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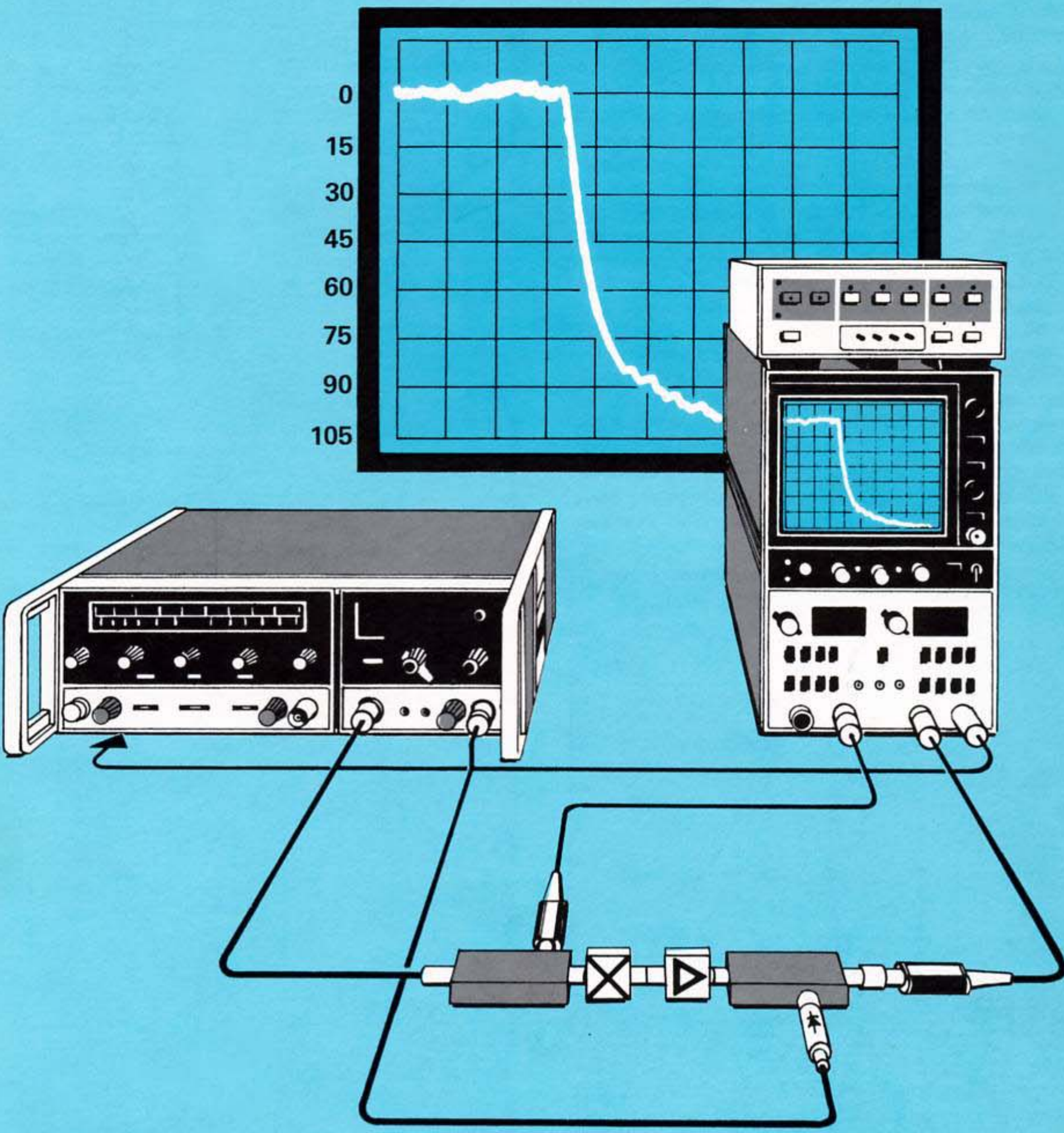
APPLICATION NOTE 155-2



100 dB Dynamic Range Measurements Using the HP 8755 Frequency Response Test Set

INTRODUCTION

Many microwave devices have test responses in excess of the 60 dB dynamic range of the HP 8755 Frequency Response Test Set. This is especially true of microwave filters. Standard measurement solutions for measuring these types of devices involve RF substitution or use of more expensive heterodyne type insertion loss test sets. RF substitution is awkward because the information must be pieced together from at least two separate measurements.

