

Noise Power Ratio (NPR) Measurements Using the HP E2507B/E2508A Multi-format Communications Signal Simulator

Product Note

HP E2508-1

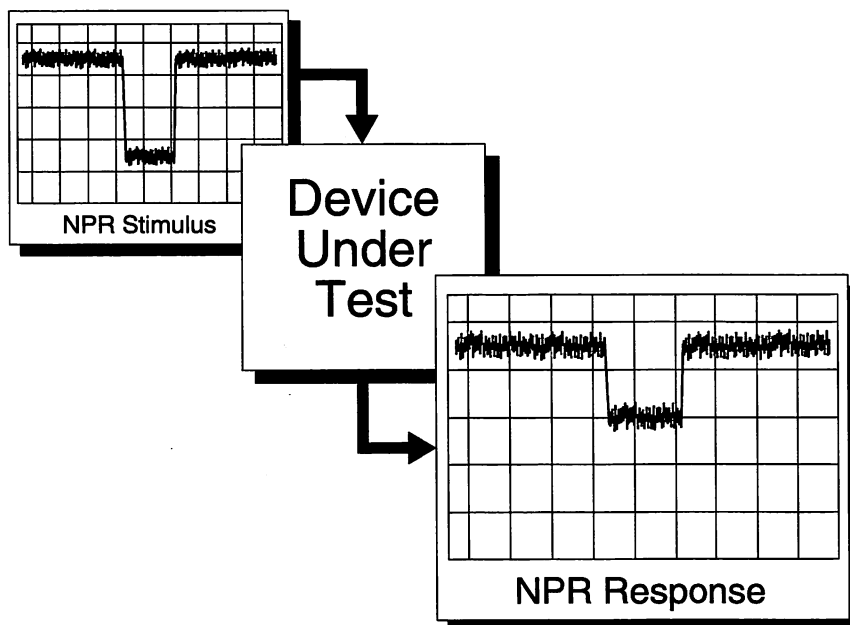


Figure 1. The HP MCSS uses digital synthesis to create the noise stimulus for noise power ratio measurements

1. Introduction

Noise power ratio (NPR) is a criterion for evaluating the performance of systems, subsystems, components and other circuits under conditions that simulate a full spectrum of traffic and interference signals. NPR is a distortion measurement that helps determine a system's maximum spurious-free dynamic range.

The NPR measurement requires a stimulus source to generate conditioned noise and a

measurement receiver to analyze the changes in the noise after it passes through the device under test. This product note shows how the HP E2507B or E2508A multi-format communications signal simulator (MCSS) can be used as a stimulus for making NPR measurements at frequencies up to 26.5 GHz and above. It also discusses using the HP 71910A wide-bandwidth receiver and the HP 89410A vector signal analyzer (VSA) together as the measurement receiver.

Traditionally, spectrum analyzers have been used as measurement receivers. However, the receiver/VSA combination offers some key advantages that include band power averaging to calculate the power in preset bands. This improves repeatability and removes the ambiguity of single-point marker measurements.

This product note is divided into five sections. Section 1 is the introduction. Section 2 is an overview of the noise power ratio measurement. Section 3 describes the equipment required to make the measurement. Section 4 shows how to create and modify waveforms. Section 5 tells how to make the measurement and discusses some of the limitations of the system. The appendix provides a step-by-step procedure for generating an NPR stimulus.

2. NPR overview

Introduced over 30 years ago, NPR has been and continues to be an objective measure of the intermodulation distortion (IMD) of active circuits in telecommunications. IMD is the result of non-linearities in these circuits. Intermodulation signals created by additional traffic

around the frequency of interest can lead to interference and degradation of bit-error rate for the channel of interest.

NPR provides an additional level of information beyond the traditional measurements such as gain, gain flatness and group delay. It allows the manufacturer to evaluate the performance of an amplifier or system in the presence of realistic signal conditions. After analyzing the NPR results, the manufacturer can choose the appropriate operating point of the device under test to maximize efficiency and still have an acceptable NPR. Figure 9 shows the relationship between NPR and output power for a typical solid-state amplifier. The NPR drops to an unacceptable level well before the device reaches the P-1dB compression point.

