmission measurements.**

As stated above, trace 3 is defined as the transmission magnitude normalized to a thru measurement (CH1/MEM1). With the normalization data saved, trace 3 can be displayed.

- **Traces** menu ; **select:** TR1 ; **TR3**
- **display ON | OFF** until ON is underlined

**Compression Measurement**

In the scalar-network state, trace 3 is formatted as log magnitude and should have a value of 0 dB. At this time, reinsert the limiter and take another measurement. Then scale trace 3 as appropriate.

- Reconnect the DUT into the measurement set-up
  - **Trigger** menu ; **SINGLE**
  - **Scale** menu (TR3 and REF LEV are active) ; **4** ; **dB**
  - **SCALE** ; **2** ; **dB**

Trace 3 shows the insertion loss of the limiter measured at the frequency of the source. At low power levels, loss through the limiter is low; at high power levels, the loss increases. Turn off trace 1, as it is no longer needed.

- **Traces** menu ; **select:** TR3 ; **TR1**
- Press **display ON | OFF** until OFF is underlined

Using the markers, the 1 dB compression point of the limiter can be found.

**Markers** menu ; **M1(↓)**

- Scroll until marker is on flat section of trace of insertion loss
- **M2(↑)** ; **delta (2-1) ON | OFF** until ON is under lined

Note that marker 1 displays the absolute-power-level input to the limiter on the left and the loss of the limiter at that power level on the right. The delta marker displays the input-power-level difference on the left and output-power-level difference on the right. Scroll the delta marker until the output power level difference is 1 dB. This is the 1 dB compression point. The results are shown in figure 56. To determine the 1 dB compression point, the marker must be set to read out the input power level at the 1 dB compression point. To accomplish this, turn off the delta marker and read the input power level on marker 2.

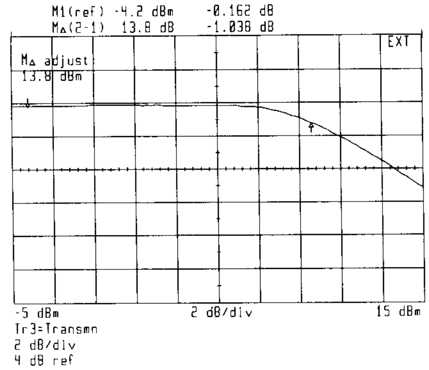


**Figure 56. Delta marker scrolled to 1 dB compression point of the response of the limiter.**

- Press **delta (2-1) ON | OFF** until OFF is underlined

The results are shown in figure 52. The 1 dB compression point of this limiter is +9.6 dBm. Turn off the markers, as they are no longer needed, and save this trace into memory 2. Then define trace 1 as memory 2, and display trace 1.

- **MARKERS OFF**
- **Traces** menu ; **select:** TR1 ; **TR3**
- **store trace** ; **TO MEM2**
- **select:** TR3 ; **TR1**
- **input:** CH1 ; **MEMx** ; **MEM2**

### Harmonic Measurements

Scale trace 1 and trace 3 for a reference level of 0 dB at the top of the screen and a scale of 10 dB per division. The traces have the same values, and one is shown above the other.

- **Scale** menu (TR1 and SCALE are active) ; **10** ; **dB**
- **REF LEV | POS** until LEV is highlighted ; **0** ; **dB**
- **select:** TR1 ; **TR3** (REF LEV is active) ; **0** ; **dB**
- **SCALE** ; **10** ; **dB**

Since the fundamental frequency insertion loss has been measured, the next measurement is the conversion loss from the fundamental frequency to the 3rd harmonic. Set the HP 70820A to receive the 3rd harmonic of the source frequency, and take a single sweep:

- **Main** menu ; **sweep options** (second level)
- **f mult numer** ; **3** ; **ENTER**
- **Trigger** menu ; **SINGLE**

After the sweep is completed, trace 1 is the insertion loss of the fundamental, and trace 3 is the conversion loss of the 3rd harmonic, as shown in figure 57. The amount of noise on trace 3 can be reduced by reducing the noise-filter bandwidth. Reduce the default bandwidth, which is 50 kHz, to 100 Hz and take another sweep. Figure 58 shows the results of this sweep. As can be seen, the noise floor of the trace decreased by about 20 dB at the low end, and the trace is much smoother. Save this trace to memory 3, and display it as trace 2.

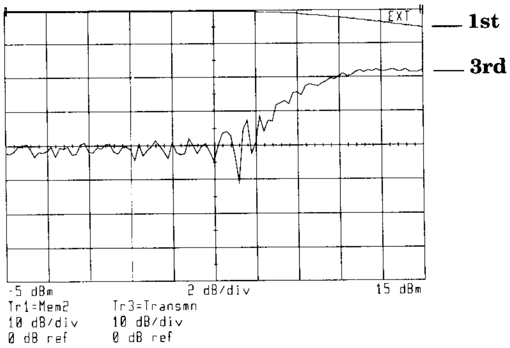


**Figure 57. Measurement of the fundamental and 3rd harmonic power levels out of the limiter, normalized to the input power level.**

- **Main** menu ; **NOISE FILTER** ; **100** ; **Hz**
- **Trigger** menu ; **SINGLE** ; wait for sweep to finish
- **Traces** menu (TR3 is active)
- **store trace** ; **TO MEM3**
- **select:** TR3 ; **TR2**
- **input:** CH2 ; **MEMx** ; **MEM3**

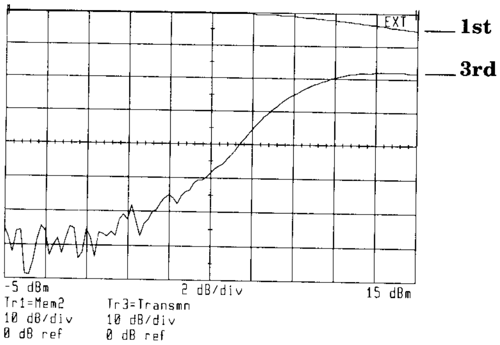


**Figure 58. The same measurement as in figure 57, but with the noise-filter bandwidth reduced from 50 kHz to 100 Hz for the 3rd harmonic measurement.**

Turn off the split-screen feature, and scale trace 2 to match trace 3.

- **Config** menu ; **split:** AUTO ; **OFF**
- **Scale** menu (TR2 is active) ; **10** ; **dB**
- **REF LEV | POS** until LEV is underlined ; **0** ; **dB**

Trace 2 and trace 3 will appear the same, and one will be on top of the other. Next, measure the conversion loss from the fundamental frequency to the 5th harmonic. Set the HP 70820A to receive the 5th harmonic of the source frequency and take a single sweep:

- **Main** menu ; **sweep options** (second level)
- **f mult numer** ; **5** ; **ENTER**
- **Trigger** menu ; **SINGLE**

After the sweep is completed, trace 1 shows the insertion loss of the fundamental, trace 2 shows the conversion loss of the 3rd harmonic, and trace 3 displays the conversion loss of the 5th harmonic, as shown in figure 59. Save trace 3 into memory 4, and display as trace 4. Then scale trace 4 the same as trace 3:

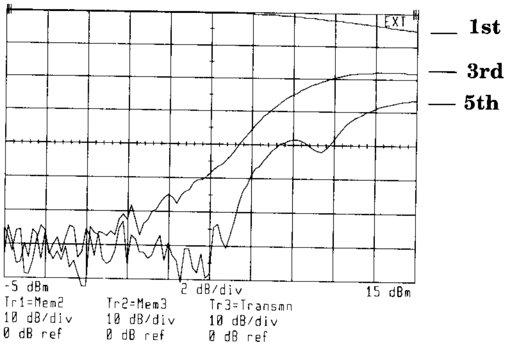


**Figure 59. Measurement of the fundamental, 3rd, and 5th harmonic power levels out of the limiter, normalized to the input power level.**

- **Traces** menu ; **select:** TR2 ; **TR3**
- **store trace** ; **TO MEM4**
- **select:** TR3 ; **TR4**
- **input:** Reflctn ; **MEMx** ; **MEM4**
- **Scale** menu (TR4 and REF LEV are active) ; **0** ; **dB**
- **SCALE** ; **10** ; **dB**

Trace 4 and trace 3 will appear the same, and one will be on top of the other. Now measure the conversion loss from the fundamental frequency to the 7th harmonic. Set the HP 70820A to receive the 7th harmonic of the source frequency and take a single sweep as follows:

- **Main** menu ; **sweep options** (second level)
- **f mult numer** ; **7** ; **ENTER**
- **Trigger** menu ; **SINGLE**

After the sweep has finished, trace 1 displays the insertion loss of the fundamental, trace 2 shows the conversion loss of the 3rd harmonic, trace 4 shows the conversion loss of the 5th harmonic, and trace 3 shows the conversion loss of the 7th harmonic, as shown in figure 53.

## Additional Capabilities

### Vector measurements

These measurements were performed as scalar measurements, although the fundamental frequency measurements in this example could have been made as vector measurements. This would be accomplished using the setup shown for vector transmission measurements in section 5.1.

### Harmonics, sub-harmonics, and offsets

This measurement example used the harmonic-measurement capability of the HP 70820A to measure the 3rd, 5th, and 7th harmonics of a signal. Other frequencies related to the source frequency of the form $f_{measured} = (m/n)*f_{source} + f_{offset}$ can be used. In the power-sweep mode of operation, the source frequency is set using the source FREQ function, located under the Main menu. The frequency-multiplier numerator, frequency-multiplier denominator, and frequency-offset functions, each located under sweep options, which is under the Main menu, control the frequency to which the HP 70820A is tuned. These frequencies remain constant throughout the sweep as the source power level is changed.

### Noise reduction

The noise-reduction techniques discussed in section 5.1, the vector network-analysis transmission measurement example, can be applied to this measurement, with one exception. The traces do not contain stable phase information, and therefore, format averaging should be used instead of vector averaging. The **FORMAT AVERAGE** function is located under the avg,hld key, which is located under the Traces menu.

## 6.2 Applying the Specifications

The applicable specifications listed in section 5.5 under network-analysis measurements also apply to power-sweep measurements.

## 6.3 Limitations

The limitations listed under network-analysis measurements (Section 5.6) also apply to power-sweep measurements.

## 6.4 Comparison with Network Analyzers

Not all network analyzers have power-sweep measurement capability. The comparison between the HP 70820A and network analyzers (Section 5.7) would also apply to power sweep measurements for those network analyzers that have this capability.

The other difference between the HP 70820A and network analyzers is that some network analyzers only allow power sweeps over a limited range, typically 30 dB. This limit is usually due to the phase-lock range of the receiver or the automatic level-control range of the source. That is, source attenuator switching during a sweep is not allowed.

The HP 70820A allows for source attenuator switching during a sweep, which allows a power-sweep measurement to be made over the full power range of the source. Caution must be taken to avoid long-term use of power sweeps that cause attenuator switching in a continuous trigger mode. Attenuators are capable of a limited number (typically greater than 1 million) of switching cycles in their lifetime.

