Wideband IF Systems: Part 1

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1 Introduction

Wider bandwidth receiver systems are necessary in the detection and study of extra-galactic sources. The instantaneous bandwidth of SIS mixers can exceed 100 GHz. Unfortunately, use of this bandwidth has been inhibited by both the IF system and the back-end signal processing. The microwave electronics following the mixer have typically been designed with a 1-2 GHz band, while the spectrometers available have been limited to 1-GHz bandwidths. Recently, acousto-optical and analog correlator spectrometers have been demonstrated that give 4 GHz of bandwidth for signal analysis. In the commercial microwave industry, the technology for wideband amplifiers, mixers, and attenuators allows easy integration of connectorized components to achieve octave-band IF systems. The push towards monolithic microwave integrated circuits (MMIC) and hybrid circuits has resulted in smaller packages, wider bandwidths, and improved performance.

As a first step towards upgrading and improving our current IF system, a microwave amplifier module was proposed and specified as shown in Figure 1. The isolator reduces reflections and ripple due to the input cable, but contributes about 0.5 dB to the noise figure of the unit. The amplifiers have typically 35 dB of gain each. The filter defines the bandwidth of the unit, while the variable attenuator can be adjusted to limit the signal strength into the power amplifier, so as not to saturate its output. Part of the signal is picked off by a 10-dB coupler and routed to one input of a microwave switch. The 50-ohm termination on the other input of the switch is used as a "zero"

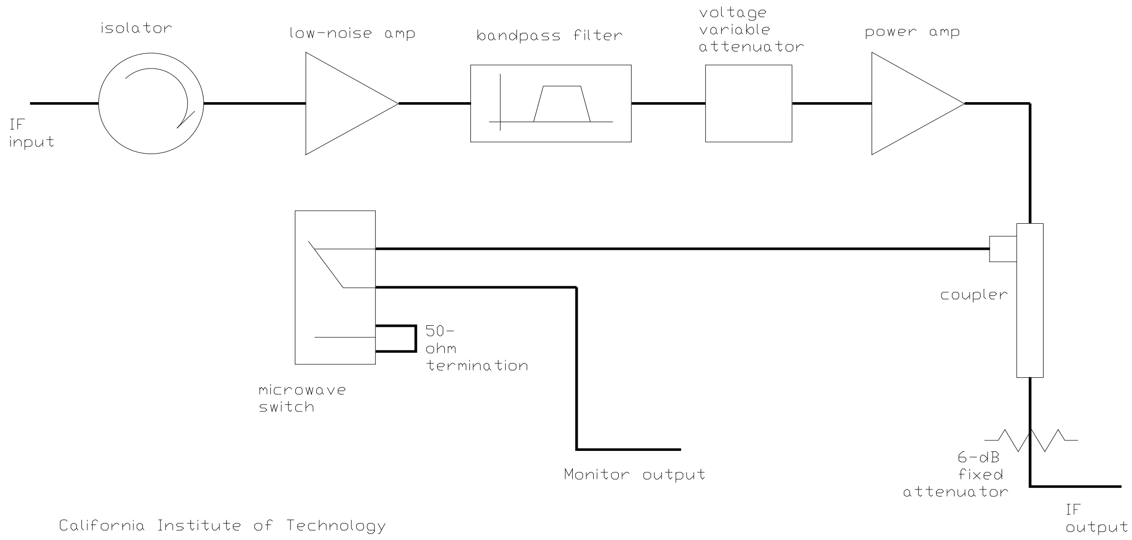


Figure 1: IF Amplifier Module Block Diagram

check (offset level) for the electronics connected to the "monitor" port of the unit. Finally, a 6-dB fixed attenuator is connected before the output of the unit, to reduce ripple due to reflections on the output cable.

A primary concern was the isolation of the switch used. Typically, the "monitor" port is connected to a diode detector and DC amplifier, for measuring the signal power available and as a way to perform noise temperature measurements. When the switch selects the 50-ohm termination, some noise power will nonetheless leak throught the switch from the power amplifier. This additional power can be thought of as an offset. Defining x = switch isolation,

$$P_{offset} = xP_{hot}$$

$$P' = P - P_{offset}$$

$$P'_{hot} = P_{hot} - P_{offset}$$

$$P'_{cold} = P_{cold} - P_{offset}$$

Using the standard definition for y-factor, $Y = \frac{P_{hot}}{P_{cold}}$,

$$Y' = \frac{P'_{hot}}{P'_{cold}} = \frac{P_{hot} - P_{offset}}{P_{cold} - P_{offset}}$$

$$= \frac{P_{hot} - xP_{hot}}{P_{cold} - xP_{hot}}$$

$$= \frac{1 - x}{\frac{P_{hot}}{P_{cold}} - x}$$

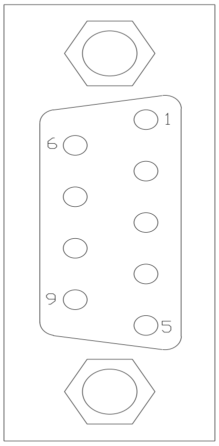
$$Y' = \frac{1 - x}{\frac{1}{Y} - x}$$

Since noise temperature is defined as $T_N = \frac{T_{hot} - T_{cold}}{Y - 1} - T_{cold}$,

$$T'_N = \frac{T_{hot} - T_{cold}}{Y' - 1} - T_{cold}$$

For y-factor values ranging from 1.4 to 2.6, T_N and T'_N values were compared for three switch isolation values: -35 dB, -20 dB, and -10 dB. The error in noise temperature using a switch with -35 dB of isolation is less than 0.3 K. With -20 dB of isolation, the error is less than 8 K, while the error having -10 dB of isolation is greater than 40 K. MMIC switches are readily available with minimum isolation values of -35 dB, thus reducing the size and cost of the amplifier units.