Although there is no recognized standard for NPR, measurement of this parameter is often required in the mobile and satellite communications industries, and is being pushed down through the vendor chain to manufacturers of amplifiers and subsystems. The noise stimulus consists of white (Gaussian) noise from which a portion of the spectrum has been removed, creating a notch in the pass band of interest. This stimulus is passed through the device under test (DUT), and the output is monitored. Non-linearities in the DUT will lead to spectral components within the notch (presumably created by intermodulation distortion). NPR is the ratio of the power of the spectral components outside of the notch to the power of those in the notch area.

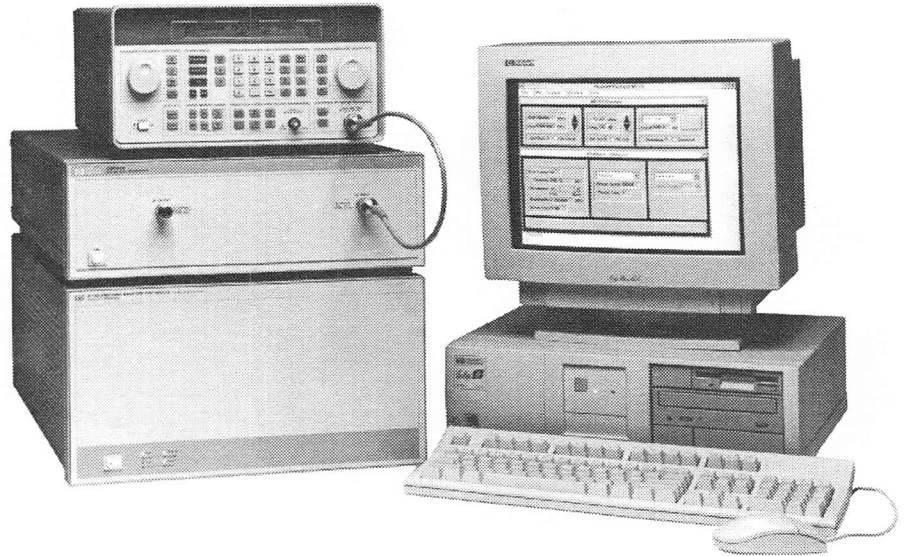


Figure 2. Multi-format communications signal simulator

The two predominate approaches for creating the NPR stimulus are analog, using an analog noise diode conditioned with bandpass and band-reject filters to create the spectral shape of the NPR stimulus; and digital, creating a synthetic noise spectrum with a digital source, then converting the signal to analog with an ultra-linear digital-to-analog converter (DAC). In the analog approach, the spectrum created is continuous and the shape of the notch is highly dependent on the filters. The signal generated by the diode noise source is non-repeatable, resulting in long averaging times. The ability to reproduce a signal from unit to unit is dependent on the filters and is generally poor.

The digital source creates a noise spectrum that is discrete, that is, it repeats in time. To create noise, multiple CW tones are generated with close spacing in frequency and random phase relationships, resulting in a pseudo-random noise stimulus. Filtering is accomplished at the generation of the signal by turning off the tones in a specific bandwidth. This results in a spectral shape that has high repeatability. More information on the use of a digital stimulus and a comparison between analog and digital techniques can be found in the paper "Effective Evaluation of Noise Power Ratio".¹

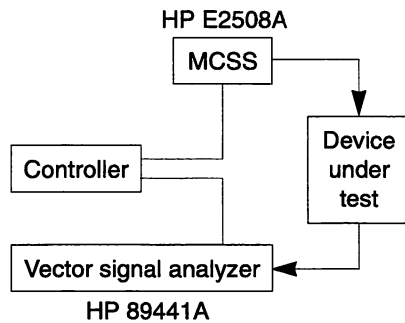


Figure 3a. RF system

3. The measurement system

The HP E2507B or E2508A multi-format communications signal simulator (MCSS), shown in figure 2, provides an accurate, precise, repeatable and fast method for creating the noise stimulus required for the NPR measurement. Using digital synthesis to generate noise, the MCSS creates CW tones in the frequency spectrum at baseband (0 to 50 MHz) with the arbitrary waveform synthesizer (AWS). These tones have controllable spacing and amplitude, and the phase relationships between the tones are random. The random phase relationships result in a largely varying signal amplitude in the time domain. Due to the repeating nature of the digitally-generated pseudo-random noise, the peak-to-average ratio is predictable and repeatable in time. The random phase relationship is set by selecting a specific phase seed. The phase seed identifies a starting point in digital synthesis for generating random phases. Generating a