# Chapter 7
## Sampled Spectrum-Analysis Measurements

The single-shot measurement mode offers a flexible, real-time digitization at up to a 20 Msample/second rate. Time domain waveforms of modulated carriers can be captured, and the AM, PM, and FM demodulated waveforms can be displayed in the time domain. The spectrum can also be captured and displayed, as shown in this chapter.

The HP 70820A can be used to accomplish sampled spectrum-analysis measurements from 0 to 40 GHz with frequency spans of 10 MHz or less. In addition to displaying power as a function of frequency, relative phase can be measured between different spectral components, as shown in the second measurement example of this chapter (magnitude and phase of FM carrier and sidebands).

The major limitation of these measurements is that the signal must have a bandwidth that is less than half the HP 70820A sample rate (typically 20 MHz/2 or 10 MHz) and that the signal is free of other responses. These limitations are because the HP 70820A has no anti-aliasing filter or preselector filter. As a result, all spectral information from 0 to 40 GHz in the input signal will mix down to the IF frequency range of 0 to 10 MHz. (This mixing allows wide-bandwidth measurements of repetitive signals, but limits these single-shot measurements.) In the sampled spectrum-analysis mode of operation, the HP 70820A is frequency calibrated for spans of 10 MHz or less (one-half the sample rate) between 0 and 40 GHz. All signals within the frequency span being measured are displayed at the proper frequency. All other signals appear in the IF and are displayed erroneously as though they are within the frequency span being measured.

This measurement mode is based on single-shot data acquisition and can be used to view frequency spans of 10 MHz or less from 0 to 40 GHz. Single-shot data acquisition is very different from the measurement of the harmonic spectrum of a repetitive waveform. Harmonic spectra can be viewed over the entire 0 to 40 GHz bandwidth of the HP 70820A.

The two measurement examples that follow show how to perform a spectrum-analysis measurement at the full IF span, then at a reduced span by using the zoom-transform function. The second measurement example also shows the phase-measuring capabilities of the HP 70820A and their application in the sampled spectrum-analysis mode of operation. Following the measurement examples is a discussion of the measurement specifications and limitations, and a comparison is made between the HP 70820A and swept spectrum analyzers.

## 7.1 10-MHz Span Example: Pulsed-RF Spectrum

### Measurement Setup and Results

The measurement setup for sampled spectrum- analysis measurements is shown in figure 60. This configuration can be used for frequency, power, and relative phase measurements within the described limitations. The input signal is connected to the channel 1 input, but the channel 2 input could also have been used. In addition, both inputs can be used to perform two-channel measurements.

- Connect signal under test to CH1 input

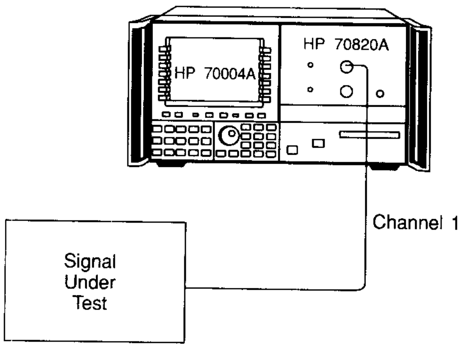


**Figure 60. Sampled spectrum-analysis measurement setup.**

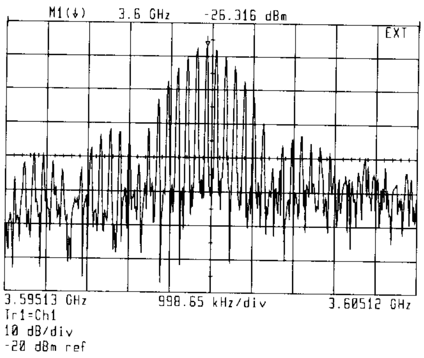


**Figure 61. Spectrum of 3.6 GHz pulsed-RF signal with 230 kHz pulse-repetition frequency and 14% duty cycle.**

Figure 61 shows the measurement results of a pulsed-RF signal with a 3.6 GHz carrier frequency and a 230 kHz pulse repetition frequency. The power level of the carrier term, -26.3 dBm, and the sidebands are displayed at 10 dB per division.

### Measurement Procedure

This description is written as though the HP 70820A had been configured not to control the source. Using the configuration procedure presented in appendix A, set the RF source to "none" before performing this measurement.

Using the setup shown in figure 60, activate the sampled spectrum analysis mode of operation by pressing the following keys:

- **IP** hardkey (Main menu will be active)
- **sweep labels** (second level)
- **# CYCLE DELAY** ; **more** 2 of 2
- **# CYCLE** ; **125** ; **cycles**
- **sweep options** (second level)
- **transIt** AUTO ; **ON**
- **prev menu**
- **sglshot ON | OFF** until ON is underlined
- **signal FREQ** (first level) ; then enter carrier frequency
- **trigger** menu ; **trg is:** EDGE ; **FREERUN**
- **Traces** menu (TR1 is active) ; **format:** TIM,RE
- **xfrm to FRQ | OFF** until FRQ is underlined

The display now appears as in figure 61. The carrier frequency must be entered, as the signal-track routine may not operate for pulsed-RF signals. Note that all spectral information falling outside the display range is folded back into the displayed spectrum.

The sampled spectrum-analysis measurement is treated as a time sweep that is transformed to frequency -- It is not a frequency sweep. The default number of trace points at instrument preset is 512. If the number of cycles had been set to 128 (instead of 125), each cycle of the carrier would be represented by four trace points in the time domain. This means that the carrier frequency is mixed to an IF frequency (in the HP 70820A) of one-fourth the sample rate, which would place the carrier at mid screen of the display since the display is of IF frequencies from 0 to 1/2 the sample rate (0 to the Nyquist frequency). But the signal was not placed at exactly mid-screen because that point represents an IF response at one-fourth the sample rate. If the input signal were placed at exactly one-fourth the sample rate, all its odd harmonics would alias to exactly the same location in the IF, and results may not be as accurate.

## Additional Capabilities

### Reducing noise, zoom transform

The noise in a trace can be reduced by using the zoom-transform feature to reduce the displayed frequency span. (**zoom ON | OFF** and **SPAN** are located within the sub-menu of the transform-control softkey, which, in turn, is located under the Traces menu.) The zoom transform does not reduce the sampling frequency, but it increases the FFT's frequency resolution by taking a longer time record. This increased frequency resolution effectively decreases the FFT resolution bandwidth and therefore reduces the noise level. With the zoom transform activated, the reduced frequency span can be moved in frequency by using the CENTER function, located under the transform control softkey, which is under the trace menu. This reduced span cannot be moved outside the original frequency window that was being measured before activating the zoom transform. The zoom transform is used in the next measurement example.

Another method of reducing the noise in this measurement is to use format averaging (**FORMAT AVERAGE**), located under the avg,hld key, which is under the Traces menu. Format averaging can be set to average from 1 to 1,024 traces. In this measurement, valid phase data is available only in a relative sense. That is, the phase between different spectral components is valid at each measurement, but the absolute phase of each response will change at random from trace to trace. The phase information may be interpreted as the instantaneous phase of all the frequency components at a specific point in time. As a result, vector averaging should not be used for this measurement. When using format averaging on a magnitude trace, a vector marker placed on the trace will read out the average magnitude and the phase of the last trace taken, as the averaging in this case applies only to the magnitude information.

The noise filter was off for the measurement, which allows a maximum IF bandwidth of 10 MHz. Turning on this filter attenuates the IF spectrum above 100 kHz, and the on-screen effect is to reduce the amplitude of all but the left side of the screen to a very low level. By reducing the number of cycles to two, for example, the signal can be placed at an IF frequency of less than 100 kHz. The result is an improvement in the signal to noise ratio of the measurement, as the noise level in the HP 70820A IF section tends to increase with frequency.

### Marker-peak interpolation

To enable markers to read out the appropriate spectral amplitude, the marker-peak interpolation function (**pk intp**) should be activated. This function compensates for the slight attenuation of spectral components that fall between FFT frequency bins. Marker-peak interpolation, which defaults on, is located under the mkr trk options softkey, which is under the Markers menu. Marker-peak interpolation only operates when the marker is moved to a spectral component using the HIGHEST PEAK, NEXT PEAK, or LOCAL PEAK functions. It does not operate when the marker is scrolled across the screen.

## 7.2 Narrow Span Measurement Example: Magnitude and Phase of FM Carrier and Sidebands

### Measurement Setup and Results

The measurement setup for sampled spectrum-analysis measurements is shown in figure 60. This configuration can be used for making frequency, power, and relative phase measurements within the described limitations. For signals with a combination for amplitude modulation and frequency modulation, sampled spectrum analysis could be used to determine the amount of AM anbd FM on the signal.

- Connect signal under test to CH1 input

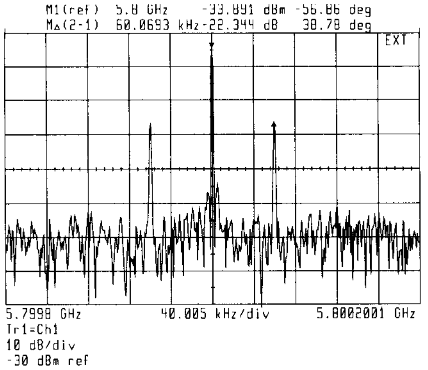


**Figure 62. Spectrum of 5.8 GHz narrowband FM signal. Markers show that carrier power is -33.9 dBm, modulation frequency is 60 kHz, sideband level is -22.3 dBc, and the instantaneous phase difference between the upper sideband and the carrier is 38.8 degrees.**

Figure 62 shows the results from the measurement of a 5.8 GHz narrowband FM signal. Marker 1 shows that the carrier power level is -33.9 dBm. The delta marker shows that the modulation frequency is 60 kHz, sideband level is -22.3 dBc, and the instantaneous phase difference between the upper sideband and the carrier is 38.8 degrees.

For FM signals, the sum of the upper and lower sidebands is ± 90 degrees out of phase with the carrier. Therefore, the expected phase difference between the lower sideband and the carrier is 90 + (90-38.8) = 141.2 degrees. Figure 63 shows that the measured value of the instantaneous phase difference between the lower sideband and the carrier is 141.7 degrees.

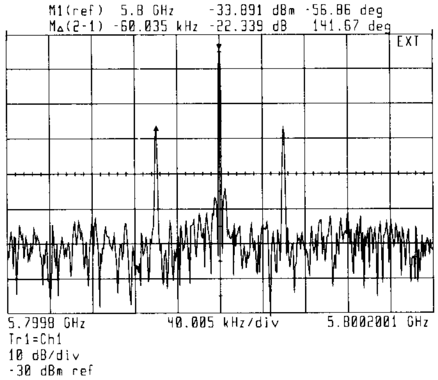


**Figure 63. Measurement of the instantaneous phase difference (141.7 degrees) between the lower sideband and the carrier.**

If the FM signal were an amplitude-modulated signal instead, the expected phase difference between the lower sideband and the carrier would be -38.8 degrees because the sum of the upper and lower sidebands is either in phase, or 180 degrees out of phase, with the carrier. For signals with a combination of amplitude modulation and frequency modulation, this phase difference between the upper and lower sidebands could be used to determine the amount of AM and FM on the signal.