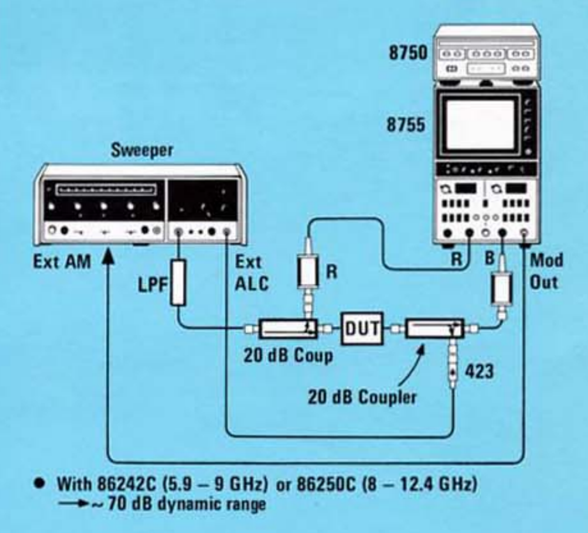
This application note discusses measurement configurations that increase the dynamic range of 8755 insertion loss measurements up to 110 dB. In general, standard instruments are used although certain characteristics of the source and the 8755 are critical. The only major addition to a standard transmission measurement configuration is a high power source before the device under test or an amplifier after the device under test. The high power source or the amplifier contribute in the expanded dynamic range configuration in the same way that they would for an RF substitution measurement. The role normally played by the step attenuator is accomplished by the source's internal PIN modulator. The difference between the expanded dynamic range configuration and an RF substitution technique is that the substitution is accomplished automatically. The leveling capability of the sweeper and the ratio capability of the 8755 work together to provide a single trace display of the full dynamic range. Figure 1 shows the setup and measurement results for a 105 dB dynamic range measurement on a 3 GHz low pass filter using the 8755 Frequency Response Test Set.

Figure 1. 105 dB Dynamic Range Measurement with the 8755.

DESCRIPTION OF OPERATION

The dynamic range of a measurement system is limited at the high end by the sweeper output power or by the maximum level that can be detected accurately. The low end is limited by the detector sensitivity. The 8755 has a 60 dB dynamic range; it can display signals as small as −50 dBm and as large as +10 dBm at the 8755 measurement detector (11664A). Two obvious solutions for making measurements beyond the +10 dBm and −50 dBm range are to use an RF pre-amplifier to improve the detector sensitivity or to apply higher input power to the device under test when its attenuation drops the signal at the detector below −50 dBm. The RF substitution technique uses a calibrated attenuator with either of these solutions to prevent overpowering the detector when the insertion loss of the device under test is small. The expanded dynamic range technique uses the external leveling capability of the sweeper to prevent the same thing.

