HEWLETT PACKARD

HP 71500A Microwave Transition Analyzer

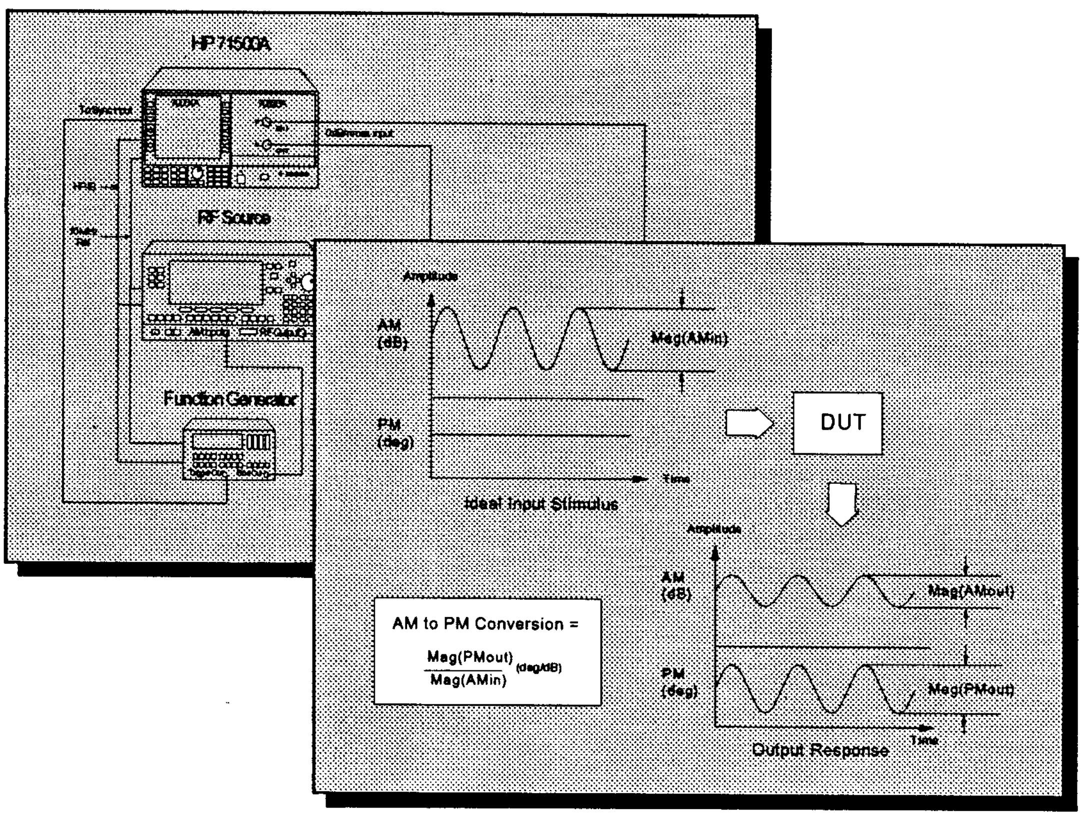
AM to PM Conversion and Translation Measurements

Product Note 70820-11

HP 71500A/70820A Product Note Series

Measure AM to PM Conversion and Translation on Frequency Converters such as Satellite Transponders.

PRELIMINARY



AM to PM Conversion and Translation Measurements on Frequency Converters Using the HP 71500A Microwave Transition Analyzer

Abstract: *this paper describes using the HP 71500A microwave transition analyzer to make dynamic AM to PM conversion and translation measurements on frequency translating devices. AM to PM conversion is a measure of undesired phase modulation caused by unavoidable signal amplitude changes. It results from device nonlinearity, and can cause signal degradation and increased bit error rates (BER). This measurement is done on components such as TWT amplifiers, or subsystems such as satellite transponders. The technique uses an AM modulated RF carrier as a stimulus, and measures the input and output signals of the DUT in the frequency domain via the fast Fourier transform (FFT). This technique also allows the measurement of AM to AM conversion and translation, and can be used on linear devices as well as frequency converters. Translation measurements characterize the modulation induced on a second, unmodulated signal in the presence of the modulated carrier.*

Introduction

What is AM to PM conversion?