To complete this measurement, a single sweep must be taken first, and then the measurements can be performed. The two-step procedure is necessary because the phase of each spectral component, as well as each sideband relative to the carrier, changes from trace to trace. The relationship between the sum of the sidebands and the carrier stays constant from measurement to measurement.

### Measurement Procedure

This description is written as though the HP 70820A had been configured not to control the source. Using the configuration procedure presented in appendix A, set the RF source to "none" before performing this measurement.

Using the setup shown in figure 60, activate sampled spectrum-analysis mode of operation by pressing the following keys:

- **IP** hardkey (Main menu will be active)
- **sweep labels** (second level)
- **# CYCLE DELAY** ; **more** 2 of 2
- **# CYCLE** ; **128** ; **cycles**
- **sweep options** (second level)
- **transIt AUTO** ; **ON**
- **prev menu**
- **sglshot ON | OFF** until ON is underlined
- **sig trk ON | OFF** until ON is underlined
- **trigger** menu ; **trg is:** EDGE ; **FREERUN**
- **Traces** menu (TR1 is active) ; **format:**TIM,RE
- **xfrm to FRQ | OFF** until FRQ is underlined
- **prev menu** ; **trnsfrm control**
- **CENTER SPAN** until SPAN appears in inverse video
- **400** ; **KHz ; ZOOM ON | OFF** until on is underlined
- **CENTER SPAN** until CENTER appears in inverse video
- **1 ;** harmnc

The display now appears as in figure 62 with the exception of the markers. The signal-track routine can be used to determine the signal frequency for this measurement, as the function works well with narrowband FM signals. If desired, the carrier frequency can be entered for this measurement and the signal-track routine turned off. Note that all spectral information falling outside the display range is folded back into the displayed spectrum.

The above keystrokes are the same as for the measurement example presented in section 7.1, except for the signal-track and transform-zoom features. Refer to section 7.1 for more information on the above keystrokes.

To use the markers to measure the carrier frequency, carrier power level, modulation frequency, modulation level, and the phase relationship between the sidebands and the carrier, press the following keys:

- **Trigger** menu ; **SINGLE**
- **Markers** menu ; **M1(↓) ;** mkr - ->
- **HIGHEST PEAK** ; **prev menu**
- **M2(↑)** ; mkr - -> ; **HIGHEST PEAK**
- **NEXT PEAK ; prev menu**
- **readout options** ; **SCL | VEC** until VEC is underlined
- **delta (2-1) ON | OFF** (1st level) until ON is underlined

The key sequence above produces a single sweep, places marker one on the carrier and marker two on one of the FM sidebands, changes the marker readout from scalar to vector, and activates the delta-marker function. The display now appears as in figure 62.
To measure the other sideband, press the following keys:

- **mkr - ->**
- **NEXT PEAK**

The display now appears as in figure 63.

### Additional Capabilities

The additional capabilities described in section 7.1, "10 MHz span example: pulsed-RF spectrum," also apply to this measurement.

## 7.3 Applying the Specifications

The accuracy of the amplitude measurements in sampled spectrum analysis includes specifications for "Absolute Amplitude RF Frequency Response, RF Corrections On," "IF Absolute Amplitude Frequency Response," and "Amplitude Accuracy vs. Input Power Level" as well as system mismatch errors.

Frequency measurement accuracy is a function of the frequency reference accuracy, the measured frequency, and the resolution of the measurement:

frequency measurement accuracy = (frequency reference accuracy * measured frequency) + resolution of measurement

This frequency accuracy requires that the signal frequency be known accurately enough to properly calibrate the frequency axis. (See section 7.4 for more information.)

With marker interpolation activated, and the signal peak determined by using one of the marker peak functions:

frequency resolution = frequency span/(50 * number of time-domain trace points).

This resolution provides a 100-fold improvement over the normal frequency resolution. However, the best way to determine the unknown frequency of a signal is to use the frequency and power measurement method described in chapter 3.

Delta-frequency measurement accuracy is the frequency reference accuracy times the delta frequency measured plus twice the frequency resolution:

Δfrequency measurement accuracy = frequency reference accuracy * Δfrequency measured + 2 * frequency resolution

## 7.4 Limitations

The HP 70820A can accomplish sampled spectrum-analysis measurements from 0 to 40 GHz, in spans of 10 MHz or less. The input compression level is 0 dBm, and the noise floor is typically -75 dBm at 1 GHz with the zoom-transform off. The noise floor can be reduced using the zoom-transform function.

The harmonic distortion of the HP 70820A is typically lower than -50 dBc, and residuals are typically lower than -65 dBm.

The HP 70820A has no anti-aliasing filter or preselector filter, and as a result, all spectral information from 0 to 40 GHz in the input signal will mix down to the IF frequency range of 0 to 10 MHz. In this mode of operation, the HP 70820A is frequency calibrated for some span of 10 MHz or less (one half the sample rate), between 0 and 40 GHz. All signals within the measured frequency span will be displayed at the proper frequency. All other signals will appear somewhere in the IF and will be erroneously displayed as though they are within the frequency span being measured.

## 7.5 Comparison with Spectrum Analyzers

The HP 70820A, in the sampled spectrum-analysis mode of operation, is similar to a dynamic signal analyzer in that the HP 70820A samples the input signal and accomplishes an FFT to determine the frequency spectrum. The major difference is that dynamic signal analyzers limit their maximum frequency to less than one-half the sample rate and have an anti-aliasing filter at the input to avoid unwanted responses. As a result, dynamic signal analyzers typically have an upper frequency limit of 100 kHz or less. The HP 70820A has no anti-aliasing filter at the input. Its absence, coupled with the presence of a wide bandwidth sampler, removes the requirement of baseband-only analysis. The maximum frequency span in this mode is limited to one-half the sample rate, but that span can be placed anywhere in the 0 to 40 GHz range.

Along with the advantage of performing measurements between 0 and 40 GHz comes the disadvantage that all spectral information between 0 and 40 GHz mixes down to the 0 to 10 MHz IF section. All signals not in the frequency span being measured appear somewhere in the IF and are displayed as though they are within the frequency span being measured. As a result, these measurements are most useful for narrow-bandwidth (less than one half the sampling rate) signals. For baseband ( < 10 MHz) measurements, the user could provide a low-pass, anti-aliasing filter.

Microwave spectrum-analysis measurements typically are performed with a swept-tuned, superheterodyne spectrum analyzer. These spectrum analyzers can tune over wide frequency ranges in a single sweep (typically up to 26.5 GHz, or more) with resolution bandwidths that typically range from 10 Hz to 3 MHz. Many microwave spectrum analyzers have preselector filters at the input. Preselectors eliminate virtually all unwanted responses, so all signals displayed by the spectrum analyzer are shown at their correct frequency and amplitude. These swept-tuned spectrum analyzers have greater sensitivity and lower distortion than the HP 70820A, making them very good for spurious testing and broadband, low-level surveillance measurements, while the HP 70820A is not suited for these applications.

As seen in section 7.2, "Narrow Span Measurement Example," the HP 70820A will measure the phase of spectral components, in addition to their amplitude and frequency. Swept-tuned spectrum analyzers cannot measure phase. In addition, for very narrow bandwidth measurements, the HP 70820A, with its adjustable sample rates down to 1 Hz and its FFT processing, offers faster update rates compared to conventional swept-tuned spectrum analyzers. In sampled spectrum-analysis mode, amplitude accuracy in the HP 70820A is similar to that of a spectrum analyzer, although the amplitude accuracy of the HP 70820A tends to be slightly better.

# Chapter 8
## Array Processing

The HP 70820A features a powerful set of math functions that are available to the user over the remote HP-IB bus or the MSIB bus. Executed by two Motorola DSP 56001 devices, these math functions allow users to download data to the HP 70820A and take advantage of the DSP algorithms designed into the product. All functions listed in this chapter also are available from the front panel for use in trace definitions.

The user can provide either 16 bit or 32 bit data. The HP 70820A uses 32 bit block, floating-point processing with a 24 bit mantissa and 56 bit accumulators. The input data can be from 32 to 1,024 complex points in length.

This chapter shows the measurement functions available to the HP 70820A user and describes the procedure for using array processing using a sample application (ADC measurements). Also included is a description of how to use the array-processing capabilities of the HP 70820A to implement three-term error correction for vector network-analysis reflection measurements.

## 8.1 Functions Available

Tables 1 and 2 show the operands and operations that are available for use in array processing. For more information on these functions, refer to the DEF (define) command in the FUNC (function) subsystem in the HP 70820A "Programmer's Guide."

| OPERATIONS | |
|---|---|
| **Symbol** | **Description** |
| VS | a versus b |
| + | addition |
| - | subtraction (two operands) |
| * | multiplication |
| / | division |
| CONV | cyclic convolution |
| CORR | cyclic correlation |
| MOD | A modulo B |
| - | negate (single operation) |
| AC | remove dc portion of signal |
| AM | AM demodulation |
| ANALY | analytic signal |
| ATAN | phase = arctan(I/R) |
| D/DX | derivative |
| DB | 20*log(x) |
| DC | remove ac portion of signal |
| DEG | unwrapped arctan() |
| DIFF | difference operator |
| DFT | discrete Fourier transform |
| EXPJ | exp(2*PI*j*real) |
| FFT | fast Fourier transform |
| FM | delta phase / delta time |
| IDFT | inverse DFT |
| IFFT | inverse FFT |
| IMAG | imaginary part of complex number |
| INTEG | integration |
| MAGN | SQR(R* R + I*I) |
| REAL | real part of complex number |
| SQRT | square root |
| SUM | summation |
| TD | time delay = -delta phase/delta f |
| (none) | copy (i.e. output = input) |

**Table 1. Operations available for array processing.**

| OPERANDS | |
|---|---|
| **Symbol** | **Description** |
| CHAN1 | channel 1 |
| CHAN2 | channel 2 |
| FUNC1 | function 1 |
| FUNC2 | function 2 |
| FUNC3 | function 3 |
| FUNC4 | function 4 |
| WMEM1 | memory 1 |
| WMEM2 | memory 2 |
| WMEM3 | memory 3 |
| WMEM4 | memory 4 |
| number | constants |

**Table 2. Operands available for array processing.**

## 8.2 Array Processing Procedure

Array processing involves five main steps. The steps are described briefly below. Later in this section, each step is discussed in detail.

1. Activate the single-sweep mode. This prevents the parameters that are set for array processing from automatically being changed when a sweep is taken.

2. Define the parameters for the preamble. The preamble is the minimum set of parameters that define a set of points with no ambiguity. Defining parameters is necessary to allow the HP 70820A to process the set of points correctly.