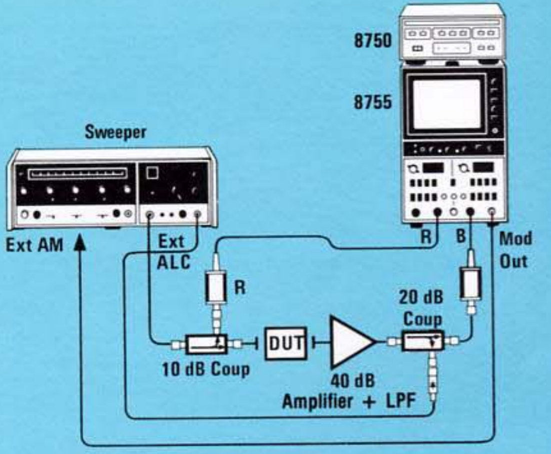
Figure 2 shows the configuration for expanding the dynamic range using a high power source. The 8755 is in a B/R ratio mode and the output power from the device under test is externally leveled using a 20 dB coupler and detector. During calibration the power level is set to provide +10 dBm to the B detector, and the leveling loop will attempt to hold this level constant. When the attenuation of the device under test is 7 dB, for example, the leveling detector calls for more power from the sweeper in its attempt to keep +10 dBm at the B detector. A +17 dBm source such as the HP 86245A (5.9 - 12.4 GHz sweeper RF unit) will be able to provide this power. Thus the power at the B detector stays at +10 dBm but the R detector sees a 7 dB increase. Since the 8755 is displaying B/R, increasing the R level has the same effect on the display as decreasing B (i.e., in this example a 7 dB loss is displayed even though the power level at the B detector has not changed). For device under test attenuation of 10 dB the leveling signal requests +20 dBm from the source to maintain +10 dBm at the B detector. If the source cannot deliver more than +17 dBm then the leveling loop opens and the level at the B detector drops 3 dB. Therefore, the B detector provides its full 60 dB dynamic range while the +17 dBm source permits utilization of 7 dB of the R detector's dynamic range making possible a total dynamic range of 67 dB. To obtain substantial improvement in dynamic range using this method would require very high power sources. For example, 90 dB dynamic range would require a 10 W source.



+ 17 dBm Source

DUT Attenuation	R-Det Level	B-Det Level	Sweeper P_0
0 dB (Calibr)	−10 dBm	+10 dBm	+10 dBm
7 dB	−3 dBm	+10 dBm	+17 dBm
10 dB	↓	+7 dBm	↓
20 dB		−3 dBm	
40 dB		−23 dBm	
60 dB		−43 dBm	
67 dB		−50 dBm	

Figure 2. Increased Dynamic Range using High Power Source.



• > 100 dB dynamic range (with proper amplifier)

+10 dBm Source

DUT Attenuation	R-Det Level	B-Det Level	Sweeper P_0
0 dB (Calibr)	−40 dBm	+10 dBm	−30 dBm
20 dB	−20 dBm	+10 dBm	−10 dBm
40 dB	0 dBm	+10 dBm	+10 dBm
60 dB	↓	−10 dBm	↓
80 dB		−30 dBm	
100 dB		−50 dBm	

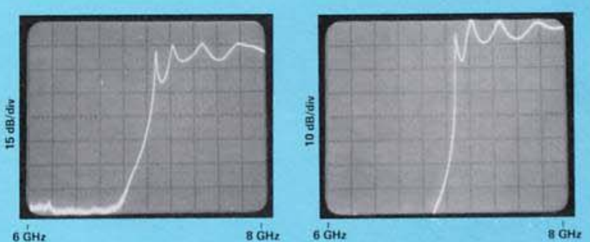


Figure 3. Increased Dynamic Range using an External Amplifier.

Figure 3 shows the configuration for expanding the dynamic range using an amplifier after the device under test. As with the high power source, the calibration power level is set such that the B detector sees +10 dBm, and the leveling loop attempts to hold this level constant. The table shows the effects of various device-under-test attenuations on the important parts of the system. With 0 insertion loss, the level at the B detector is +10 dBm and the sweeper output power is −30 dBm. Moving to 40 dB insertion loss, the leveling loop holds the power at the B detector constant by increasing the source power to +10 dBm. The R detector therefore goes up 40 dB hence the ratio B/R shows 40 dB insertion loss. The main point is, with a 40 dB amplifier, 40 dB dynamic range is displayed by the R detector with the B detector held constant. An additional 60 dB dynamic range is displayed by the B detector with the R detector held constant, giving a total system dynamic range of 100 dB. If the amplifier is placed after the device under test, its critical characteristic is gain, and it needs to supply only +10 dBm. If the amplifier is placed before the device under test, it needs to supply a power level equal to 10 dBm plus its gain. This is, in fact, analogous to the high power source configuration so we can model both configurations using a 10 dBm source and an amplifier; the only difference being the placement and output power of the amplifier.