Commercial companies were contacted to obtain bids for the design and construction of this module. CTT, Inc. [1] won the contract, and began work in October of 1998. Two prototypes were built, covering the bands of 3-6 GHz and 4-8 GHz. The units were delivered at the end of February, 1999. The amplifier modules measure 9.90” long, 3.65” high, and 1.00” wide. SMA panel connectors are used at the “RF in”, “RF out”, and “RF monitor” ports. A 9-pin D-subminiature plug labeled “J1” allows connection for power and control voltages. Figure 2 shows the 9-pin connector, along with the pin assignments. The following sections explain and report the measured performance of the units, and compare the measured data to the specifications.



Pin No.	Function
1	+15 V
2	−15 V
3	Attenuator
4	Monitor
5	+15 V return
6	−15 V return
7	Atten. return
8	Mon. return
9	No connection

Figure 2: J1 Amplifier Unit plug

2 Measurement Setup

The following test equipment was used in the measurements:

- Hewlett-Packard 8719D Network Analyzer
- Hewlett-Packard 85852D Calibration Kit
- Hewlett-Packard 85131-60012 Test Port Cables
- Hewlett-Packard 8563E Spectrum Analyzer
- Anritsu ML83A Power Meter
- Anritsu MA72B Power Sensor
- Kikusui PAB 25-1TR DC Power Supply
- in-house built 0-6 VDC power supply

Unit	Attenuator Setting	Voltage, VDC	Current, mA
4-8 GHz	-10 dB	+1.10	1.10
	-20 dB	+2.06	3.11
3-6 GHz	-10 dB	+1.40	1.71
	-20 dB	+2.85	4.76

Table 1: Variable Attenuator Settings

The Kikusui power supply was used for +/-15 VDC bias and +5 VDC for digital switching, while the in-house adjustable DC power supply was used for controlling the voltage-variable attenuator in the units. Referring to the J1 plug, the "monitor" pin has +5 VDC on it for TTL control of the switch. The 50-ohm load is connected to the "monitor" port in the switch's normal state. By applying ground to the "monitor" pin, the signal from the coupler is connected to the "monitor" port. The "attenuator" pin requires an adjustable voltage between 0-6 VDC for controlling the attenuator. Table 1 shows the voltages and currents required for setting the attenuation to -10 dB and -20 dB for each unit. The voltage and current values were checked during different periods of operation, and were found to be repeatable. All the pins labeled "return" are connected to ground.

Full two-port calibration was performed on the network analyzer, with the analyzer output power level set to -10 dBm, frequency band set at 0.5-12.5 GHz, and number of points representing the waveform set to 801. Figure 3 shows the test setup for measuring S21 and S22 at the "RF out" port on the units, and S21 on the "monitor" port. Since the gain of the units was 60 dB minimum, three 20-dB fixed attenuators were attached to the input of the unit. These attenuators were individually measured for S21 as shown in Figure 4. Table 2 lists the attenuation flatness, which for all three attenuators totaled +/-0.232 dB. In software, the losses of the attenuators were subtracted from the measured response of the unit to arrive at the actual gain response of the units. S21 data at the "RF out" port was recorded with

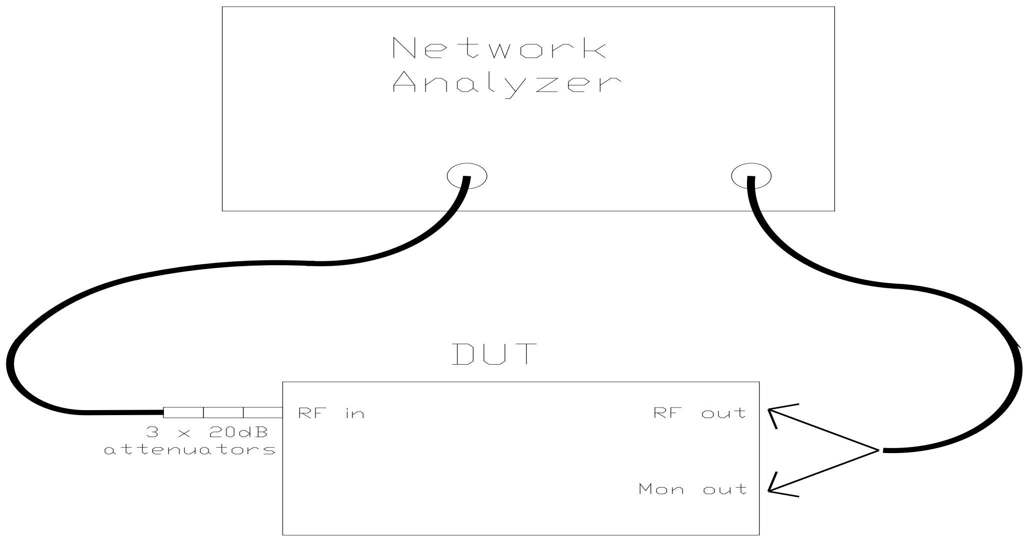


Figure 3: Simplified Test Setup Diagram

the variable attenuator set to 0 dB and -10 dB. S21 data was recorded at the "monitor" port with the switch in the "OFF" position and "ON" position. To measure S11 at the "RF in" port, the fixed attenuators were removed, and the internal variable attenuator was turned up to its maximum value of -31 dB, to reduce the power into the second half of the units.

With a 50-ohm termination at the "RF in" port, the units were connected to the spectrum analyzer, to detect any oscillations across the frequency band. None were found. Using the power meter, standard noise temperature tests were performed for the entire band as a single figure of merit. Hot/cold readings were taken with the attenuator set to 0 dB and -10 dB. To determine the 1-dB output power compression points, the network analyzer was configured to sweep the input power from -70 dBm to -50 dBm at a single frequency, and the output power was displayed on the screen. Markers were used to locate the point when the power fell by 1 dB. Figures 5–16 show the measured data.