3. Download the data to be processed into memory, channel, or trace arrays. In general, it is best to download the data into memory arrays to avoid accidentally writing over the array during data acquisition.

4. Define a trace in terms of the arrays that have been downloaded in step 3 and the available math operations. Immediately after the traces are defined, the operations specified are executed, regardless of the state of the internal sweep.

5. Upload the data from the appropriate trace.

Steps of the array-procedure are described below. Each step uses the BASIC programming language.

### Step 1: Activate the Single-Sweep Mode in the HP 70820A.

```
10 ASSIGN @Mta TO 711        !HPIB address of HP 70820A
20 OUTPUT @Mta;”SWE:MODE ASIN”  !auto trigger, single sweep
30  OUTPUT @Mta;”STOP”     !stop acquiring data
```

Single-sweep mode now is activated and ready for array processing.

### Step 2: Define the Parameters for the Preamble.

The preamble is a list of parameters that define the data on which operations will occur. The preamble contains thirteen items, each of which must be input to the HP 70820A in a specific order. These terms are defined below in the order that in which they must be specified.

Calculation of preamble parameters is explained, using an example to illustrate, in the following description of the parameters. For this example, 512 points of input data are taken from an external analog-to-digital converter at a 10 MHz rate. The voltage range of the analog-to-digital converter is 0 to 10 volts. The digitized signal is a sine wave. In the example, the array-processing capability of the HP 70820A will be used to determine the harmonic distortion introduced by the analog-to-digital converter. The list of preamble parameters follows:

**DOMAIN** - This parameter informs the instrument about the type of data to be downloaded. For this example, the array of points is specified as real time-domain data. The domain command contains two parts that are separated by a comma. The first part specifies the type of time-domain data, and the second part specifies the type of frequency-domain data.

For this example, the data is specified as REAL,OFF. See the DOM (domain) command, found in the WAV (waveform) subsystem, for more information.

**DATA TYPE** - The data type is set to RTIM, which indicates time-domain data composed of real data only. Imaginary data, therefore, is assumed to be zero. See the DTYP (data type) command, found in the WAV (waveform) subsystem, for more information.

**UNITS** - This parameter defines the horizontal and vertical units, both of which are linked to the data type. Since the example is a time-domain trace, seconds comprise the horizontal units, and volts constitute the vertical units. These units are specified in order: horizontal,vertical. In this example, units are SEC,VOLT. See the UNIT command in the WAV subsystem for more information.

**FORMAT** - This parameter determines the internal word size for the data points, either INT16 (16-bit integers) or INT32 (for 32-bit integers). Data for this example is 16-bit integers. See the FORM (format) command in the WAV subsystem for more information.

**TYPE** - The TYPE parameter sets the post processing mode for trace data to activate such functions as averaging, minimum hold, and maximum hold. For this example, no post processing will be specified by using the NORM (normal) parameter. See the TYPE command in the WAV subsystem for more information.

**POINTS** - The POIN (points) parameter specifies the number of points in the trace. A minimum of 32 points and a maximum of 1,024 points may be specified. This example specifies 512 points. See the POIN command in the WAV subsystem for more information.

**TINC (time increment)** - This parameter specifies the time per trace point in the time domain. For this example, the time-domain data was sampled at a 10 MHz rate, which gives a time per point value of 100 ns, or 1 E-7 s. The allowable range of the TINC parameter extends from 0 to 1 s. See the TINC command in the WAV system for more information.

**TOR (trigger origin)** - The TOR command determines the position of the first data point relative to the trigger point. For this example, data is downloaded without regard to a trigger point; therefore, set the value of TOR to 0. See the TOR command in the WAV subsystem for more information.

**VINC (voltage increment)** - This command specifies the voltage increment of the trace data. VINC informs the HP 70820A of the value of 1 lsb (least significant bit). The equation to determine this parameter is given by:

1 lsb = voltage range / (YTOP - YBOTtom + 1)

Where YTOP = 16,383 ($3FFF_{16}$) for 16-bit data and
YTOP = 1,073,741,823 ($3FFFFFFF_{16}$) for 32-bit data;

and YBOTtom = -16,384 ($-4000_{16}$) for 16-bit data and
YBOTtom = -1,073,741,824 ($-40000000_{16}$) for 32-bit data.

For 16-bit data, the actual data range is from -32,768 to 32,767. YTOP and YBOT are set to -16,384 and 16,383 to allow for overranging. The same approach is used for 32-bit data. For this example, the external ADC has a voltage range of 10 volts, and 16-bit data is being used. The VINC value is equal to:

1 lsb = 10 / (16,383 - (-16,384) + 1)
1 lsb = 10 / 32,768
1 lsb = 3.05176 E-4

See the VINC command in the WAV subsystem for more information.

**VOR (voltage origin)** - The VOR parameter sets the center of the voltage range for the downloaded data. In the example, the external data was taken from an ADC, which measured from 0 to 10 V. Therefore, the origin value is equal to 5 V. See the VOR command in the WAV subsystem for more information.

**FINC (frequency increment)** - The FINC parameter is used like the TINC parameter, except that FINC is used for frequency data instead of time-domain data. The FINC command sets the frequency increment between adjacent points in the frequency domain. The frequency increment is related to the sampling frequency by:

frequency increment = sampling frequency / length

where length is the number of frequency-domain points, including both positive and negative frequencies. In the example, time-domain data is entered, but a frequency increment must be entered for proper scaling if the data is to be transformed to frequency.

The equation to calculate the frequency increment is:

FINC = Fs / length

Where Fs = 10 MHz and length = 512 for this example. This results in a frequency increment of 19.53125 kHz.

See the FINC command in the WAV subsystem for more information.

**FOR (frequency origin)** - The FOR command determines the starting frequency of the data in the frequency domain. In this example, the input data is a time-domain trace, and the FOR parameter is set to 0. See the FOR command in the WAV subsystem for more information.

**YREF (Y reference)** - This parameter sets the numeric (binary) value that corresponds to the center of the voltage range specified by VINC and VOR. At this writing, only one value is possible: 0. See the YREF command in the WAV subsystem for more information.

In summary, the following parameters will be used for the preamble.

DOM= REAL,OFF
DTYP= RTIM
UNIT= SEC,VOLT
FORM= INT16
TYPE= NORMal
POIN= 512
TINC= 1E-7
TOR= 0
VINC= 3.05176 E-4
VOR= 5
FINC= 19.531E3
FOR= 0
YREF= 0

These parameters are formed into a string array and then written to the HP 70820. The string array appears as:

```
40 Preamble$="REAL,OFF,RTIM,SEC,VOLT,INT16,NORM,512,1E-
        7,0,3.05176E-4,5,19.531E3,0,0"
```

Output the data to the HP 70820A using the following command. For proper operation, a space must be included after "PRE."

```
50 OUTPUT @Mta;"WAV:PRE  "&Preamble$
```

After this command is executed, the HP 70820A is ready to receive the trace data.

## Step 3: Download the Data to Be Processed.

### Header

A header must precede data that is output (downloaded) to the HP 70820A. The header uses the form:

#<D><N>

where <D> is an ASCII digit indicating how many digits are in <N>, and <N> is an ASCII number indicating the number of bytes that will follow.

The example contains 512 points of 16-bit data, which is equivalent to 1,024 bytes. (Each byte is 8 bits.) The header is:

#41024

The array containing the data is called Values. It must be scaled for a range of -16,384 to 16,383, representing 0 to 10 volts. For example, a voltage reading within TINC/2 of 5 volts is represented by the value 0. Use the following statements to download the data to the HP 70820A.

```
60     Linefeed = 10  !define the ascii value of the linefeed
70     N = 512                 !number of words to download
80     Header$=VAL$(2*N)  !string value = number of bytes
90     Header$=VAL$(LEN(Header$))&Header$
100    OUTPUT @ Mta;”WAV:SOUR WMEM1"  !download to mem1
110    OUTPUT @ Mta USING “#,K,K”;”WAV:DATA #”,Header$
120    FOR J=0 TO N-1
130    OUTPUT @Mta USING “#,W”;Values(J)
140    NEXT J
150    OUTPUT @Mta USING “#,B”;Linefeed END
```

### Discussion of Program

Line 80 defines the string variable for Header$ as 2*N, which is the number of 8-bit bytes. If the data were 32 bits, then the number of bytes would have been 4*N. At this point, the value of Header$ = 1,024.

Line 90 completes the formation of the variable part of the header. The LEN(Header$) will return the number of digits in the header, which is equal to 4. The final value of Header$ is set equal to 4, concatenated with the old value of Header$, which was 1,024. This results in a final value to the Header$ string variable of 41,024.

Line 100 informs the HP 70820A of the location where the data is to be downloaded. In this example, the data is loaded into memory 1.

Line 110 outputs two different quantities. Both are output using the ASCII format, as specified by the use of K,K in the USING statement. The first quantity that is output is the actual command “WAV:DATA #.” The # is actually the first part of the header. Recall that the format of the header was #<D><N>. The <D><N> are contained in the variable Header$. The # is sent with the command.

After this instruction is completed, the HP 70820A expects to receive 1,024 bytes of data.

Lines 120-140 output the data. The FOR NEXT loop will output 512 values in the W format. The W format is 16-bit integer. Specified in the header are 1,024 bytes, and 512 words is the equivalent number in the W format. Therefore, the byte count of the HP 70820A and the word output from the BASIC controller are consistent.

Line 150 terminates the data transfer by sending a linefeed. The EOI signal is sent with the linefeed.

### Step 4: Define a Trace in Terms of the Downloaded Data.

#### Performing an FFT on Time-Domain Data

Once the data has been downloaded, array processing is accomplished by defining a trace in terms of the downloaded memory array, except when performing an FFT or IFFT. FFT and IFFT can be performed in the same way as all other operations, or they can be performed simply by changing the domain. The latter method provides an easier approach to performing FFTs and IFFTs. Both methods are discussed in this section, as other operations require the use of trace definitions.

#### Changing Domains to Perform an FFT

Performing an FFT on the data of the example simply requires instructing the HP 70820A to switch from the time domain to the frequency domain. The preamble originally set the HP 70820A to the time domain. The following commands switch the HP 70820A to the frequency domain (assuming that the source command that was output in line 100 in the example has not been overwritten to specify a different source):

```
160  OUTPUT @Mta;”WAV:DOM OFF,MAGN”  !magnitude of freq
170  OUTPUT @Mta;”WAV:MAGN LIN,LOG” !lin time, log freq
```

Line 170 specifies that the magnitude of the frequency-domain data is logarithmic, while the time-domain is linear. For linear output of the FFT, change the command to:

```
170  OUTPUT @Mta;”WAV:MAGN LIN,LIN”
```

All that remains is to read the data from the HP 70820A. The following section describes how to perform the same FFT operation using the function subsystem.