signal using the same phase seed will always produce the same random phase set. This allows for repeatability in the peak-to-average ratio, ensuring that all of the devices under test receive the same stress from the source, and provides repeatability from system to system. The AWS uses a DAC to convert the signal from digital to analog. The baseband signal is then upconverted to the frequency of interest and sent into the DUT. By turning the tones "On" in areas simulating noise and "Off" in notch areas, the MCSS functions as a noise source and filter to create the noise spectrum and a notch in the band of interest. By using a digital stimulus, this system provides both flexibility and repeatability when creating NPR signals.

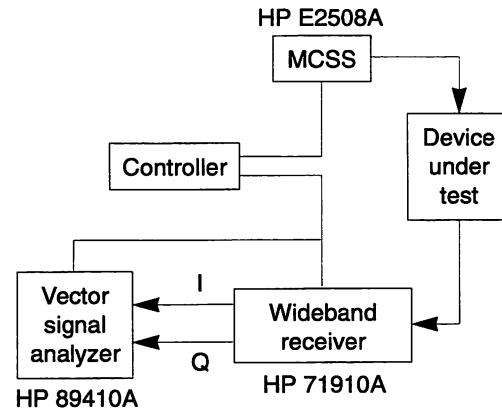


Figure 3b. Microwave system

The MCSS can be used with standard or custom upconverters for frequency coverage up to 26.5 GHz.

Traditionally, a spectrum analyzer has been used for the receiver portion of the system. The spectrum analyzer has limitations in its ability to measure the average power accurately across a fixed bandwidth. The HP 89440 series vector signal analyzers (VSAs) eliminate this measurement uncertainty by using band power markers to average the power in a fixed bandwidth.

Two possible configurations using the MCSS as an NPR stimulus and the VSA as a measurement system are shown in figure 3. Figure 3a uses the downconverter supplied with the HP 89441A for frequencies up to 2.65 GHz with an IF measurement bandwidth of 10 MHz. Figure 3b replaces the downconverter portion of the HP 89441A with the HP 71910A modular measurement system wide-bandwidth receiver.