3 Conclusions and Recommendations

Table 3 compares the measured data to the original specifications. The units perform well in the areas of gain, noise figure, input VSWR, switch isolation, and 1-dB power compression point. Gain flatness and output VSWR did not meet specifications. After talking with the engineers at CTT, the idea was promoted that the S22 measurement was in error, due to the relatively low power source level. It was thought that the additional noise power from the first stages of amplification was contributing to the measured reflected power at the port, thereby increasing the returned power and resulting in a higher S22 measurement. A second measurement was performed at a higher source power level, with little change in the S22 measurement, as shown in Figures 17-18. Studying the operational manual on the Hewlett-Packard network analyzer reveals that the signal measured, per frequency point, is down-converted to a 4-kHz band, then applied to an analog-to-digital converter for digitizing and processing. This bandwidth is so narrow that the noise power emanating from the amplifier output cannot possibly affect the measurement of S22. Another unsettling fact is the large ripple in the 3-6 GHz module, at the lower end of the band. CTT, Inc., has been contacted, and these units have been returned for adjustment to improve their overall performance.

The measured noise figure for both units, although within specification, is in error due to non-zeroing of the power meter before and during the measurements. The setting of the internal attenuator should have little effect on the unit's noise figure. This measurement, along with the other ones which failed, will be checked once the units are returned.

References

[1] CTT, Inc., 3005 Democracy Way, Santa Clara, Ca. 95054 (408)988-8521.

The following tables and figures are the first measurements of the 4-8 GHz and 3-6 GHz units, performed on March 5, 1999.

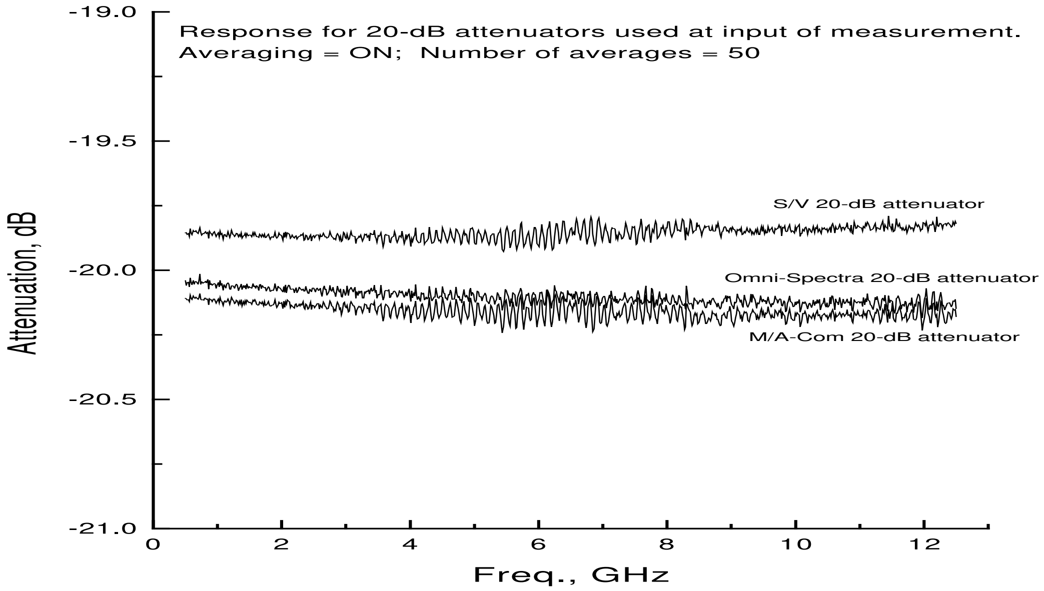


Figure 4: Measured 20-dB fixed attenuator

Attenuator	**Range**	**Flatness**
Omni-Spectra	-20.015 to -20.184 dB	+/- 0.085 dB
M/A Com	-20.086 to -20.242 dB	+/- 0.078 dB
S/V	-19.790 to -19.928 dB	+/- 0.069 dB

Table 2: 20-dB fixed attenuator data, 0.5-12.5 GHz

Parameter	**specification**	**4-8 GHz unit measurements**	**3-6 GHz unit measurements**
gain (atten.=0 dB)	60 dB min.	70.3-65.0 dB	70.0-65.3 dB
gain flatness (atten.=0 dB)	+/- 1.0 dB	+/- 2.65 dB	+/- 2.35 dB
gain flatness (atten.=-10 dB)	+/- 1.0 dB	+/- 2.55 dB	+/- 1.30 dB
1-dB gain compression	+6 dBm	> +11.5 dBm	> +11.5 dBm
Input VSWR	1.5:1 max. (-14 dB max.)	< 1.5 : 1	< 1.5 : 1
Output VSWR	1.22:1 max. (-20 dB max.)	< 1.5 : 1	< 1.5 : 1
Noise Figure	3.5 dB max.	2.3 dB (atten.=0 dB) 1.6 dB (atten.=-10 dB)	2.8 dB (atten.=0 dB) 2.0 dB (atten.=-10 dB)
Switch Isolation	-35 dB min.	-50 dB min.	-45 dB min.
DC power	+15 V @ 1 A max.	+15 V @ 300 mA	+15 V @ 300 mA