AM to PM conversion is a measurement done to help characterize the nonlinear performance of a device or subsystem. It is a measure of the amount of undesirable phase deviation (the PM) which is induced by amplitude variations inherent in the system (the AM). This undesired PM is caused by unintentional amplitude variations such as power supply ripple, thermal drift, or multipath fading, or by intentional amplitude change that is a result of the modulation type used, such as the case with QAM or pulse modulation. AM to PM conversion is a scalar quantity, usually expressed in °/dB (see figure 1). A related measurement is AM to AM conversion, which is defined as the magnitude of the output AM divided by the magnitude of the input AM. It is expressed in units of dB/dB.

A single AM to PM conversion measurement is done at one particular RF carrier frequency and power level, but multiple measurements can be done to characterize AM to PM conversion versus RF frequency, power level, or AM frequency.

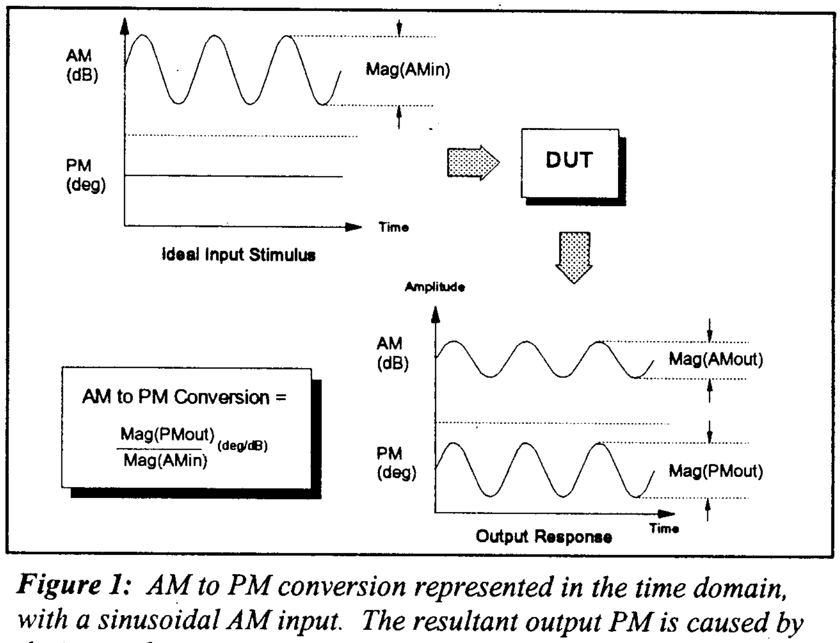


Figure 1: AM to PM conversion represented in the time domain, with a sinusoidal AM input. The resultant output PM is caused by device nonlinearity.

Why measure AM to PM conversion?

AM to PM conversion is most commonly measured on power amplifiers which use traveling-wave tubes (TWTs) or power FETs, or subsystems which contain power amplifiers such as satellite transponders. It is a particularly critical parameter in systems where phase (angular) modulation is employed, because undesired phase distortion causes analog signal degradation, or increased bit error rates (BER) in digital systems. Examples of modulation types that use phase modulation are FM, QPSK, or QAM in telecommunications systems, or Barker-coding in radar systems.

While it is easy to measure the BER of a digital communication system, this measurement alone does not provide any insight into the underlying phenomena which cause bit errors. AM to PM conversion is one of the fundamental contributors to BER, and therefore it is important to quantify this parameter in communication systems.

Demo program

While the AM to PM conversion and translation measurements can be done manually, they are best done with the aid of a computer. A test program, written in any of several languages, such as BASIC, C++, or HP-VEE, could run on an external controller, or an HP Instrument BASIC (IBASIC) program could run internally in the HP 71500A.

A demonstration IBASIC program has been written which performs AM to PM conversion and AM to PM translation measurements, using both single and two-carrier inputs. This program can either run on a stand-alone instrument controller, or run internal to the HP 71500A. The program lacks a polished user interface -- variables must be edited before the program executes. The measurement techniques used are described in the following section, under the Modulation Method (page 4).

Measurement Description

Traditional Method using a VNA

The traditional method for measuring AM to PM conversion is to perform a logarithmic power sweep using a vector network analyzer (VNA). The measurement block diagram for a non-frequency translating component is shown in figure 2. The RF source and power splitter are shown integrated within the VNA/test set, but in some setups they may be external.