### Using the Function Subsystem to Perform an FFT

The function subsystem is used to define functions (traces) in terms of the available math operations using the available channels and waveform memories as operands. The following steps will accomplish an FFT on the input data:

```
160  OUTPUT @Mta;”FUNC1:DEF  (FFT(WMEM1))”
170  OUTPUT @Mta;”WAV:SOUR FUNC1"
180  OUTPUT @Mta;”WAV:DOM OFF,MAGN”
190  OUTPUT @Mta;”WAV:MAGN LIN,LOG”
```

Line 160 defines the function, FUNC1, as the FFT of WMEM1, where WMEM1 is the location to which the time-domain trace was downloaded. Line 170 changes the source for the remaining WAV commands to FUNC1. Lines 180 and 190 are exactly as described previously.

These two examples illustrate clearly that performing an FFT is easier using the first method. However, when array processing becomes more involved, the second method is very flexible. For example, suppose you wish to multiply the FFT array by a constant. This operation may be accomplished by the following statement:

```
160  OUTPUT @Mta;”FUNC1:DEF  (4.5*FFT(WMEM1))”
```

### Performing an IFFT on Frequency-Domain Data

Inverse FFT is another very useful function. inverse FFT can be computed similarly to the method described for the FFT. The first method is to change from the frequency domain to the time domain. This method assumes that the waveform is in the frequency domain. The original time-domain waveform can be obtained as follows:

```
200  OUTPUT @Mta;”WAV:DOM REAL,OFF” !back to time
```

The same operation can be performed using the function commands in the HP 70820A as follows:

```
200  OUTPUT @Mta;”FUNC2:DEF (IFFT(FUNC1))”
210  OUTPUT @Mta;”WAV:SOUR FUNC2"
220  OUTPUT @Mta;”WAV:DOM REAL,OFF”
```

### Step 5: Upload the Data from the Appropriate Trace.

The final operation in the array processing is to read the processed data from the HP 70820A.

```
230  DIM Waveform(1024)
240  OUTPUT @Mta;”WAV:SOUR FUNC1"      !get function 1 data
250  OUTPUT @Mta;”WAV:DATA?”          !request data
260  ENTER @Mta USING “#,2A”;Header$  !Header$ is 2
                                      string characters
270  FOR J=0 TO N-1
280  ENTER @Mta USING “#,W”;Waveform(J) !16 bit words
290  NEXT J
300  ENTER @Mta;Trailer$
```

At this point in the program, the data has been output from the HP 70820A and stored in the waveform array. Additional processing can now proceed in the BASIC program.

## 8.3 Using Array Processing for One-Port VNA Error Correction

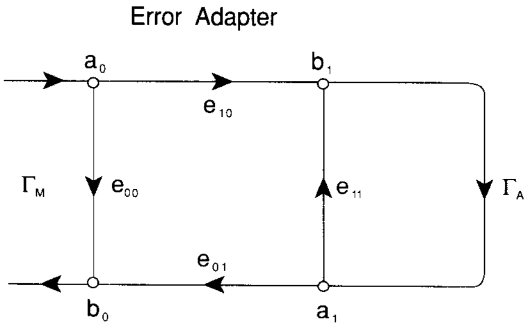
The array processing capabilities of the HP 70820A can be used to apply vector error correction to measured data. This section shows how to apply three-term vector error correction to a reflection coefficient measurement.

The normalization process used in section 5.2, “Reflection Measurement Example,” corrects for frequency response errors, but not for errors due to system directivity or port match. This correction procedure corrects for all three error terms.

The correction factors are calculated from measurements, made with the HP 70820A, of three known standards. These calculations are accomplished using an external controller. The correction factors are loaded into the trace memory of the HP 70820A. A trace is then defined in terms of measured data and the correction factors. Once correction factors have been calculated, the external controller is no longer required, since all correction data has been stored into the HP 70820A and will be applied to each new measurement.

### One-Port Error Model

Figure 64 shows the errors inherent in a reflection measurement system. All linear errors of the system were modeled as a two-port error adapter between the measurement system and the device under test. The reflection coefficients, $\Gamma_M$ and $\Gamma_A$, are the measured and actual reflection coefficients, respectively. System directivity is $e_{00}$, $e_{11}$ is the source match at the measurement port, and $e_{10}*e_{01}$ is the system frequency response.



$e_{00}$ = Directivity
$(e_{10}\, e_{01})$ = Freq Response
$e_{11}$ = Port Match

Measured

$$\Gamma_M = \frac{b_0}{a_0} = e_{00} + \frac{(e_{10}\, e_{01})\, \Gamma_A}{1 - e_{11}\, \Gamma_A}$$

Actual

$$\Gamma_A = \frac{\Gamma_M - e_{00}}{e_{11}\, (\Gamma M - e_{00}) + (e_{10}\, e_{01})}$$

**Figure 64. Graph of one-port measurement flow with errors represented by two-port error adapter**

$\Gamma_A$ is the desired result and can be determined by $\Gamma_M$ and the three error terms: directivity, frequency response, and source match.

## Correction Equation

The actual reflection coefficient is related to the measured reflection coefficient by the following equation:

$$\Gamma_A = (\Gamma_M - e_{00}) / [\, e_{11} * \Gamma_M + (\, e_{10} * e_{01} - e_{00} * e_{11}\,)\,]$$

## Determination of Error Terms

The three error terms can be determined from the measured reflection ($\Gamma_M$) of three different, known terminations ($\Gamma_A$). This determination typically is accomplished using some combination of shorts, offset shorts, opens, capacitance modeled opens, $Z_0$ terminations, and sliding terminations.

The various methods that can be used, as well as the method of determining the error coefficients from these measurements, are presented in “An Analysis of Vector Measurement Accuracy Enhancement Techniques" and "Appendix to an Analysis of Vector Measurement Accuracy Enhancement Techniques," Hewlett-Packard RF and Microwave Symposium and Exhibition, 1982.

### Load Correction Factors into Memory

The equation used to calculate the actual reflection coefficient from the measured data contains three parts, each of which consists of one or more of the error terms. Once the error terms have been determined, these three parts should be calculated and stored into three separate memory registers of the HP 70820A as follows:

Memory 1 = $- e_{00}$ (-1 * directivity)

Memory 2 = $e_{11}$ (source match)

Memory 3 = $e_{10} * e_{01} - e_{00} * e_{11}$(frequency response - dir * match)

### Define Corrected Trace

To apply the correction coefficients to measured data, a trace must be defined using the correction equation shown above. The value of $\Gamma_M$ for a ratioed reflection measurement is equal to the ratio of channel 1 to channel 2. The trace definition for the corrected measurement is:

Trace 1 = ( CH1/CH2 + WMEM1) / ( WMEM2 * CH1/CH2 + WMEM3 )

### Applying the Correction Factors

For each reflection measurement made, trace 1 is recalculated to apply the correction factors to the new data. The external controller no longer is required for the vector error correction.

# Chapter 9

## Optimizing Measurements: Operation of the HP 70820A

## 9.1 Hardware Configuration and User Adjustable Components

### Introduction to the Block Diagram of the HP 70820A

The simplified block diagram for the HP 70820A is shown in figure 65. The incoming signals to channel 1 and channel 2 are sampled at a rate ($F_s$) between 10 MHz and 20 MHz, dependent upon the signal frequency and the type of measurement being made. The output of the samplers is sent to the 0 to 10 MHz intermediate frequency (IF) sections. The IF sections contain switchable low-pass filters and step-gain amplifiers. After filtering and amplification, the IF signals are sampled at the same rate as the RF inputs and then are converted to a digital signal by analog-to-digital converters (ADC).

After being digitized, the signals are sent into the buffer memories (MEM). These buffers hold the samples until the trigger point is determined. By using the buffer memory, signals can be viewed before the trigger event occurs. Once the trigger point has been determined, and all necessary data has been acquired, the appropriate data is sent to the digital-signal-processing (DSP) chips. The type of DSP processing performed depends on the specific measurement being made. The output of the DSP chips is sent to the microprocessor, which performs the final processing on the trace data; for example, the microprocessor calculates the complex ratio of the DSP outputs for a gain/phase measurement. The microprocessor also performs many other instrument control functions.

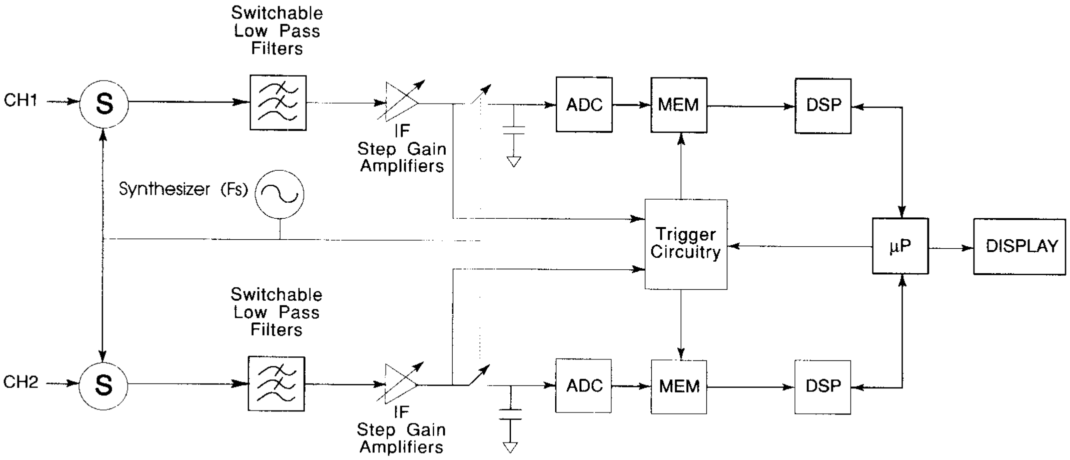


**Figure 65. Simplified block diagram of HP 70820A.**

### Input Samplers Mix Input Signals to Lower Frequencies

The input samplers are used to replicate the 0 to 40 GHz RF signals of interest in the 0 to 10 MHz IF sections. This frequency compression is accomplished by sampling the input signals with a very narrow pulse. The sampling pulse is approximately 15 ps wide and can be thought of as a comb of frequencies from 0 to 40 GHz with a spacing equal to the sampling frequency. Due to the width of the sampling pulse, there is a decrease in the amplitude of the sampler's response with increasing RF frequency (approximately 6 dB down at 40 GHz). This amplitude change is compensated for by the RF corrections applied to the digitized data.

When the signal of interest is a sine wave, such as for vector-voltage and network-analysis measurements, the RF signal of interest mixes with the sampling pulse. The resulting IF response occurs at the frequency equal to the difference between the input signal and the nearest comb tooth of the sampling pulse, as shown in figure 66. The HP 70820A selects the sampler frequency such that the desired IF frequency is obtained. If, for example, the RF signal was a 7 GHz sine wave and the desired IF frequency was 100 kHz, the sampler frequency would be chosen to be slightly less than 20 MHz, such that its 350th harmonic was 100 kHz below 7 GHz. The result is that a sample of the RF input is taken every 350 cycles of the RF signal, and each sample represents a different point of the RF signal, as shown in figure 67. The exact IF frequency used for these single sine-wave measurements depends on the measurement being made and the input frequency. Further discussions can be found in the sections describing specific measurements in this and other notes of the Product Note 70820 series.