Table 3: SPECIFICATIONS VS. MEASURED DATA

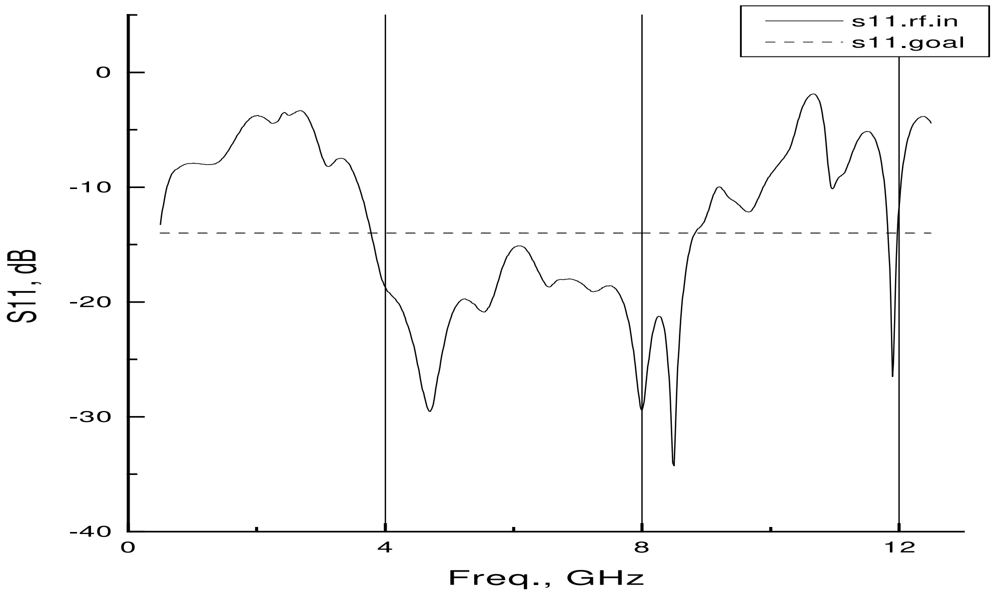


Figure 5: S11, 4-8 GHz unit

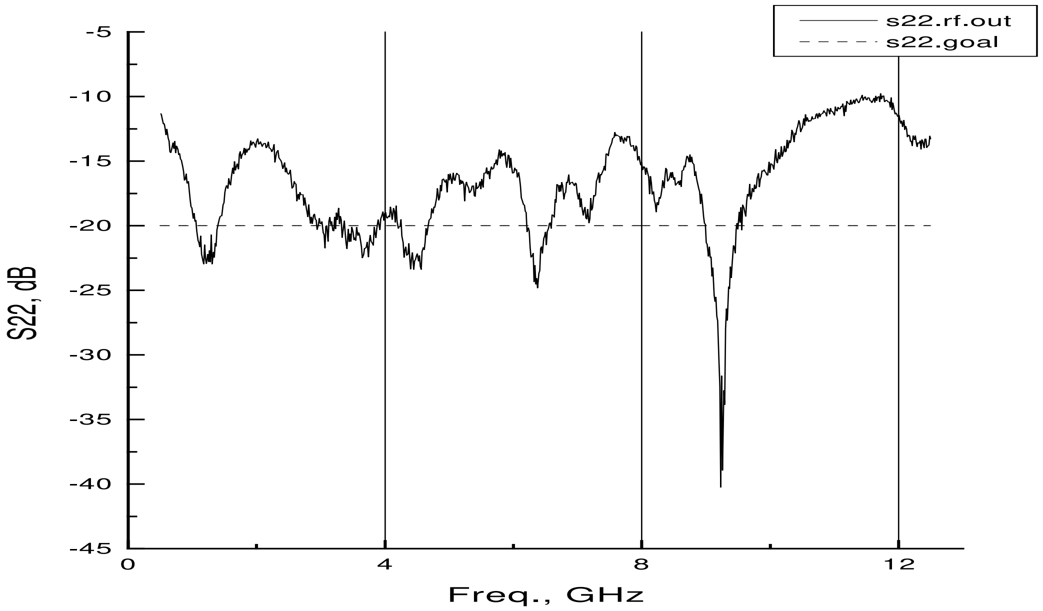


Figure 6: S22, 4-8 GHz unit

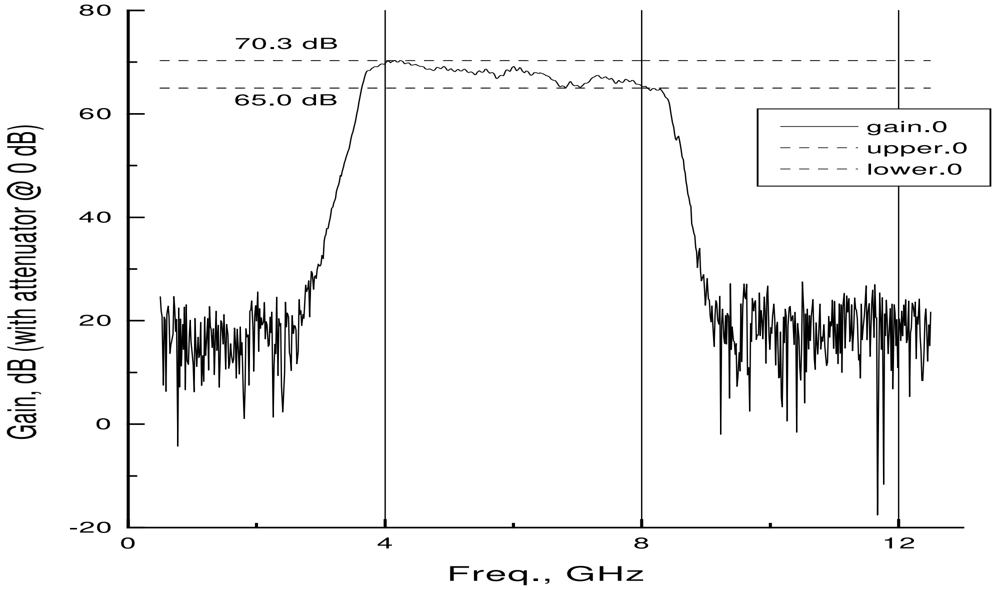