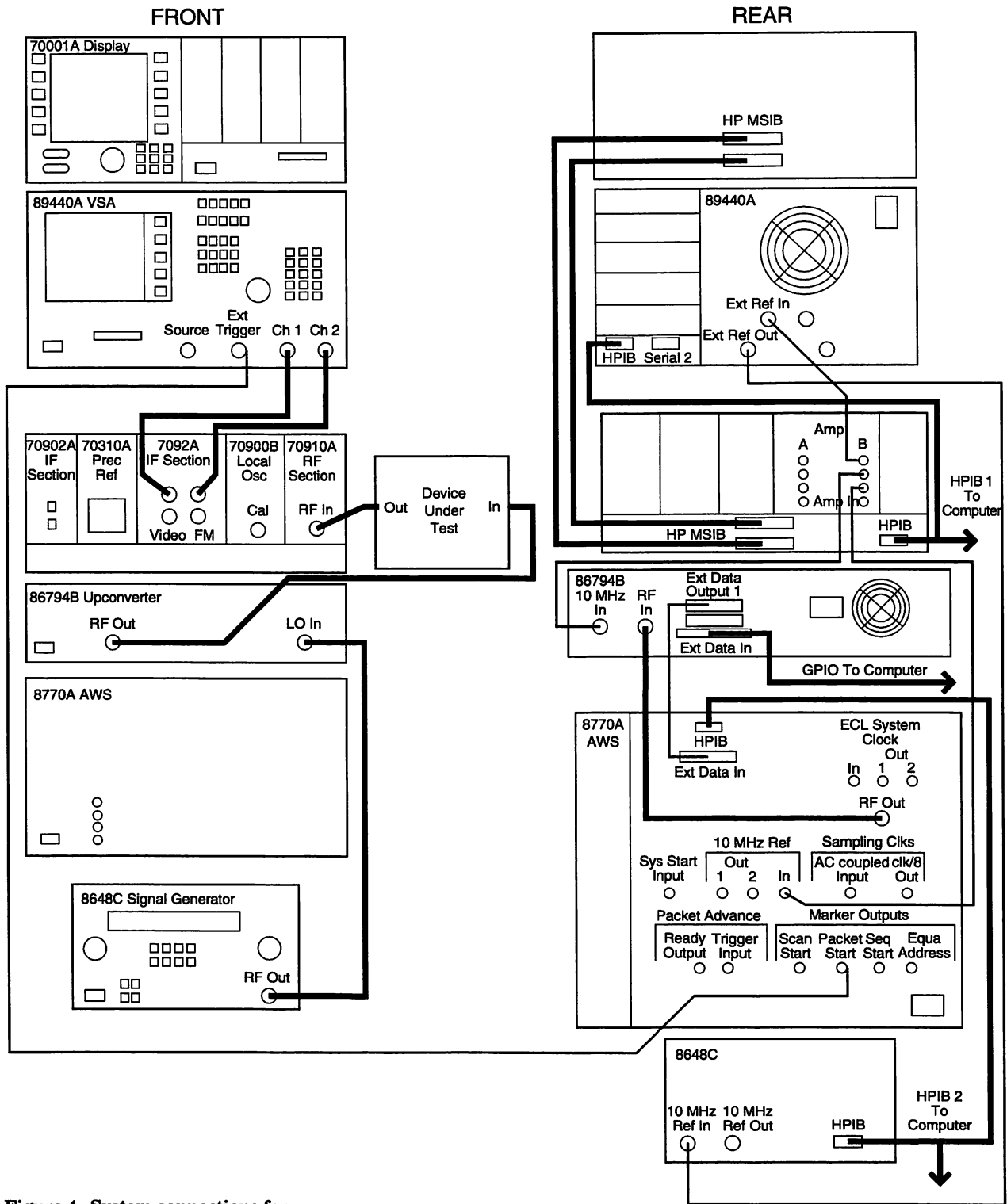


Figure 4. System connections for a microwave NPR measurement system

This increases the frequency capability to 26.5 GHz and the IF measurement bandwidth to 20 MHz. By using the HP 71910A, we are able to generate the I and Q signals and send them to the VSA separately. Using the second 10 MHz input option and the I +jQ feature on the VSA, the effective bandwidth is doubled. This combination of receiver and analyzer is described in more detail in Hewlett-Packard product note 89400-13.² Table 1 is a list of equipment required to set up this configuration. The HP 71910A comprises a variety of modular equipment and is shipped as a unit.

4. Generating an NPR stimulus

The MCSS software makes it easy to create an NPR waveform. Several degrees of flexibility are built into the application. You have complete control of the five key parameters required for creating an NPR stimulus. Center frequency, spectral bandwidth, notch depth, notch width and total power level are all easily controlled from the Windows-like interface. Figure 5 shows an example of an NPR stimulus and its key components. MCSS allows you to control each of these parameters using the NPR application software within the MCSS.

Figure 6 shows the default screen for the NPR application. You set the center frequency for the NPR spectrum and the initial power level in the MCSS Control window. The upper frequency limit is 2.0 GHz for the HP E2507B, and 2.5 GHz for the HP E2508A. Once you generate an NPR signal, you can change its center frequency and power level in real time, that is, without generating a new NPR signal. The RF frequency and the power are set in the upconverter and do not require a new digital waveform from the DAC.

Table 1. Required equipment

Model Number	Option	Description
HP E2508A or E2507B		Multi-format communications signal simulator
HP 89410A	1C2, AY7, AY9, AYA, AYB, AYH, UFG, UG7	Vector signal analyzer
HP 71910A		Wideband receiver