WHAT LIMITS THE USEFUL DYNAMIC RANGE?

The amplifier gain is the basic determining factor for the amount of expanded dynamic range; however, many other factors enter into final determination of the system dynamic range.

The sweeper leveling modulator must be capable of varying the output over a range greater than the amount the dynamic range is expanded. A close look at the leveling system indicates that the control voltage from the detector is always at the same level. The output power, however, is varied over a wide range by the RF modulator to compensate for changes in the insertion loss of the D.U.T. This is not the normal situation for a leveling loop, and it is difficult to predict the modulator control range for a particular sweeper plug-in from data sheet specifications. Appendix 1 gives typical performance of most HP 8620 series sweeper plug-ins for this application.

The coupling factor of the reference detector coupler also affects the ultimate dynamic range. The R channel has a maximum 60 dB dynamic range. With a +10 dBm source, if a 10 dB coupler is used, this leaves only 50 dB. If a 20 dB coupler is used, the R channel can vary over only 40 dB, and so forth.

The use of a resistive power splitter instead of the reference coupler reduces the dynamic range the same as it would in a standard transmission setup. However, this loss in dynamic range can easily be compensated for by additional amplifier gain. The use of a resistive splitter instead of the leveling coupler after the amplifier can also be compensated by increased gain; however, the amplifier must also supply higher output power. For a splitter with 6 dB insertion loss, an amplifier would need to supply 6 dB more gain and 6 dB higher output power to get the same dynamic range as with the directional coupler.

Another major limiting factor to the ultimate dynamic range that the system can ahcieve is broadband (KTB) noise. Table 1 shows the chart of the setup in Figure 3 including the input power levels at the amplifier. At 100 dB insertion loss, the amplifier input power is −90 dBm. If the amplifier covers a 2 Ghz range, say 2-4 GHz, then KTB in this bandwidth is −81 dBm. Assuming a 10 dB noise figure with 40 dB gain, the noise power in this 2 GHz bandwidth after the amplifier is −31 dBm. A DC detection system will respond to this noise reducing the potential dynamic range 19 dB. AC type detection overcomes this limitation. The 8755 can accurately detect a −50 dBm, 27 kHz modulated signal in the presence of up to −20 dBm of unmodulated broadband noise. The use of AC modulation does require at least 20 dB more dynamic range from the sweeper leveling modulator. This will be discussed further in the accuracy section.

DUT Attenuation	Amplifier Input Power	KTB in 2 GHz BW	Signal to Noise in 2 GHz Bandwidth Assuming a 10 dB NF Amplifier
0	−30	−81	+41
20	−30	−81	+41
40	−30	−81	+41
60	−50	−81	+21
80	−70	−81	+ 1
100	−90	−81	−19

Table 1. Amplifier input power levels for the measurement configuration shown in Figure 3.

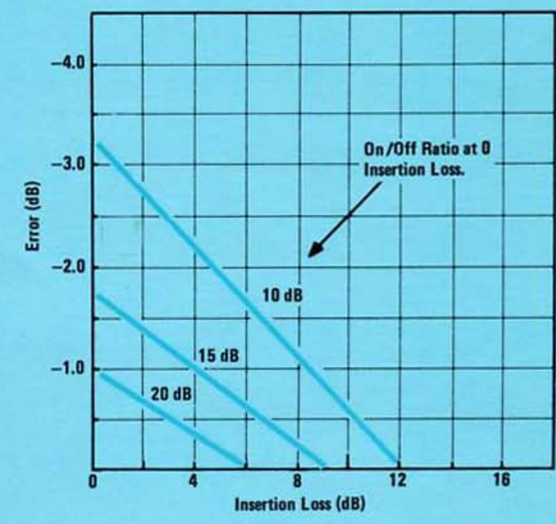
As with any transmission measurement using diode detection, harmonic and spurious signals can interfere to either reduce the dynamic range or cause spurious responses. The presence of the amplifier complicates the situation. Placing a low pass filter after the amplifier can eliminate harmonic interference from octave bandwidth measurements. For multioctave measurements an extremely pure source and low distortion amplifier would be required.