The displayed data is formatted as the phase of s21 (transmission) versus power. AM to PM conversion can be computed by choosing a small amplitude increment (typically 1 dB) centered at a particular RF power level, and noting the resultant delta phase (using markers or the raw trace data). Dividing this phase change by the amplitude change gives AM to PM conversion in °/dB (see figure 3). Alternately, a trace differentiation could be done which would give a direct, continuous

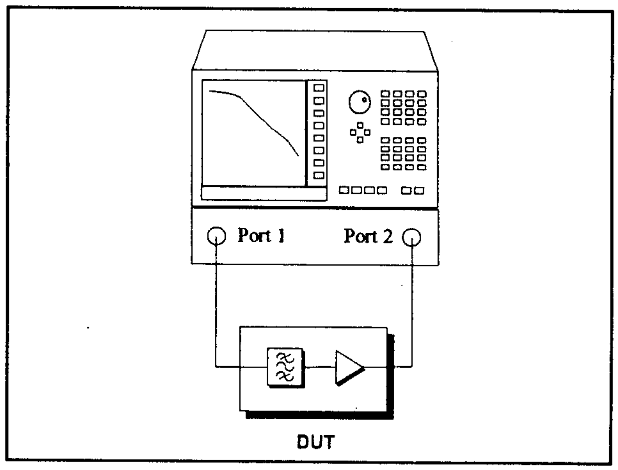


Figure 2: *Measurement setup for non-frequency translating components using a vector network analyzer.*

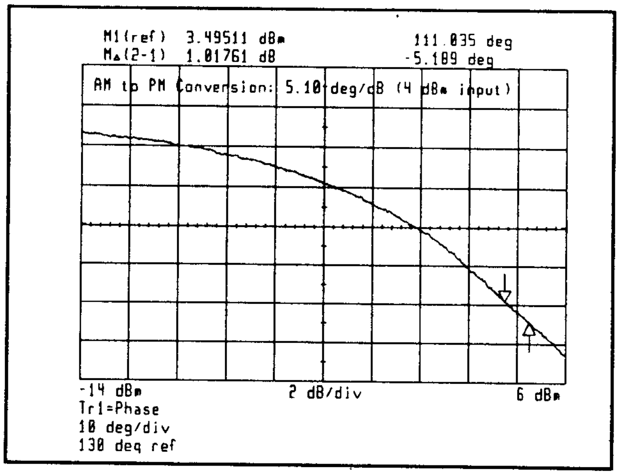


***Figure 3:** Trace showing AM to PM conversion obtained from a power sweep.*

trace of AM to PM conversion versus RF power.

Measuring frequency converting devices

This technique can be used with frequency translating devices such as up or down converters, but a reference mixer or DUT is required, as well as a common local oscillator (LO) for the test and the reference device. This ensures phase coherency between the test and reference channels (see figure 4).

Limitations using a VNA

While the VNA technique works well in many applications, it has some limitations and restrictions. First of all, the VNA must be capable of doing a power sweep at a fixed frequency. Most current VNAs provide this capability, but it may not be available in older instruments.

Secondly, if a test device is especially sensitive to temperature, then the thermal variation which occurs during a power sweep, which is relatively slow, can cause a different outcome than what would result from the actual AM modulated RF carrier.

Finally, VNA measurements of frequency converters can be a problem. Often it is desirable to measure the absolute performance of a device, instead of referencing it to a "golden" mixer or DUT. This is not possible using a VNA since a reference converter is always required. In addition, there are many converters that have internal LOs which are not accessible for the reference channel of the VNA. This is often true for satellite transponder measurements.