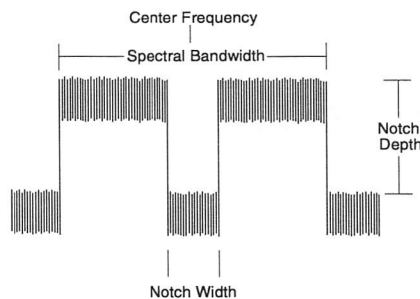


Figure 5. Critical features of an NPR stimulus

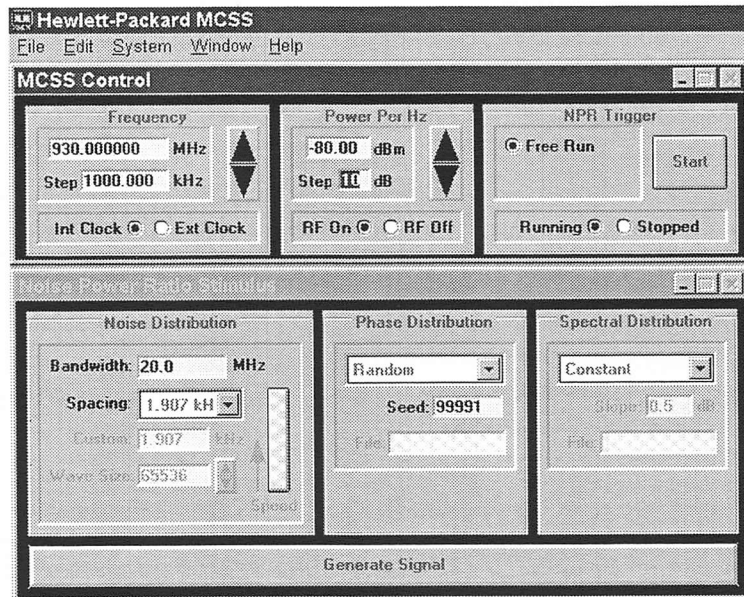


Figure 6. NPR application display

By using the Noise Power Ratio Stimulus window (also shown in figure 6), you can specify all the special signal parameters for the noise signal. These parameters include those mentioned at the beginning of this section plus the spectral density, the phase information and any necessary amplitude shaping.

You set the bandwidth and the spectral spacing of the tones for the noise spectrum in the Noise Distribution panel of the Noise Power Ratio Stimulus window (figure 7). You can choose bandwidths from 10 kHz to 35 MHz for the noise spectrum. Only bandwidths up to 25 MHz are recommended, however, due to possible band-edge limitations of the MCSS upconverter. For a listing of the specific bands generated by the MCSS, please refer to the technical specification for the MCSS³.

Spectral spacing is the space between the tones generated by the MCSS. These tones, generated with the phase parameters set in the Phase Distribution panel, create the noise stimulus for the NPR measurement. The default phase distribution is random. This most accurately represents Gaussian noise. (The options for phase distribution are random, parabolic, constant and custom.)

The closer the tones are spaced, the more closely this stimulus will represent Gaussian noise. The disadvantage of smaller tone spaces is that it will increase the time required to generate a signal the first time.

Table 2 shows typical times required to generate a 20 MHz spectrum with various spectral spacings.

Figure 8 shows the Notches window. This window, usually found minimized and below or behind the stimulus window, allows control of up to ten notches. Maximize this window by either clicking on it or using the window's pull-down menu. You can set width, depth and offset from the center frequency for each notch. The system has a 1 MHz notch at the center frequency as a default. Examples of uses for additional notches include looking at the IMD in special bands and creating CW tones in the primary notch for use as a calibration tool. The on-line help menu shows how to create multiple notches.