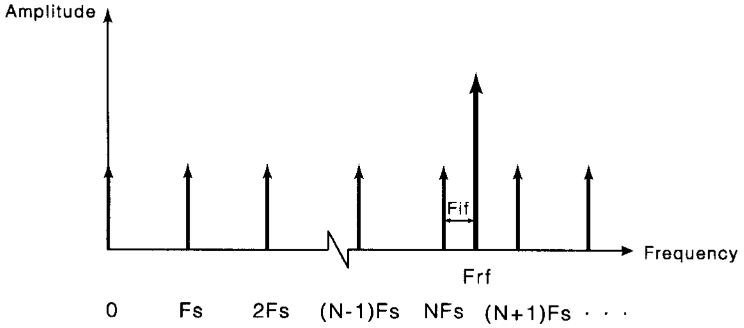


**Figure 66. Frequency spectrum of sampling pulse and input RF signal for single sine-wave measurements. The IF frequency is equal to $F_{RF} - N*F_s$.**

For measuring signals with harmonic content, a signal is reproduced in the IF section such that the harmonics are placed in the IF with the same ordering as in the RF signal. Figure 68 shows the frequency spectrum of the sampling pulse and the RF signal for the measurement of the harmonics in addition to the RF fundamental. In this measurement mode, the IF response due to the 2nd harmonic of the RF signal is at twice the frequency of the IF response due to the fundamental component of the RF signal. The IF response of the 3rd harmonic is at three times the frequency of the fundamental, and so on. For example, for a signal with a fundamental frequency of 1 GHz and a desired IF fundamental frequency of 100 kHz, the sampling frequency is chosen to be slightly less than 20 MHz, such that its 50th harmonic is 100 kHz below 1 GHz. As a result, the 100th harmonic is 200 kHz below 2 GHz, placing the IF component due to the RF signal's 2nd harmonic at 200 kHz; the 3rd harmonic appears at an IF frequency of 300 kHz, and so on, as shown in figure 68. As with the sinusoidal example in figure 67, the sampling occurs such that the samples sequentially move through the repetitive waveform, resulting in the RF signal being reproduced in the IF section with an expanded time scale, as shown in figure 69. Figure 70 shows the frequency- and time-domain views of the input RF signal, as well as the resulting IF signal, for the input shown in figure 69. For this type of measurement, the RF signal is reproduced in the IF section with a compressed frequency spectrum and expanded time scale.

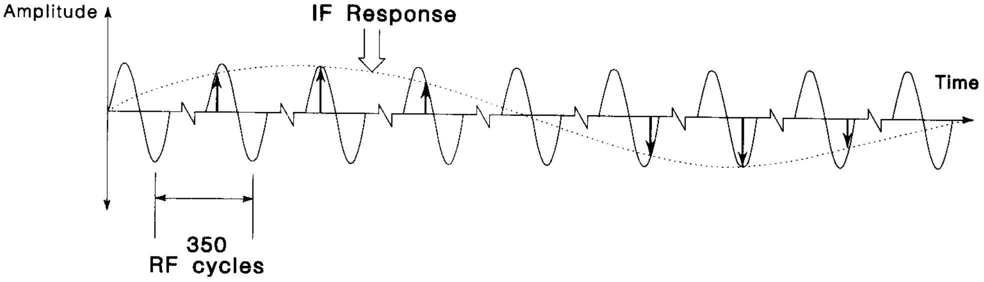


**Figure 67. Time-domain display of input RF signal and the samples resulting in the IF signal. Many cycles of the RF signal occur between each sample. For the example of a 7 GHz signal, there are 350 cycles of the RF signal between samples. The input signal is expanded in time in the HP 70820A IF.**

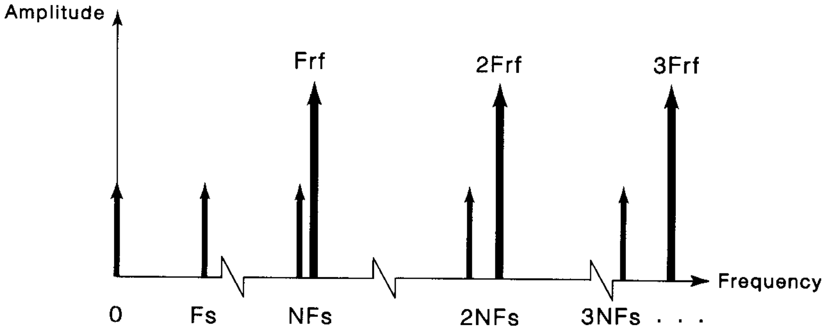


**Figure 68. Frequency spectrum of sampling pulse and input RF signal for measurement of fundamental and harmonics. The IF frequency for the fundamental term is equal to $F_{RF}$-N*$F_s$. The IF frequency of the 2nd harmonic is twice that, and so on. The IF spectrum is a compressed version of the RF spectrum.**

Some measurements require different sampling schemes than those described above. Refer to the appropriate section of this or other notes of the Product Note 70820 series for the method of sampling used in a particular measurement.

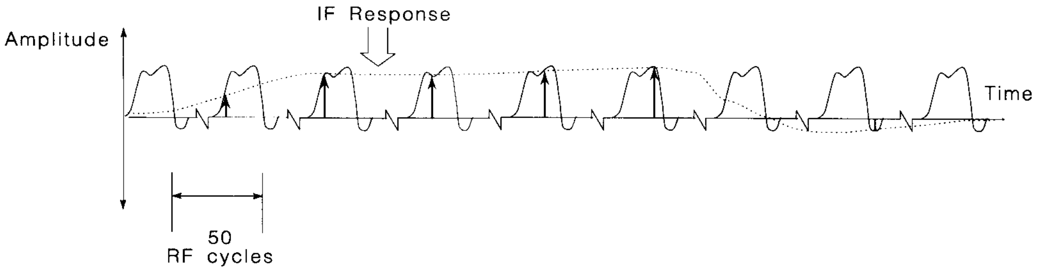
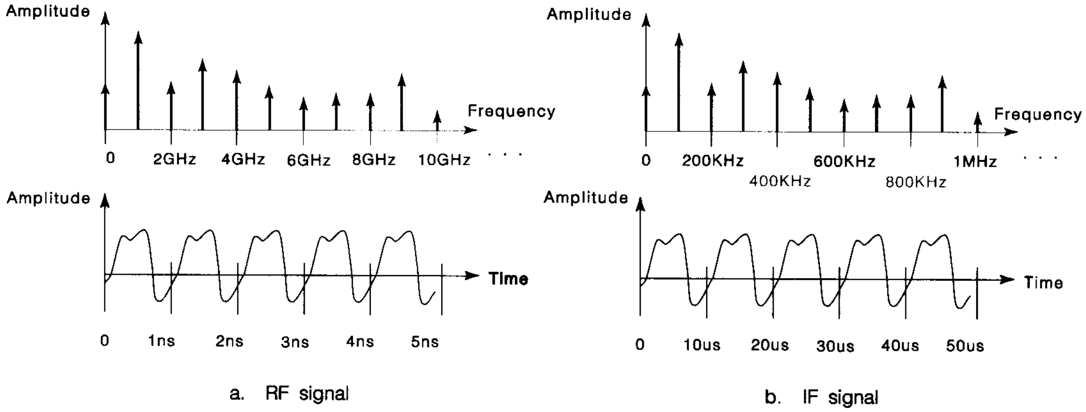


**Figure 69. Time-domain display of input RF signal and the samples resulting in the IF signal. Many cycles of the RF signal occur between each sample. For the example of an RF signal with a fundamental frequency of 1 GHz, 50 cycles of the RF signal occur between each sample.**



a. RF signal

b. IF signal

**Figure 70. Time- and frequency-domain views of (a) the input RF signal and (b) the resulting IF signal for the repetitive signal shown in figure 69. The IF signal is a compressed-spectrum version of the RF signal.**

To perform gain and phase measurements, the relative phase and magnitude of the channel 1 and channel 2 signals must be preserved in the IF section. The relative magnitudes and phases of the incoming signals are preserved by simultaneously driving the two input samplers and calibrating the two HP 70820A IF sections from a common calibrator output.

For most measurements, the HP 70820A must know the RF input frequency to select the sampler frequency properly. This can be accomplished in three ways: The operator can enter the RF frequency; the HP 70820A can measure the signal frequency; or, when the HP 70820A has control of the source, the analyzer has set the source frequency and therefore recognizes it. While the sampling rate may vary between 10 MHz and 20 MHz, in general the sample rate is kept as close as possible to 20 MHz for improved noise performance. The improved noise performance for a sampler frequency near 20 MHz is due to the use of lower sampler harmonics for mixing and a narrowband bandpass filter applied to the sampler oscillator for sampler frequencies near 20 MHz.

Signal-measuring functions (FIND SIGNALS and SIGNAL TRACK) can be used to determine and tune to the highest amplitude signal between 0 and 40 GHz. With the sampler frequency between 10 MHz and 20 MHz, any signal between 0 and 40 GHz will be within 10 MHz of one of the frequency comb teeth of the sampler, and therefore the signal will be converted down to a response in the 0 to 10 MHz IF bandwidth of the HP 70820A. By performing measurements of the IF spectrum with various sampling frequencies, the HP 70820A can determine the frequency of the largest incoming signal and then tune to receive the largest signal.

The 40 GHz input frequency range of the HP 70820A allows it to capture wide-bandwidth periodic waveforms and measure all the harmonics of a signal at the same time. In contrast is the swept spectrum analyzer, which sweeps through the frequency spectrum and views only a single harmonic of a signal at a time. No preselector filter is located in front of the input samplers, so all signals of sufficient amplitude between 0 and 40 GHz produce an IF response between 0 and 10 MHz.

### Selectable Low-pass Filters Reduce IF Noise Level

The switchable low-pass filters in the IF section of each channel are 100 kHz, 7 MHz, and 10 MHz. For measurements where all the desired spectral information is below 100 kHz, the 100 kHz filter is used to reduce the system noise level. For most other measurements, the 10 MHz filter is used. In addition to reducing the noise level, the IF filters also reduce the sampler oscillator feedthrough in the IF signal. The 7 MHz filter is used to reduce the sampler oscillator feedthrough in those cases where sample rates lower than 14 MHz are used.

### Step-Gain Amplifiers Amplify IF Signals for Sensitivity and Triggering

The variable-gain IF amplifiers shown in figure 65 consist of 6 dB and 12 dB amplifiers, adjustable in 6 dB steps from -6 to 36 dB of gain. When the 100 kHz low-pass filter is selected, an additional 24 dB of gain is available, and the gain can be adjusted from -6 to 60 dB in 6 dB increments. Although the amplifiers shown are located at the output of the low-pass filter, various amplifier stages and low-pass filter stages actually are intermixed, improving the dynamic range of the measurements. The filters and amplifiers are shown as single blocks in figure 65 for simplicity.