Figure 7: S21 with atten.=0 dB, 4-8 GHz unit

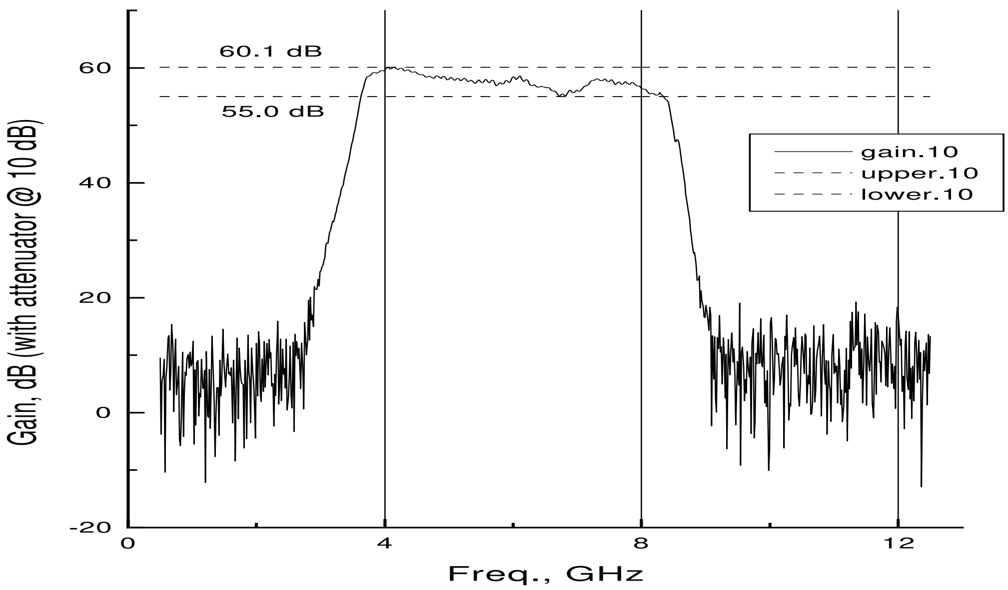


Figure 8: S21 with atten.=10 dB, 4-8 GHz unit

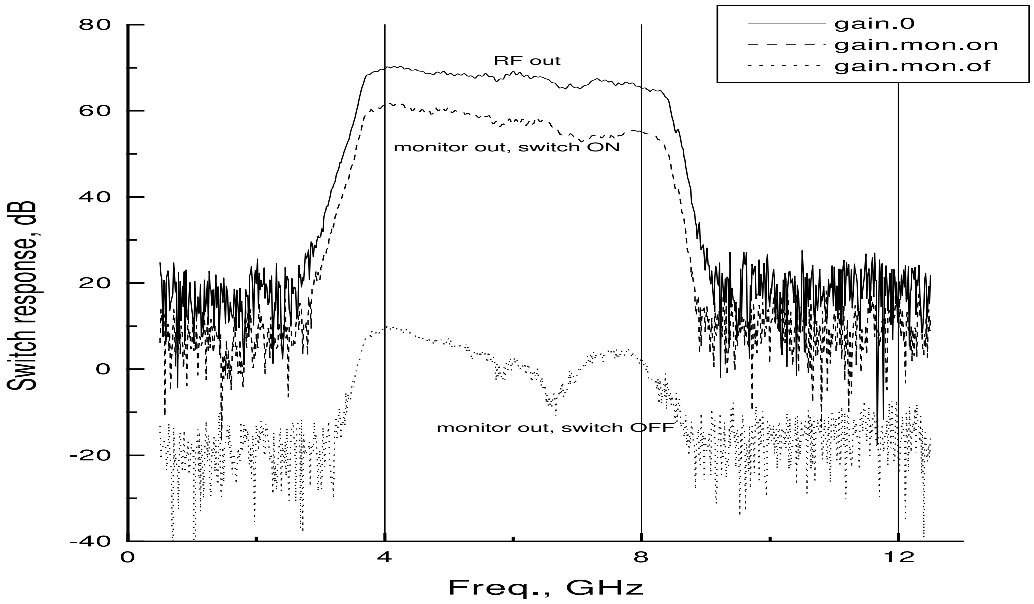


Figure 9: Switch response, 4-8 GHz unit

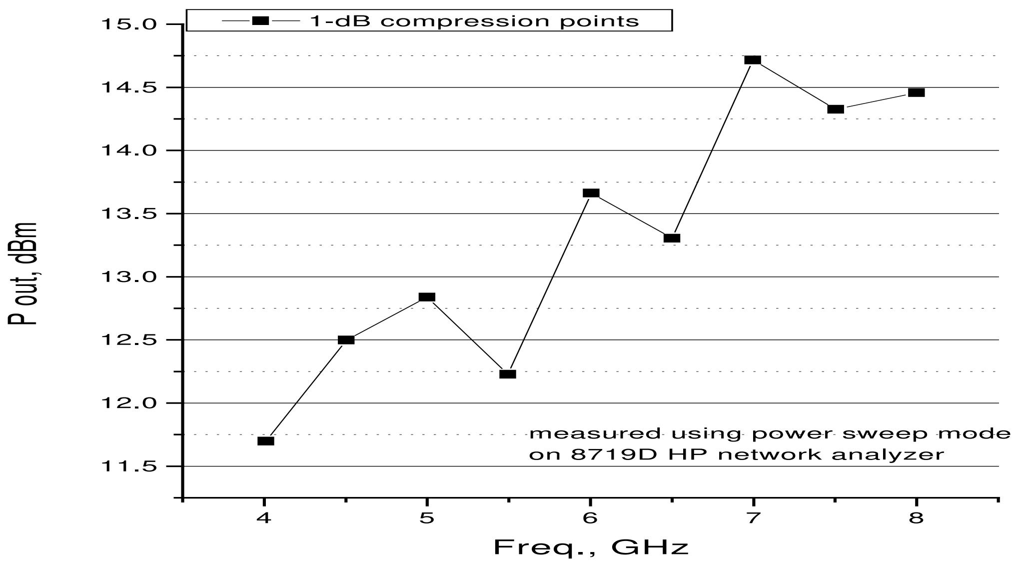