Table 2. Time requirements for signal generation

Spacing (Hz)	Time (seconds)
7,630	5
3,820	7
1,910	7
954	21
470	32
238	105

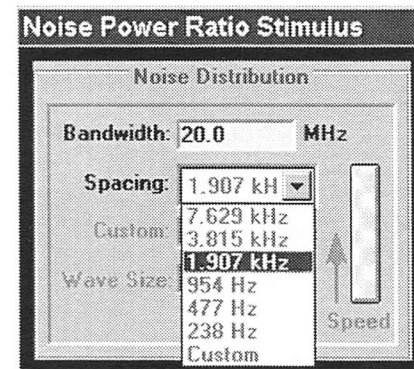


Figure 7. Noise Distribution panel

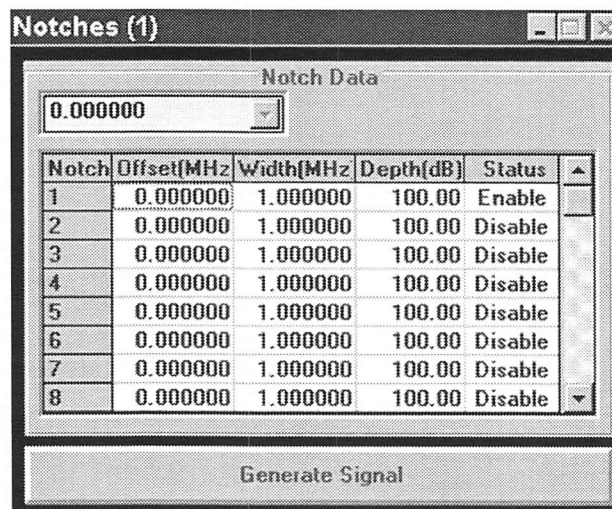


Figure 8. Notches window

Clear definition of notch edges makes repeatable and accurate measurements inside the notch possible. Unlike the analog method, which can have rounded notch edges as a result of filter shaping, the digital techniques used in the MCSS create the notch by turning off the tones in the notch area. This creates the “brick wall” effect seen in the NPR stimulus. Figure 10 shows the sharpness of the notch wall created by the MCSS. The maximum achievable notch depths vary depending on the width of the noise spectrum and the width of the notch. For a 30 MHz spectral bandwidth with a 1 MHz notch, typical notch depth is 38 dB. With narrower spectrums, you can obtain notch depths as great as 50 dB. This depth creates a baseline for the measurement. Figure 9 shows the baseline of the MCSS for the conditions given by flattening out the NPR curve in the -40.0 to -36.0 dBm power-input range. In this situation, the NPR baseline reading is 38.0 dB.

It is desirable to have the input signal's NPR at least 10 dB lower than the NPR of the device under test. This ensures that the effect of the input signal is negligible when measuring the DUT's NPR.⁴

A consideration for setting notch width is the number of IMD products present in the notch. IMD products, or tones, in the notch are a result of intermodulation distortion from the spectrum being generated outside of the notch. As the notch width decreases, the number of IMD tones in the notch decreases to a point where there are too few IMD products

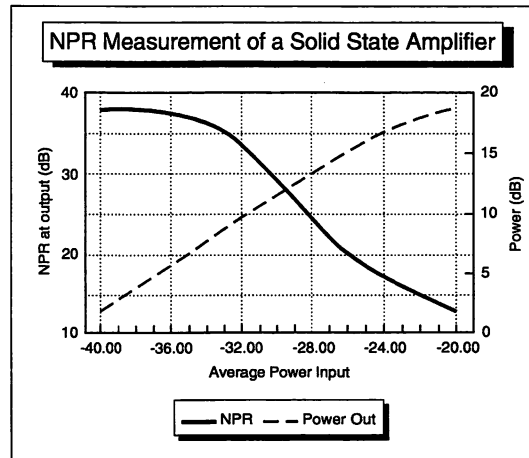


Figure 9. NPR measurement using a 30 MHz noise spectrum at 850 MHz center frequency with a 1 MHz notch width

in the notch to accurately calculate the average power. If narrow notch widths are required, compensate by decreasing the spacing of the generated tones and increasing the width of the notch that is used to calculate the average power. The use of the band power marker feature of the VSA, discussed further in Section 5 of this document, simplifies this process. A 10 kHz notch, the smallest recommended notch width with a tone spacing of 238 Hz, will have 42 tones in the notch.

(See appendix for a step-by-step procedure for generating an NPR stimulus signal.)

5. Making the measurement

After signal generation, perform the measurement analysis with the receiver and analyzer listed in Section 3 of this document. The most important advantage of using the HP 89410A vector signal analyzer is the band power marker feature, which averages the power over a specific bandwidth. This improvement over a typical spectrum analyzer measurement

removes the guesswork associated with a single marker and its relative placement.

The graph shown in figure 9 shows NPR vs average input power. This data, taken with the system setup shown in figure 3b, shows the relationship between NPR and input power. The signal was set up with a 30 MHz bandwidth and a 1 MHz notch. The band power marker feature, with a spacing of 300 kHz, was used to capture the average power for the measurement. Output power, shown on the second Y-axis, was taken with a single CW tone generated by the MCSS multi-tone application and a power meter using an average-power sensor. The graph shows the rate at which the NPR drops off as power into the DUT is increased. The power out curve shows that the NPR has dropped to a very low level (less than 12 dB) while the power out is still in the linear region.

The setup for the receiver and the VSA, listed in tables 3 and 4, uses the HP 71910A set to the receiver mode as a downconverter for the VSA. This allows the usable bandwidth of the HP 89410A to be expanded to 20 MHz by splitting the I and Q output to two channels. Video averaging is used with 32 samples at each input power setting to smooth the display. The center frequency of the receiver is offset from the MCSS center frequency by 1 MHz to ensure that the zero crossover point created by the VSA in the receiver mode is moved out of the notch.