With the AUTO RANGE feature activated, the IF step-gain amplifiers are set automatically for the largest possible signal at the analog-to-digital converters, without over-driving them. Since the step gains are settable in 6 dB increments, the AUTO-RANGE function attempts (within the gain limits of the amplifiers) to position the peak of the signal in the top 6 dB of the ADC's range. This feature allows for large dynamic-range measurements, as shown in figure 6. When measuring the high-amplitude portion of the filter's response, the gain is set low; when measuring the high-rejection portions of the filter, the gain is set high.

When the AUTO RANGE function is turned off, the step gain is set by adjusting the full-scale measurement range of the IF hardware. With the range set to 640 mV full scale, the gain is set to the minimum value. Reducing the range increases the gain in the IF section.

### IF Signals Are Digitized by Sample-and-Hold ADC

After filtering and amplification, the IF signal is sampled, held, and converted to a digital signal. The sample-and-hold circuitry operates from the same sampler oscillator as do the RF input samplers, and the sampling occurs at the same rate. The analog-to-digital (A/D) converters are 10 bit, 20 MHz A/D converters. The outputs of the A/D converters are placed in the buffer memories. Whether each sample is used or not used depends on the frequency of the input RF signal and the type of measurement being performed. The ability not to use all the data allows the sample rate to be set anywhere from 20 MHz down to 1 Hz.

### Internal Triggering to 40 GHz

The HP 70820A is capable of internally triggering on channel 1 or channel 2 inputs from 0 to 40 GHz. 40 GHz triggering is made possible by triggering on the IF signal after amplification rather than at the RF input. For many measurements, determining the trigger point based on the IF signal levels is possible; other measurements require post-ADC processing, as indicated by the microprocessor input to the trigger circuitry.

Phase triggering provides one example of requiring post-ADC processing. In order to determine the phase trigger point, an FFT is performed on the data, and the phase of the fundamental component is used to determine the trigger point. The FFT enhances the signal-to-noise ratio, providing stable triggering in measurements having low signal-to-noise ratios. Once the trigger point has been determined, it is related to a pointer position in the buffer memory.

### Buffer Memories Give Pre-trigger Viewing

After the signals are digitized, they are moved into the 256 Ksample buffers. Most measurements don't use the entire memory; rather, they use a portion of the memory that is up to two times larger than the number of trace points. The maximum number of trace points allowed is 1,024. Incoming data is looped through the buffer until the trigger point is determined. One full trace prior to the trigger constitutes the maximum amount of pre-trigger data that can be viewed. This corresponds to a delay of minus one-half trace. The delay can be increased up through zero (for measurements where the trigger point is at the middle of the trace) all the way to 1,000 trace lengths. An exception to this limit of a maximum delay of 1,000 trace lengths occurs in some pulsed-RF measurement modes, where much greater delays (up to ± 2 periods of the pulse modulating signal) are possible. The very long delays are useful when making measurements on very-low-duty cycle-pulsed RF signals having fast rising and falling edges. Once the trigger point is determined, data collection continues until the entered delay value is satisfied. Data then is sent to the digital signal processing chips.

### DSP Chips and Microprocessor Calculate and Format Results for Display

Each channel contains a DSP56001 digital signal processor (DSP), which uses 24-bit integer processing and 56-bit accumulators. These DSP chips are used for many functions such as signal filtering, convolution, correlation, amplification, and FFTs. In addition, user-defined functions can take advantage of the DSP56001 capabilities.

These DSPs also allow the HP 70820A to be used as an array processor. Trace data or externally generated data of up to 1,024 complex points may be loaded into the HP 70820A and operated on. Using the HP 70820A as an array processor requires no knowledge of the DSP56001. All interfacing with the processor is managed by the HP 70820A. Operation of the HP 70820A as an array processor is discussed in more detail in chapter 8, "Array Processing" in this product note.

The output of the DSP chips is fed to the 68000 microprocessor, which performs the final processing on the trace data. The 68000 microprocessor performs many instrument-control functions, as well as data manipulation. For the sake of speed, the 68000 microprocessor uses the DSP chips as coprocessors, when possible.

## 9.2 Measurement-Specific Signal Processing

### Frequency and Power

The frequency and power recall state evokes the table mode of the HP 70820A, which measures the input signals and presents a tabular listing of the results. The tabular information includes frequency, power, and phase (for harmonic or two-channel measurements).

The table-mode measurements of the HP 70820A are taken separately from the normal trace measurements. In the continuous trigger mode, the table measurements are performed after each standard trace measurement is completed. In this mode, the HP 70820A alternates between standard measurements and table measurements. In the single trigger mode, if no traces are defined (only the table data is displayed), the standard measurement is not performed. Only table data is taken.

Four table-menu functions affect the table-measurement process of the HP 70820A:

- filter ON | OFF: This key controls a 100 kHz low-pass IF filter. With this filter off, the IF bandwidth is from 0 to 10 MHz. With this filter on, all signals to be measured are mixed down to an IF frequency less than 100 kHz. Using the noise filter results in greater frequency accuracy, based on the algorithms used.

- INCLUDE HARMONICS: When this function is off (not underlined), the HP 70820A treats all responses as independent signals, regardless of their harmonic relationship. With this function on (underlined), all harmonics of a signal are associated with that signal and are not treated as separate signals. For example, with the include-harmonics function on, a 1 GHz signal with a strong 2nd-harmonic content is treated as one signal with an associated harmonic. With include-harmonics off, the 1 GHz signal and its 2nd harmonic are treated as two separate signals. This difference is important in the way the information is measured and displayed.

- signals ONE | ALL: This function determines whether only one signal is measured (the largest signal, if signal track is on), or whether all signals (up to five) are measured. With INCLUDE HARMONICS on, only fundamental frequencies count as signals, so that one signal and its harmonics are displayed with the SIGNALS function set to ONE. With SIGNALS set to ALL, up to five signals can be measured. If include harmonics is also on, all five signals and their harmonics, up to the 16th, can be displayed.

- sig trk ON | OFF: The signal-track function monitors incoming signals for frequency changes. If a change occurs, signal frequencies are redetermined, and the largest is measured. The signal-track function determines the input frequencies using a two-step process. The first step is to perform 16 measurements with 16 different sample rates. The input frequencies are determined based on the resulting IF responses for each input-sample rate. The second step uses a sample rate that places each signal at a different IF frequency, and then the signal frequencies are determined precisely.

For measurements of single signals, the signal-track routine is evoked only after an IF frequency change is detected or after eight measurements have been made. A good reason exists for occasionally rechecking the signal frequency even if no IF frequency change has been detected: It is possible for the input signal to change frequency but result in the same IF frequency. For multiple signal measurements, the signal-track routine is repeated before each measurement to determine each frequency.

With signal track off, the HP 70820A continues to perform measurements at the specified frequencies, regardless of signal changes. For the measurement of stable frequencies, turning signal track off improves measurement speed.

The measurement process used depends on the combination of the above settings and the number of signals being measured. Signal track does not affect the measurement routine used, but it does affect events between measurements. These measurement procedures assume that the signal frequencies are known. The frequencies are determined by the signal-track routine or the find-frequencies function (which is similar to a one-time signal-track measurement), or they are entered into the signal list by the user.

- filter OFF, INCLUDE HARMONICS OFF: For signals with frequencies greater than 10 MHz, the sample rate is chosen to be as close to 20 MHz as possible, such that the resulting IF frequency of the largest signal is approximately one-fourth the sample frequency. If more than one signal is measured, the other signals will cause the IF frequency to be somewhere between 0 and 10 MHz. The exact value of the input sample rate is set so that the various IF responses do not fall within 500 kHz of each other, if possible. The IF signals are sampled at the same rate as the input signals, and 4,096 points are taken. An FFT is performed, and the frequency, amplitude, and phase of the specified signals are determined by interpolation.

For signals with frequencies less than 10 MHz, the IF frequency of the signal is equal to the input frequency and may not be at one-fourth the sample rate. For signals much less than 5 MHz, the IF sample rate is effectively reduced by not using all the IF samples. In this way, the IF sample rate is reduced to approximately four times the signal frequency. As with the above case, a 4,096 point FFT is computed and used to determine the frequency, amplitude, and phase of the specified signals.

- filter OFF, INCLUDE HARMONICS ON: In this mode of operation, a separate measurement is performed for each signal. Since INCLUDE HARMONICS is on, harmonics do not count as separate signals.

For signals with frequencies greater than 10 MHz, the sample rate is chosen to be as close to 20 MHz as possible, such that the resulting IF frequency is at approximately 78 kHz. This places the first 100 harmonics of this signal from 78 kHz to 7.8 MHz. The IF response is then sampled at the same rate as the input signal. The exact value of the sample rate is chosen such that the other signals and their harmonics, up to the user-specified number of harmonics, do not fall within eight post-FFT frequency bins of the signal to be measured and its harmonics. After 4,096 IF samples are taken, an FFT is performed, and then interpolation is used to determine precisely the frequency, amplitude, and phase of the specified signal and its harmonics.

For signals less than 10 MHz, the IF frequency of the signal is equal to the input frequency and is not at 78 kHz. For signal frequencies greater than 100 kHz, the first 100 harmonics of the input signal cannot be placed into the IF without some foldover. All harmonics will be in the 0 to 10 MHz IF, but they will not be in consecutive order, as is the case for signals greater than 10 MHz. The exact value of the sample rate is chosen such that the first 100 harmonics do not fold on top of one another in the IF. In addition, the exact value of the sample rate is chosen such that the other signals and their harmonics, up to the user specified number of harmonics, do not fall within eight post-FFT frequency bins of the signal to be measured and its harmonics. For signals with frequencies much less than 100 kHz, the IF sample rate is effectively reduced by not using all the IF samples. In this way, the IF sample rate is reduced to approximately 100 times the signal frequency. As with the above case, a 4,096 point FFT is computed and used to determine the frequency, amplitude, and phase of the specified signals.

- filter ON, INCLUDE HARMONICS OFF: In this mode, a separate measurement is completed for each signal. Since INCLUDE HARMONICS is off, harmonics count as separate signals.

For signals greater than 10 MHz, the sample rate is chosen to be as close to 20 MHz as possible, such that the resulting IF frequency is at approximately 78 kHz. The IF response is then sampled at the same rate as the input signal. The exact value of the sample rate is chosen such that the other signals do not fall within eight post-FFT frequency bins of the signal to be measured. In order to maintain a frequency accuracy of 1 part in $10^8$, the FFT requires a specific time record. Since 4,096 of the IF samples are used, the appropriate time record is obtained by not using all of the IF samples. The FFT is performed, and then interpolation is used to determine precisely the frequency, amplitude, and phase of the specified signal.