Figure 10: 1-dB compression points, 4-8 GHz unit

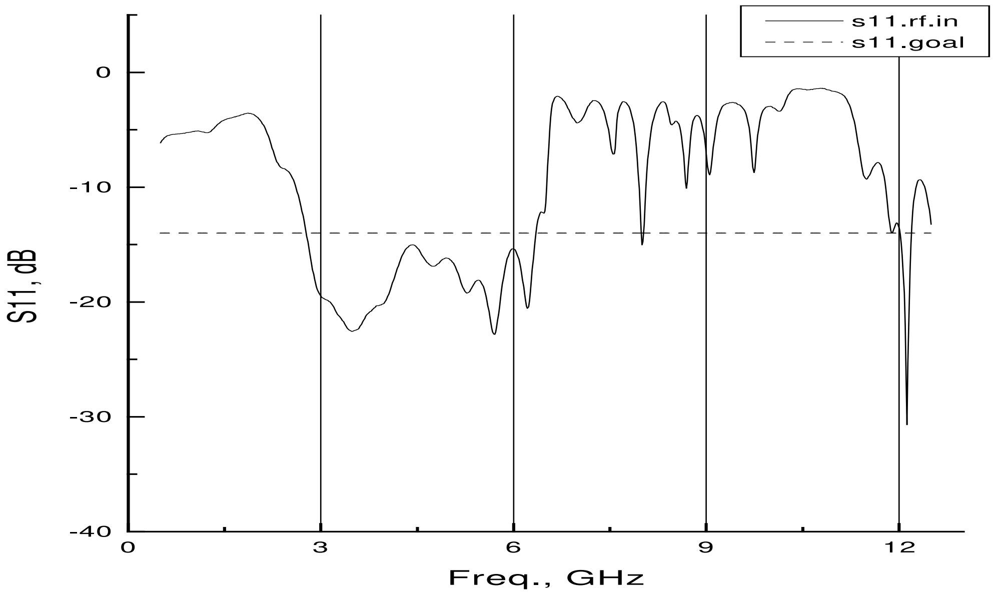


Figure 11: S11, 3-6 GHz unit

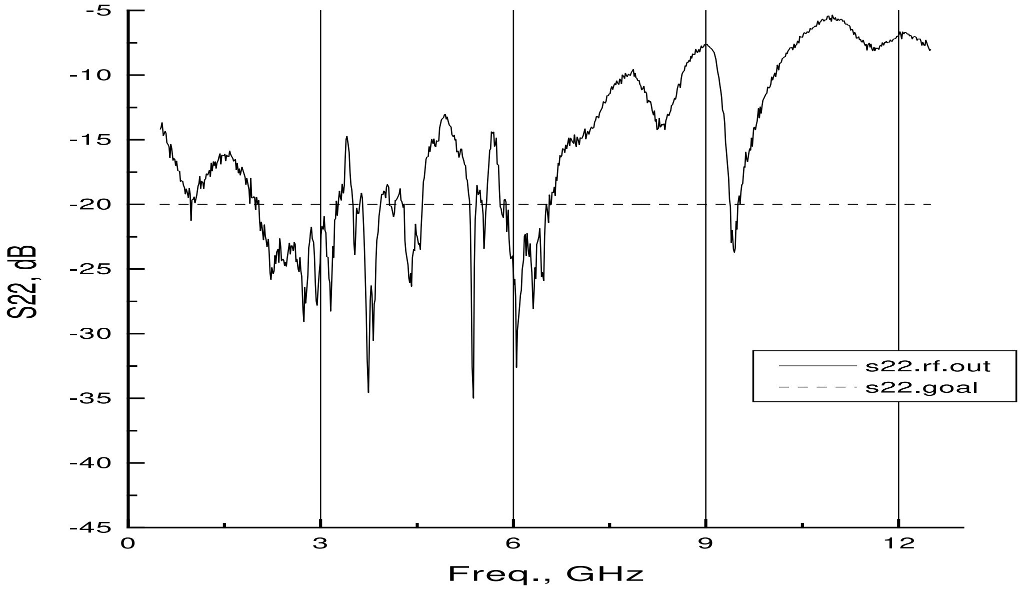


Figure 12: S22, 3-6 GHz unit

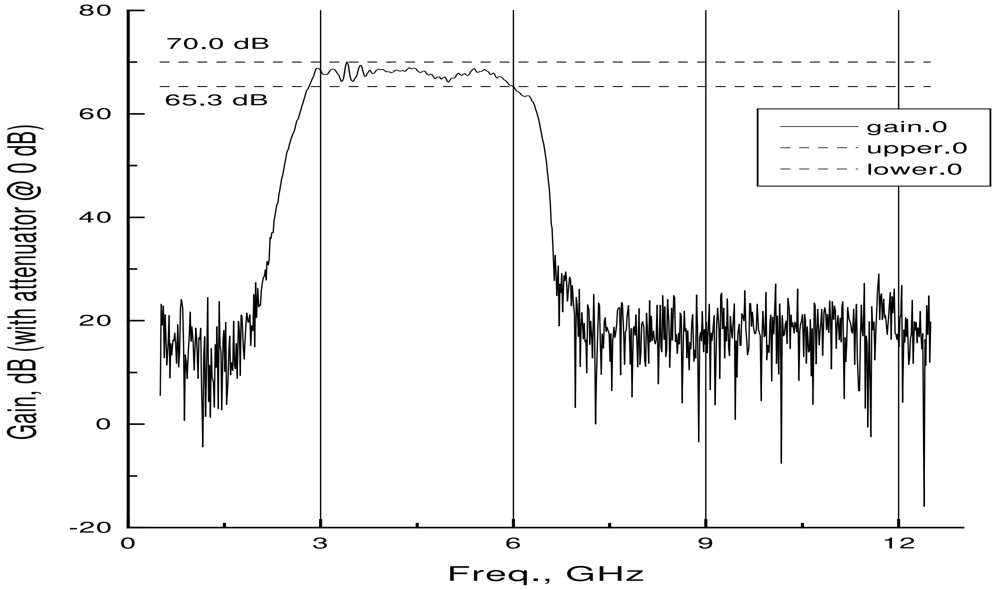


Figure 13: S21 with atten.=0 dB, 3-6 GHz unit