To calculate NPR, measure the average power in the noise spectrum and the average power in the notch. The NPR shown in figure 9 was calculated from data taken with the band power markers spaced 300 kHz apart. Figure 10 shows the VSA display with the markers activated. In this case, 30% of the notch floor was used in the power measurement. For a 1 MHz notch, the width of the band power markers should not be less than 25% of the notch width. Marker widths between 30% and 60% will yield less than 0.3 db difference in the final NPR number. The bandwidth of the marker must be the same for both the in-notch reading and the noise reading.

For narrow notch widths, it may be necessary to have more than 50% of the notch inside the band power markers to ensure that sufficient IMD tones are captured to make a valid average power reading.

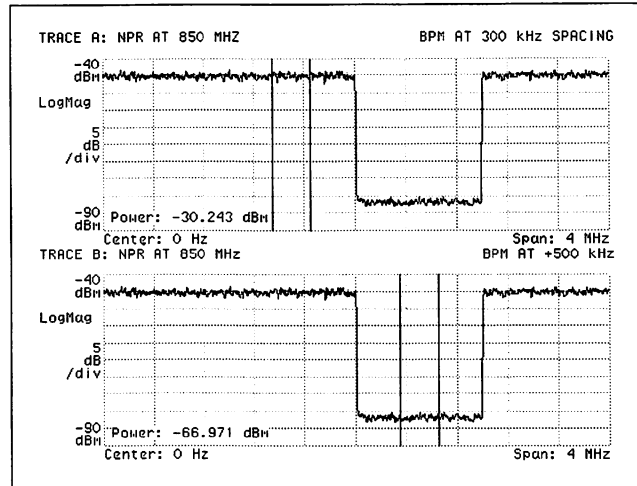


Figure 10. Using the band power markers to calculate the NPR

Table 3. Setup requirements for the HP 71910A

User	Receiver Mode
Frequency	MCSS center frequency - 500 kHz
IF Gain	Appropriate level to avoid overdriving the VSA
RF attenuation	
IF Bandwidth	100MHz

Table 4. Setup requirements for the HP 89410A VSA

Instrument Mode	Vector	
Receiver	IF Section ch1-j*ch2	
Freq span	2.5 MHz	
Res BW	10 kHz	
Num freq pts	1,601	
Main window	Flat top	
Input coupling	DC on both channels	
Input	50 ohm	
Averaging	on	
Num avg	32 or more	
Display	2 Grids	
	Trace A	Trace B
Marker function	Band power marker on	Band power marker on
Band center	-500 kHz	500 kHz
Band width	300 kHz	300 kHz
Marker	off	off

Insufficient IMD products in the notch will result in a very irregular notch bottom, making average power readings difficult. The measurement area may be any place inside the notch that is not affected by the resolution bandwidth (RBW) of the analyzer. That is, the measurement must be away from the walls of the notch. For accurate measurements, the measurement area should be at least 5 RBW bandwidths away from the notch edge to ensure a correct average power reading.⁴

The difference (in dB) between the average power in the noise spectrum and the average power in the notch is the NPR. The NPR for the example in figure 10 is 36.7 dB.

Care must be exercised when using this configuration to avoid overdriving the input to the VSA. Manually adjust the IF gain and RF attenuation to keep the power level constant. This can be accomplished by setting the gain of the receiver so that the over power light on the VSA comes on, then backing the IF gain of the receiver down 1 dB per step until the over power light goes off. This indication should be monitored each time you change the power to the device under test.

Set up the VSA with the number of frequency points set to 1601 and video averaging "On" with at least 32 sample sweeps. After changes are made to the DUT, press the "Meas Restart" button on the VSA to take a new measurement.

Conclusion

Noise power ratio measurements with the MCSS provide a level of real-life simulation that is unmatched by other techniques. The simple, straightforward windows of the software interface reduce the time required to make a measurement. Changing frequencies, changing power levels, and adding or changing notch parameters such as width and location is quickly accomplished.

The digitally-generated stimulus is highly repeatable, removing ambiguity and uncertainty from the measurement.

By simplifying the NPR measurement and making it repeatable, the MCSS transforms it from an uncertain and time-consuming measurement to a reliable tool that can be used throughout the manufacturing process.