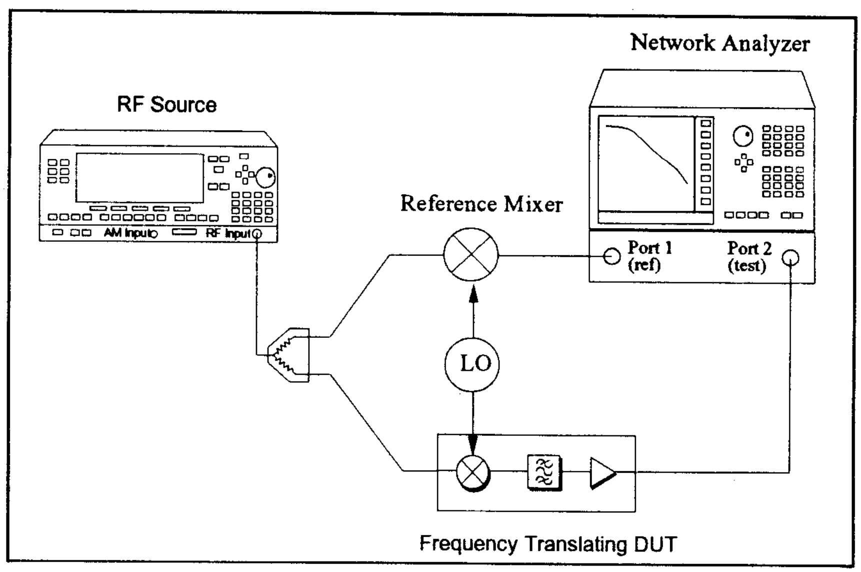


***Figure 4:** Measurement setup for frequency translating devices using a vector network analyzer.*

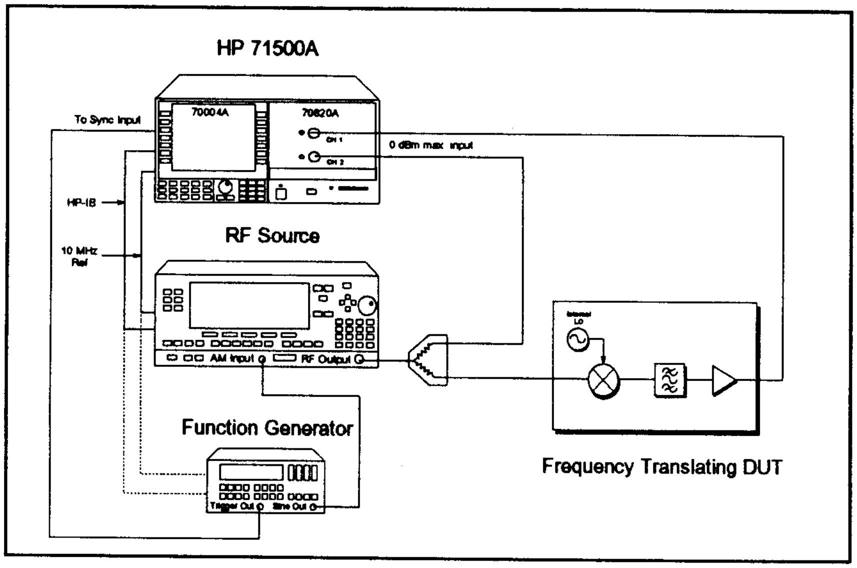


Figure 5: Measurement setup for AM to PM conversion of a frequency translating device using the modulation method and the HP 71500A.

The measurement setup for a single carrier is shown is figure 5. The setup is the same for amplifiers and converters. The technique does not require a simultaneous measurement of channel 1 and channel 2 to get ratioed data (CH1/CH2). Instead, the modulated carrier present at channel 1 is measured, followed by a measurement of the modulated carrier present at channel 2. For frequency translating devices where the two carriers are at different frequencies, the sampling frequency of the HP 71500A is set differently for each measurement.

Modulation Method

AM to PM conversion

The modulation method for measuring AM to PM conversion can be done on both linear or frequency translating devices. This technique is typically used when the VNA method would not work, or would give inaccurate or incomplete results. It is a more direct measurement of AM to PM conversion, since an actual AM modulated carrier is used as a stimulus. It can provide characterization versus modulation frequency, which measures the modulation bandwidth over which a DUT is susceptible to AM to PM conversion. The modulation method also allows two-carrier measurements of AM to PM and AM to AM translation.