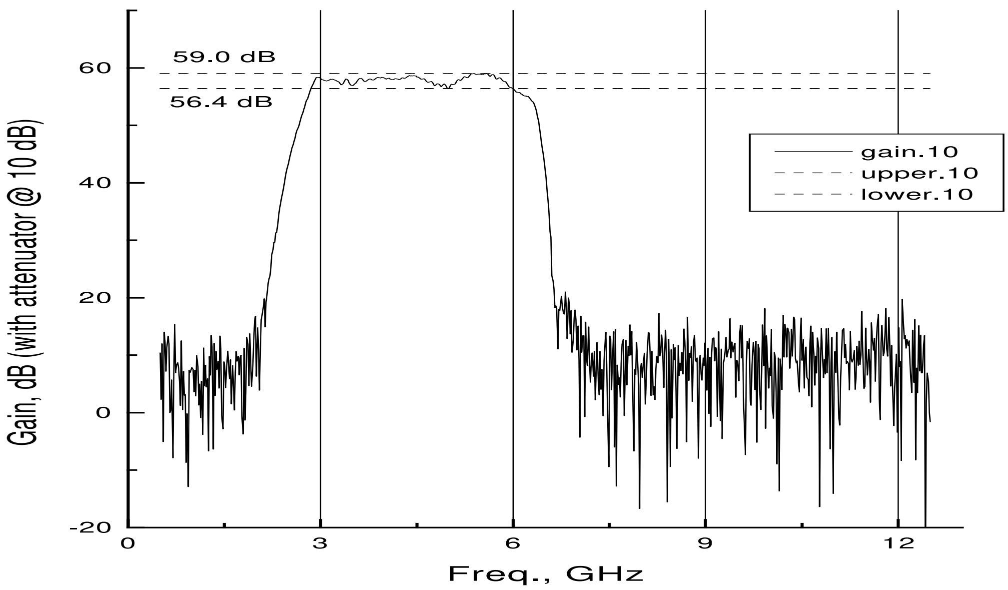


Figure 14: S21 with atten.=10 dB, 3-6 GHz unit

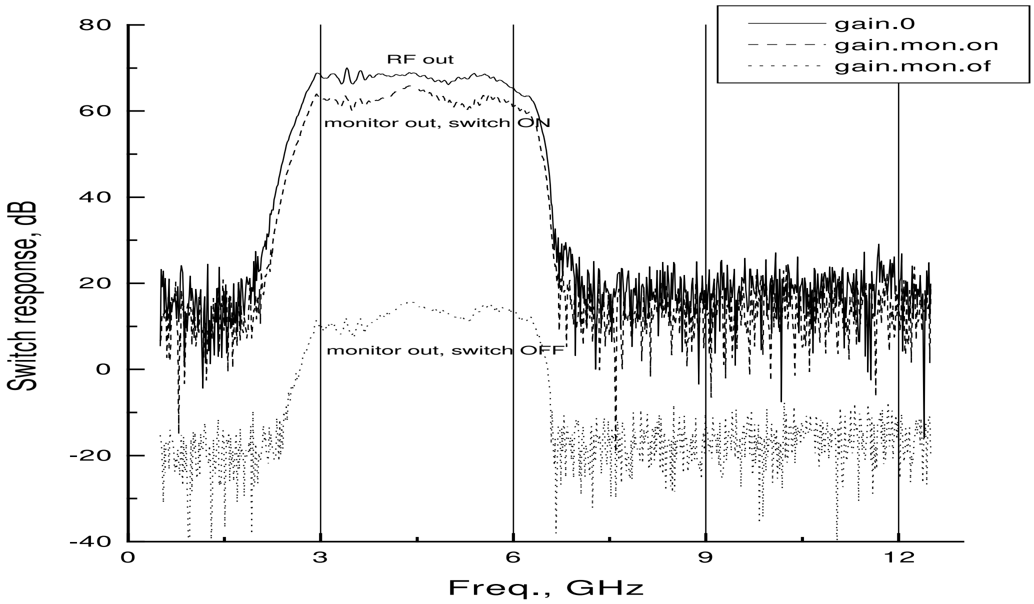


Figure 15: Switch response, 3-6 GHz unit

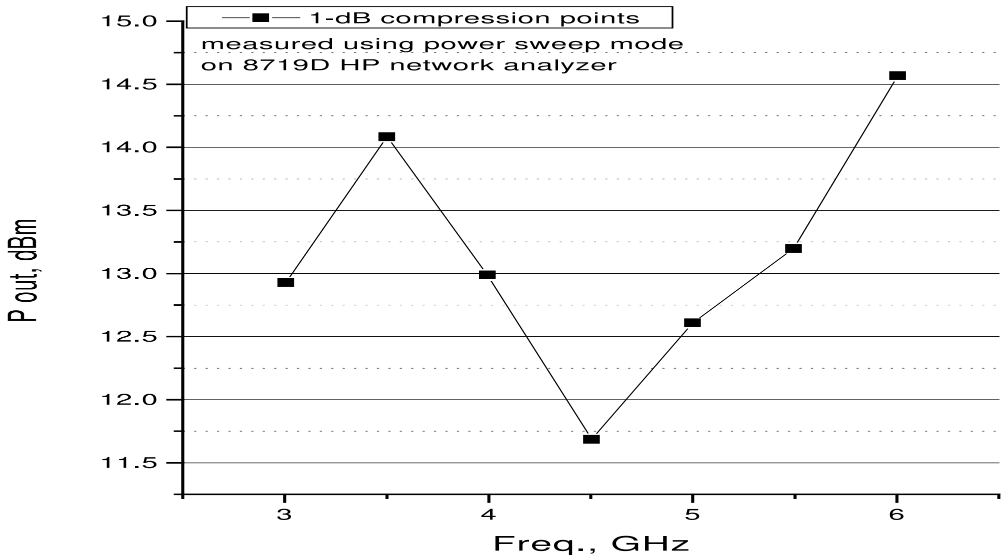