Appendix

Signal generation using the MCSS

The MCSS is shipped with the NPR application installed. The following is a procedure for generating an NPR stimulus signal with this application.

For additional information on the MCSS and its setup, refer to the on-line help program included with the system software.

1) Launch the NPR application by double-clicking on the NPR icon. Figure 6 shows the default screen for NPR signal generation.

Table 5. Frequency bands for the MCSS

Frequency (MHz)	E2507B	E2508A
800-1000	Yes	Yes
1400-1600	Yes	Yes
1600-1800	Yes	Yes
1800-2000	Yes	Yes
2100-2300	No	Yes
2300-2500	No	Yes

2) Input the appropriate center frequency for the noise spectrum in the MCSS Control window. (Table 5 shows the possible frequency ranges for the MCSS. Inputs must be in MHz.)

3) Input the appropriate starting power level in the MCSS Control window.

Note: The NPR application allows the signal power to be entered as Average Power or as Power per Hz. Double-click on either of these labels to toggle between the two. The MCSS system can generate a signal with 0.1 dB resolution. However, the signal power level is changed with a 1 dB step attenuator. Finer resolution requires that you regenerate the signal each time after setting the new level.

4) Set the bandwidth for the noise spectrum. The bandwidth for the spectrum may be any value from 10 kHz to 40 MHz. However, the maximum warranted bandwidth for the noise power ratio application is 25 MHz. Bandwidths larger than 25 MHz may result in rolloff of power at the band edge (see table 5). If the rolloff as viewed on the VSA is not evident, or is not considered a problem, than wider bandwidths may be used.

5) Set the spacing for the noise tones generated by the MCSS.

Note: When selecting "Custom" spacing, the "Custom" and "Wavesize" windows will become active. You can specify the custom spacing by either of these two windows. If you are going to import this signal into the dynamic signal environment (DSE), you must set a specific wave size (or file size). All files used in the DSE must be either the same size or an integer multiple of the shortest file size being used. More information on this is available in the DSE help menu.

The "Speed Bar" is an indicator for the approximate time needed to produce the currently-defined noise signal. The bar represents approximately 16 minutes on a 66 MHz 486 PC. A solid green bar all the way to the top indicates that the current signal can be generated very quickly (usually in only a few seconds). A green bar that fills only $\frac{1}{2}$ of the indicator means that the signal will take about 8 minutes to generate. The indicator is not accurate in the lower $\frac{1}{4}$ of the range. Green bars below the $\frac{1}{4}$ level indicate up to an hour for generation time. Red bars mean that an hour or more may be needed. Depending on the number of points in the noise waveform (Wavesize), the signal could take many hours or even days to generate.

6) Set the phase distribution and spectral distribution in the appropriate panels as desired. The on-line help menu contains in-depth descriptions of each of the options. The default phase distribution is random.

7) Create the notch. Double-click on the Notches icon or select the Notches window from the pull-down menu. This icon is usually located below or behind the NPR Stimulus window. Figure 8 shows the Notches window. Maximize the Notches window. The top of the Notches window will display how many notches are activated.

8) Set the specific criteria required for each notch. Notch offset, width, depth and status are set in the Notches window. The on-line help menu contains an in-depth description of each option. One notch at the center frequency with a 1 MHz width is set as a default.

9) Generate the signal by clicking on the Generate Signal.

Note: Once the signal is generated, the parameters in the MCSS Control window can be changed in real time, that is, without generating a new signal. Any parameters modified in the NPR Stimulus or Notches windows will not take effect until a new signal is generated.

References:

1. *Effective Evaluation of Noise Power Ratio*. Rolly Hassun, Hewlett-Packard, Oct. 1996.

2. *Extending Vector Signal Analysis to 26.5 GHz with 20 MHz Information Bandwidth*. Hewlett-Packard Product Note 89400-13, Oct. 1995.

3. *HP E2507B/2508A Models 60 and 100 Technical Specifications*. Lit. no. 5964-1603E.

4. *Evaluating IRIDIUM®⁵ Amplifiers with a New Noise Power Ratio Technique*. Proceedings of the Second Annual Wireless Symposium, Steven E. Yates, Feb. 1994.

⁵ IRIDIUM® is a U.S. registered trademark and servicemark of IRIDIUM, Inc.

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