AM to PM Translation

AM to PM translation is a two-carrier measurement typically done on components that will be used in a multi-signal

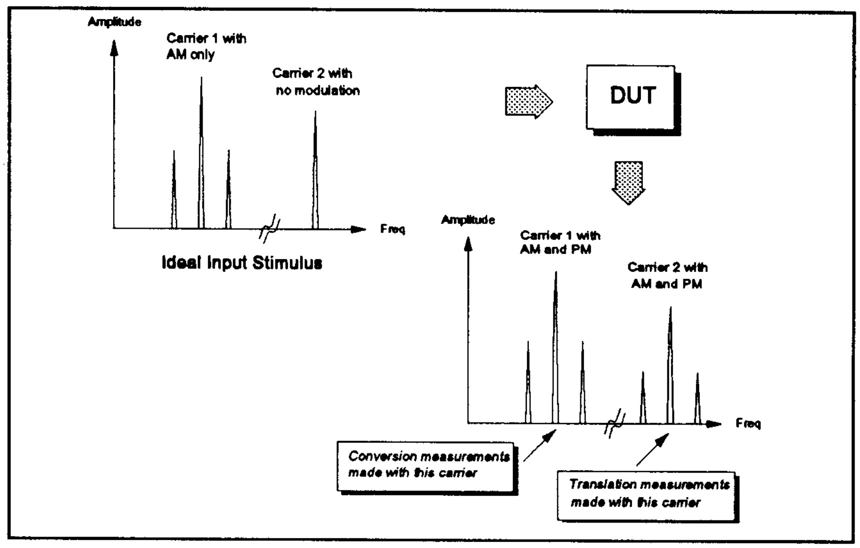


Figure 6: AM to PM conversion and translation represented in the frequency domain, with a sinusoidal AM input. Conversion measurement need only a single carrier, while translation measurements require a second, unmodulated carrier.

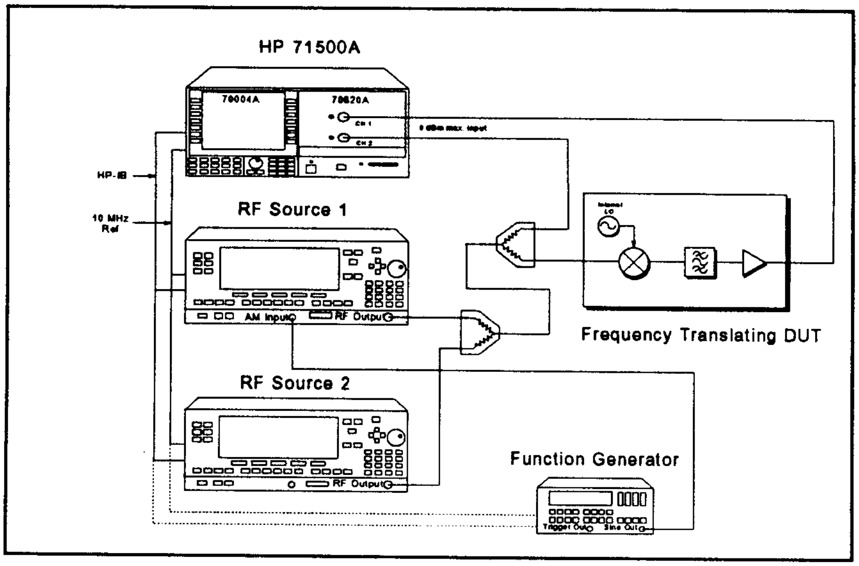


***Figure 7:** Measurement setup for AM to PM translation of a frequency translating device using the modulation method and the HP 71500A.*

environment, such as in communication systems with adjacent channels. This measurement is done on both linear and frequency translating devices. The two carriers are summed together to form the stimulus; one is AM modulated, and the other is unmodulated. The second, unmodulated carrier usually has a lower signal power than the modulated carrier, to simulate a smaller signal in the presence of a larger, adjacent channel signal (see figure 6).

Ideally, if the DUT were perfectly linear, the second, smaller signal would remain unmodulated at the output. However, most high-power amplifiers exhibit some nonlinear behavior, especially if they are operated at or near saturation. The effect is that undesired AM and PM modulation is induced on the second carrier. Because this carrier is always at a frequency different from that of the larger carrier, the term translation is used instead of conversion. AM to AM translation measures the amount of incidental AM on the second carrier, while AM to PM translation measures the amount of incidental PM on the second carrier. The measurement setup for two-carrier measurements is shown in figure 7.