Figure 16: 1-dB compression points, 3-6 GHz unit

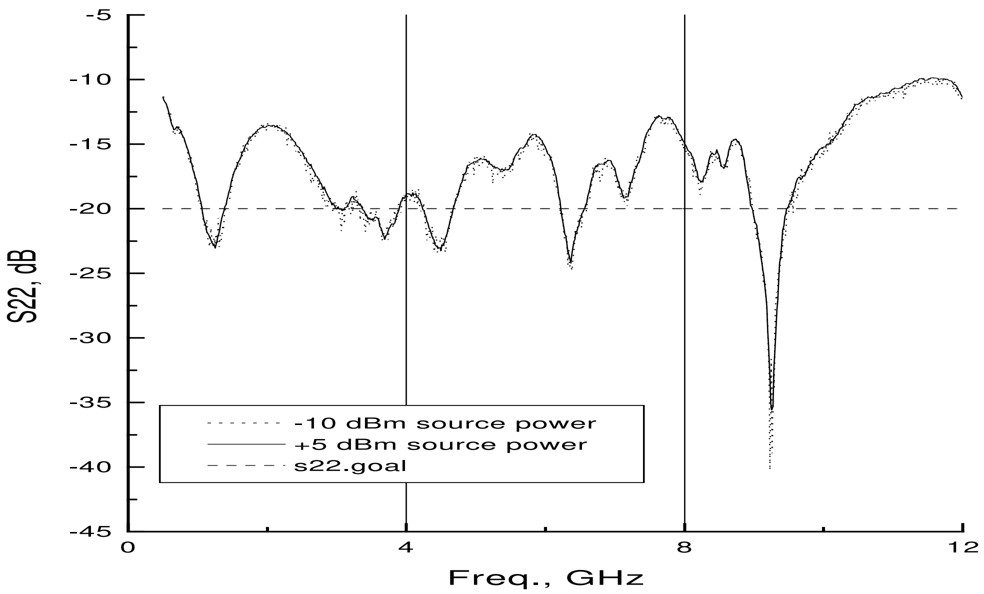


Figure 17: S22 with 2 different input power levels, 4-8 GHz unit

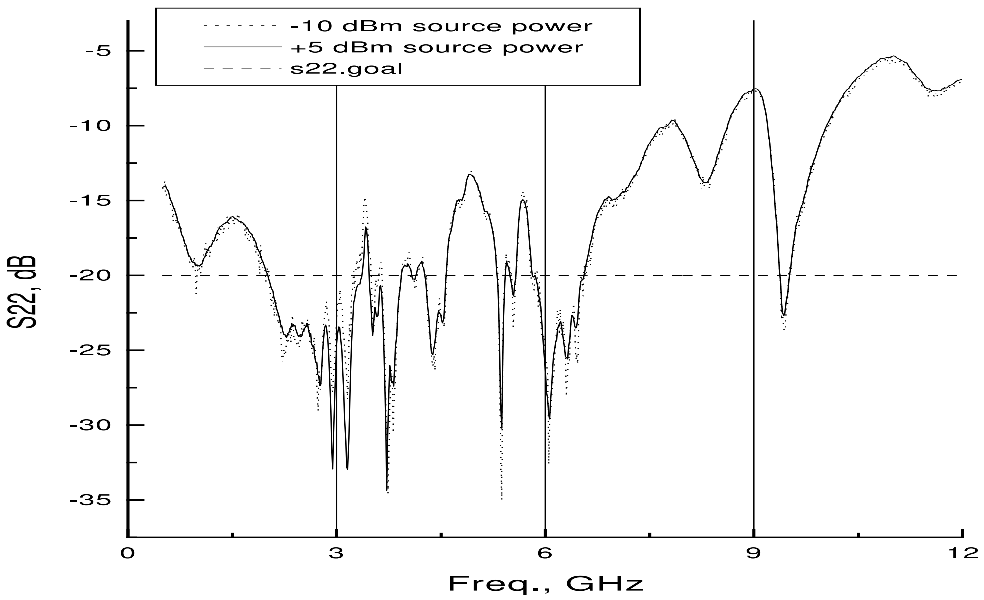


Figure 18: S22 with 2 different input power levels, 3-6 GHz unit