For signals less than 10 MHz, the IF filter is turned off, but the frequency-accuracy is maintained.

- filter ON, INCLUDE HARMONICS ON: In this mode, a separate measurement is performed for each signal. Since INCLUDE HARMONICS is on, harmonics do not count as separate signals.

For signals greater than 10 MHz, the sample rate is chosen to be as close to 20 MHz as possible, such that the resulting IF frequency is at approximately 5 kHz. This will place the first 20 harmonics of this signal from 5 kHz to 100 kHz. The IF response is then sampled at the same rate as the input signal. The exact value of the sample rate is chosen such that the other signals and their harmonics, up to the user-specified number of harmonics, do not fall within the 100 kHz pass band. In order to maintain a frequency accuracy of 1 part in $10^8$, a certain time record is required for the FFT. Since 4,096 of the IF samples are used, the appropriate time record is obtained by not using all the IF samples. The FFT is performed, and then interpolation is used to determine precisely the frequency, amplitude, and phase of the specified signal and its harmonics.

For signals less than 10 MHz, the IF filter is turned off but the frequency-accuracy is maintained. The IF filter must be turned off because signals between 100 kHz and 10 MHz cannot be placed in the 0 to 100 kHz IF pass band.

### Vector Voltage

The vector-voltage recall state evokes the table mode of the HP 70820A, which measures the input signals and presents a tabular listing of the results. The tabular information includes frequency, gain, and phase. Vector-voltage measurements are performed the same way as frequency and power measurements, except that the ratio of the signals at the two input channels is displayed rather than the absolute values at one of the input channels.

## Network Analysis

In the network-analysis mode of operation, the HP 70820A steps the source from the start frequency to the stop frequency in equally spaced frequency steps. The number of frequencies is equal to TRACE POINTS and can be set to a maximum of 1,024. At each frequency, the HP 70820A tunes to receive the signal and measures the signals at channels 1 and 2. The input data is then processed depending on how the traces are defined.

Since each point of the network-analysis sweep is a separate measurement, the autorange function can be used to set the step-gain amplifiers as appropriate for each point, allowing for wide dynamic-range measurements. For example, when measuring the pass band of a bandpass filter, the signal is large and little gain is required in the IF section. When measuring the out-of-band part of the filter, the incoming signal is very small and much IF gain can be used.

## Network Analysis for Signals Greater than 10 MHz

For signal frequencies greater than 10 MHz, the sample rate is set as close to 20 MHz as possible, such that a harmonic of the sampler oscillator is 78.125 kHz lower in frequency than the signal. An IF signal frequency of 78.125 kHz results. For signals within 78.125 kHz of 10 MHz, the sampler frequency is set to 78.125 kHz above the signal frequency. Since the IF signal is always 78.125 kHz, the 100 kHz IF filter is turned on.

The IF signal is then sampled and digitized at the same rate as the input signal. Only one-twentieth of the IF samples are used, resulting in an effective IF sample rate of the input sample rate divided by 20 (typically 1 MHz).

The number of IF samples taken depends on the noise-filter bandwidth specified by the user. For a 1 kHz noise-filter bandwidth, a time record of approximately 1/1,000 Hz, or 1 ms, is required. At an IF sample rate of 1 Msamples/second, the number of samples required is $1{,}000{,}000 * 0.001 = 1{,}000$. Once these samples have been taken, the digital filtering is applied to the 78.125 kHz signal and the magnitude and phase of the signal at each channel is determined.

## Network Analysis for Signals Less than 10 MHz

For signal frequencies more than 78.125 kHz below 10 MHz, the input sample rate cannot be set to within 78 kHz of the input signal. For these signals, the input sample rate is set to 20 MHz, and the IF bandwidth is 10 MHz. The IF frequency in this case is equal to the input signal frequency.

As in the above case, the number of IF samples taken depends on the noise-filter bandwidth specified by the user. The difference is that 20 times as many samples will be required for the same noise-filter bandwidth. For example, with an IF sample rate of 20 MHz, and a noise-filter bandwidth of 1 kHz, a time record of approximately 1 ms is required (just as in the above example). At an IF sample rate of 20 Msamples/s, the number of samples required is $20{,}000{,}000 * 0.001 = 20{,}000$. This value is 20 times more than required in the above example and results in a slower update rate due to the additional processing required.

### Power Sweeps

Power-sweep measurements operate in the same way as network-analysis measurements, except that each measurement is made at the same frequency. The frequency is fixed, and the power is stepped from the start power to the stop power in equally spaced steps. The number of power levels is equal to TRACE POINTS and can be set to a maximum of 1,024.

### Sampled Spectrum Analysis

The HP 70820A operates in a single-shot sampling mode that limits the maximum span to one-half the sampling rate. The time-domain data then is transformed to frequency. The sampling rate is chosen to place a harmonic of the sampler frequency at the frequency corresponding the lowest frequency of the measurement. The span of the measurement is equal to one-half the sample rate.

The sample rate will be automatically set by the HP 70820A, but the user can set it, if desired, to any value between 1 Hz and 20 MHz. A low sample rate can be used to improve frequency resolution and to place the IF component at a frequency of less than 100 kHz so that the noise filter can be turned on.

A second way to reduce the frequency span is to use the zoom-transform function. Use of this function does not change the sample rate. By taking a longer record of time data, the frequency resolution of the transform is increased. The resolution is increased by the amount required to display the reduced span with the same number of trace points that were in the pre-zoom trace. Using the zoom transform effectively lowers the resolution bandwidth of the measurement, which reduces the noise level and improves the frequency resolution.

# Appendix A
## Compatible Sources and HP 70820A/Source Configuration Procedure

**Synthesizers Supported with Drivers**

| | Frequency Range (GHz) | Frequency Resolution | Frequency & Power Controls | RF Out ON/OFF Control | Pulsed-RF Carrier Freq Adjustment | Pulse Mod ON/OFF Control |
|---|---|---|---|---|---|---|
| HP 3325B[1,2] | 1 μHz[2] to 21 MHz | 1 μHz | Yes | No | Yes | No |
| HP 3335A[1,2] | 200 Hz to 81 MHz | 1 mHz | Yes | No | Yes | No |
| HP 8340 | 0.01 to 26.5 | 1 Hz | Yes | Yes | Yes | Yes |
| HP 8341 | 0.01 to 20 | 1 Hz | Yes | Yes | Yes | Yes |
| HP 83620A Opt 008 | 0.01 to 20 | 1 Hz | Yes | Yes | Yes | Yes |
| HP 83622A Opt 008 | 2 to 20 | 1 Hz | Yes | Yes | Yes | Yes |
| HP 83623A Opt 008 (hi pwr) | 0.01 to 20 | 1 Hz | Yes | Yes | Yes | Yes |
| HP 83624A Opt 008 (hi pwr) | 2 to 20 | 1 Hz | Yes | Yes | Yes | Yes |
| HP 83640A Opt 008 | 0.01 to 40 | 1 Hz | Yes | Yes | Yes | Yes |
| HP 83642A Opt 008 | 2 to 40 | 1 Hz | Yes | Yes | Yes | Yes |
| HP 836xx W/O Opt 008 | | 1 kHz | Yes | Yes | No[3] | Yes |
| HP 8672A | 2 to 18 | 1-3 kHz | Yes | Yes | No[3] | Yes |
| HP 8673B | 2 to 26 | 1-4 kHz | Yes | Yes | No[3] | Yes |
| HP 8673C | 0.05 to 18.6 | 1-4 kHz | Yes | Yes | No[3] | Yes |
| HP 8673D | 0.05 to 26 | 1-4 kHz | Yes | Yes | No[3] | Yes |
| HP 8673E | 2 to 18 | 1-3 kHz | Yes | Yes | No[3] | Yes |
| HP 8673G | 2 to 26 | 1-4 kHz | Yes | Yes | No[3] | No |
| HP 8673H | 2 to 12 or 5 to 18 | 1-3 kHz | Yes | Yes | No[3] | Yes |
| HP 8662A[1] | 0.000100 to 1.28 | 0.1 Hz | Yes | No | Yes | Yes |
| HP 70320A (HP 8644A)[1] | 0.000252 to 2.06 | 0.01 Hz | Yes | Yes | Yes | Yes |
| HP 70325A (HP 8645A)[1] | 0.000252 to 2.06 | 0.01 Hz | Yes | Yes | Yes | Yes |
| HP 70322A (HP 8665A)[1] | 0.000100 to 4.20 | 0.01 Hz | Yes | Yes | Yes | Yes |

Use of a synthesizer under HP-IB or HP-MSIB control and sharing a common 10 MHz time base, while not absolutely required, is highly recommended to simplify the use of the instrument. Drivers for synthesizers consist of HP-IB/HP-MSIB drivers in the HP 70820A to control the source frequency, power level, RF output on/off, and pulse modulation on/off from the HP 70820A. Custom drivers for other HP-IB synthesized sources, may be defined over (IEEE-488). RF sources generally have lower phase noise than microwave sources and are recommended for repetition rates < 1 GHz.

[1] The HP 3325, HP 3335, HP 8662A, and HP 7032x synthesizers do not support a "signal settled" bit. To be safe, the user should include a dwell time sufficient to let the signal settle in frequency sweeps. The dwell time required depends on the noise filter BW used and accuracy desired.

[2] The HP 3325B and HP 3335A work well for frequency and power sweeps or any case where approximately one cycle is on screen. But these instruments have jitter that is inversely proportional to the repetition frequency. When observing fast events at low repetition frequencies, this jitter may make the HP 3325B and HP 3335A unsuitable for delta time measurements with the HP 70820A. HP recommends using the internal pulse generator (as a time base for low repetition frequencies) to trigger an external signal source reducing the jitter problem. The HP 3325B is supported only down to 0.1 Hz.

[3] For pulsed-RF component characterization, the HP 70820A may adjust the carrier frequency slightly from what was chosen to allow the AM/PM demodulation routines to work properly. Because of this adjustment, synthesizers with at least 1 Hz frequency resolution are recommended for pulsed-RF component characterization.

### Source Configuration Procedure

Configuring the microwave transition analyzer with a synthesized source allows the analyzer to control such source parameters as frequency, power level, RF output on/off, and pulse modulation on/off.

Configuration is accomplished using functions located under RF source under the Config menu. The model of the source to be used is selected under RF src:. Several model numbers of RF sources will be displayed. Select the softkey adjacent to the model number of the RF source that is to be used. (For those measurements where control of the source is not desired, select "NONE" under the list of sources.) Then, select HPIB or MSIB communication and set the source address on the communication bus selected.

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**HEWLETT PACKARD**

For more information, call your local HP sales office listed in your telephone directory or an HP regional office listed below for the location of your nearest sales office.

United States:
Hewlett-Packard Company
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Rolling Meadows, IL 60008
(708) 255 9800

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No. Hollywood, CA 91601
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Atlanta, GA 30339
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Shinjuku-ku
Tokyo 160, Japan
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