Normalization

Normalization is used to remove the effect of undesired PM present on the input signal. If ideal AM modulators existed, there would be no need for normalization, since the input signal would only be amplitude modulated, with no incidental PM. The PM present at the output would then be a result only of the DUT. However, most AM modulators induce some amount of PM on the carrier. This is certainly true of the AM modulator in the HP 8360 series of synthesizers. In order to perform an accurate AM to PM conversion measurement, the effect of input PM must be removed from the output.

Normalization can only be done in a vector sense. In other words, not only is the magnitude of the PM needed, but the phase as well. Consider an input signal that has 10° of PM in addition to 1 dB of AM . Now say the DUT generates 35° of PM. If the DUT generates its PM in phase with the input PM, then the output PM would measure 45°. However, if the DUT generated PM 180° out of phase with the input PM, then the output would indicate only 25°. The correct answer can only be obtained by knowing the phase relationship of the input and output PM signals. This is achieved by triggering the measurement.

The measurement setup depicted in figure 5 shows the trigger signal being generated by the modulation signal source. This signal is routed to the sync input on the rear panel of the HP 71500A. It synchronizes the measurements done at the input and output of the DUT, providing a phase reference. In order for this phase reference to be valid, the electrical length of the DUT must be small compared to the wavelength of the modulation signal. This is generally the case (for example, the wavelength of a 10 KHz signal in air is 30 Km).

An alternative to using an external trigger signal would be to use the phase of the demodulated AM as a reference. This would allow normalization no matter how electrically long the DUT was. This solution has the problem however that for components that strip away AM (such as a transponder containing a limiter or a fully-saturated amplifier), there would be no AM present on the output signal, and therefore a phase reference could not be derived. In this case, normalization could not be done.

For the AM to PM translation measurement, phase normalization is not done. It is assumed that any PM on the second carrier is caused only by the AM (and not the PM) on the modulated carrier. For this reason, no trigger is necessary to perform the measurement.

Single-Shot mode

When measuring signals with less than 10 MHz bandwidth, it is desirable to use the HP 71500's single-shot mode of operation. With this mode, the input signals do not have to be known as accurately as in the repetitive mode of operation. This is especially useful when measuring a component with an internal LO that cannot be locked to the HP 71500A, such as a satellite transponder. AM to PM conversion measurements are typically done with AM frequencies well below 5 MHz, so the resultant modulated signal falls within the single-shot bandwidth of the HP 71500A and no aliasing occurs. It is possible to do measurements above this frequency by taking into account the amount of aliasing that has occurred, but the current IBASIC demo program does not support this.

When doing AM to PM translation measurements, the 10 MHz limit does not apply to the frequency separation between the two carriers. This is because only one carrier is measured at a time. It is the modulation bandwidth on each carrier that is of concern, not the carrier frequency itself.

Measuring in the frequency domain

Any arbitrarily modulated signal can be represented as the linear sum of two other modulated signals, one being purely AM, and the other purely FM. Therefore, a signal can be measured in the frequency domain and as long as phase information of the sidebands is available, it can be mathematically decomposed into an AM and FM portion. Note that it is not possible to do this measurement with a standard (non-FFT) swept spectrum analyzer, since no phase information of the spectrum is provided. Once the FM portion of a signal is determined, the PM portion can also be computed. By dividing the magnitude of the corrected PM portion of the output signal by the magnitude of the AM portion of the input signal, AM to PM conversion is obtained, in units of °/dB.

Using the FFT

The HP 71500A uses the fast Fourier transform (FFT) to convert time domain data to the frequency domain. The FFT has the benefit of applying "processing gain" to the signal, which is a way of saying that the signal-to-noise-ratio (SNR) is improved. Further noise reduction can by achieved by a related process called the zoom FFT. A zoom FFT acquires a larger time record than an ordinary FFT would, to get better frequency resolution. Only the desired portion of the frequency domain data is then displayed, while the rest is discarded. The only disadvantage of using the zoom FFT is that it is slower, due to the need to acquire and process longer traces. The zoom FFT allows a trade-off between measurement speed and measurement accuracy.

Demodulation using markers

The actual demodulation of the signal is achieved by placing a marker on the carrier and the modulation sidebands, and reading out amplitude and phase information. A computer program is necessary to perform the vector math to convert the acquired marker values into AM, FM and PM components.