MEASUREMENT ACCURACY

The accuracy analysis for a standard transmission measurement considers the mismatches between the source, the device, and the detector. An analysis of an expanded dynamic range measurement must also include the presence of the amplifier and subsidiary effects from RF modulator limitations. The amplifier gain variations with frequency show up as frequency response on both the calibration and measurement traces. Grease pencil comparison or digital normalization using the HP 8750A Storage-Normalizer can eliminate this effect on the measurement. Amplifier gain compression, however, does not affect the calibration and measurement traces equally and will lead directly to measurement error. Selection of the amplifier, therefore, should be based on its output power for 1 dB gain compression. The amplifier should also be free from spurious gain variations with power input that can sometimes result from transistor self-biasing.

As mentioned earlier, an AC detection system can provide a substantial improvement in the dynamic range by allowing the detectors to ignore unmodulated broadband noise. An AC detection system, however, requires a minimum RF modulation on/off power ratio for accurate measurements. With the 8755 a 30 dB on/off ratio is needed for full accuracy. Generally the RF can be square wave modulated either by modulating the source directly using its internal PIN modulator or by modulating the source externally using the HP 11665B external modulator. Unfortunately with the expanded dynamic range configuration external modulation before the amplifier interferes with external leveling. External modulation after the amplifier (by placing an 11665B modulator before each of the detectors) modulates the broadband noise eliminating the advantage an AC system provides. This is, however, a viable technique for maintaining a >30 dB on/off ratio when only moderate dynamic range expansion is needed. The best solution is to modulate the source directly and most HP 8620 series sweeper plug-ins can be directly modulated. The source's internal PIN modulator should be capable of varying the output power over a range greater than the amount that the dynamic range is expanded and in addition be able to maintain a 30 dB on/off ratio. Typical sweeper plug-ins have PIN modulators with total control ranges from 40 to 60 dB hence can allow dynamic range expansion from 10 to 30 dB with full accuracy.

Sometimes a compromise can be made between accuracy and dynamic range when the modulator cannot provide enough control. One good compromise is to adjust the amplifier gain so there is a 15 dB on/off ratio at 0 insertion loss. This would give the maximum dynamic range with on/off ratio induced error of 1.7 dB at 0 dB insertion loss, .8 dB at 5 dB insertion loss and no error below 10 dB insertion loss. To prevent this error from affecting the calibration portion of the measurement, the calibration should be done with an attenuator instead of a "thru" section. The value of the attenuator should be equal to the gain of the amplifier and a corresponding 8755 reference level offset should be used. A chart of the on/off ratio induced error using this compromise procedure is shown in Figure 4.



The amplifier gain determines the on/off ratio at 0 insertion loss for a particular sweep oscillator plug-in.

Figure 4. On/Off Induced Error Versus Insertion Loss

ACKNOWLEDGEMENT

The basic idea for extending the dynamic range of the 8755 was conceived by David Layden, Naval Avionics Facility, Indianapolis, Indiana.

APPENDIX 1

Recommended Equipment and Typical Performance for Expanded Dynamic Range Measurements.

SWEEP OSCILLATOR PLUG-INS

The following HP 8620 series sweeper plug-ins are directly compatible with the 8755 modulation.

HP Model #	Frequency Range	Typical Modulator Control Range	Total Potential Dynamic Range With 15 dB 15 On/Off Ratio
86290A/B	2-18 GHz	60 dB	105 dB
86222A/B	.01-2.4 GHz	40 dB	85 dB
86240A/B	2-8.4 GHz	45 dB	90 dB
86245A	5.9-12.4 GHz	54 dB	99 dB

AMPLIFIERS (These all exceed the requirement for > 10 dBm)

HP Model #	Frequency Range	Gain
8447E	0.1 to 1.3 GHz	> 22 dB
489A	1 to 2 GHz	> 30 dB
491C	2 to 4 GHz	> 30 dB
493C	4 to 8 GHz	> 30 dB
495A*	8 to 12 GHz	> 30 dB

*Information on 12.4 to 18 GHz available on request