Marker options

There are two options for marker placement. One option uses the highest peak function, while the other uses direct placement and the local peak function. Using the highest peak function allows the measurement to be done even if the LO in the DUT drifts somewhat, or if the modulation frequency is not known exactly (this is often the case when using an external signal generator to generate the modulation signal).

If there are contaminating signals present, it is possible that, as a result of using highest peak, the marker will find an incorrect signal which may be bigger than a desired signal. This can happen, for example, when the DUT produces significant carrier harmonics that are not filtered away. To avoid this, it is possible to use direct marker placement and the local peak function. In this mode, the marker is set to where the signal is expected, and a local peak is done to ensure that the peak of the signal is found. However, if the LO frequency of the DUT has drifted enough, or has significant amounts of residual FM, or the modulation frequency cannot be set accurately enough, the marker may be placed too far from the signal for a proper local peak. This will result in a bad measurement. Direct marker placement with local peak should only be used in an environment with very stable and accurately known signal frequencies. When using a manual modulation source, it may be necessary to fine-tune the modulation frequency to match the value used in the program, to ensure correct marker placement. The user has to edit the program to choose between highest or local peak.

Large-scale modulation (phase versus drive)

AM to PM conversion measurements use small amounts of AM (typically 1 dB). A related measurement, called "phase versus drive", measures a device's phase response resulting from large-scale logarithmic AM modulation (typically 20-30 dB). Phase versus drive is commonly measured in the satellite industry. When a triangle-wave is used with log AM, this measurement produces a phase response plot like that obtained from a power sweep done on a VNA. Instead of performing the measurement in the frequency domain, it is done in the time domain in order to show the nonlinear behavior more readily (it is hard to get a good understanding of nonlinear behavior from looking at a series of harmonics in the frequency domain). The HP 71500A can do this measurement on frequency converters, using the same setup as shown in figure 5.

Accuracy Considerations

Noise Issues

Carrier to Noise Ratio (CNR)

The primary cause of measurement uncertainty will be due to noise present in the system. Optimum performance can be achieved when using the HP 71500A by maximizing the signal power present at the instrument input channels. Signals should be as close to (but not above) 0 dBm as possible. The measurements will also be affected by the noise introduced by the DUT. There are two techniques for improving the CNR of the measurement. One is to increase the amount of zoom FFT used, and the other is to employ averaging.

Zoom FFT

The larger the zoom FFT value, the greater the noise processing gain, which results in an improved CNR. Larger zoom FFT values result in longer trace acquisition times, allowing a trade-off between measurement speed and accuracy.

Averaging

Averaging reduces noise by taking multiple measurements. N averages increases both the measurement accuracy and time by a factor of N. The accuracy improvement expressed in dB is 10*log(N). A 3 dB improvement requires doubling the number of averages.

Instrument Nonlinearities

Amplitude and phase response

The other source of measurement error is due to potential amplitude and phase nonlinearities versus frequency in the RF samplers and the IF processing portion of the HP 71500A. The RF amplitude response is calibrated at the factory (to 40 GHz), and the internal instrument calibration routine reduces both amplitude and phase nonlinearities of the IF chain to small (but finite) levels. Although single-channel RF phase response is not calibrated or specified, its contribution to phase nonlinearity is extremely small due to the relatively small bandwidth of the typical test signals, compared to the (approximately) 20 GHz uncorrected bandwidth of the input samplers.

Preliminary tests show that using the modulation technique with the HP 71500A yields excellent results compared to other test techniques.

Appendix A: Useful Conversion Formulas

Converting from log AM to percent modulation:

$$\%mod = 100 \times \frac{1-10^{(\frac{-dB}{20})}}{1+10^{(\frac{-dB}{20})}}$$

Converting from percent modulation to log AM:

$$dB = -20 \times \log\left[\frac{1-\left(\frac{\%mod}{100}\right)}{1+\left(\frac{\%mod}{100}\right)}\right]$$

AM sideband levels:

$$dBc = 20 \times \log(\frac{\%mod}{200})$$

Example:

1 dB = 5.75% modulation; sideband levels = -30.8 dBc

David J. Ballo, SRSD - December 1993