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Low Noise Amplifier Gain Compression and Intermodulation Distortion Measurements

Bill Shillue

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Abstract-Measurements are made on LNA's designed by NRAO's Central Development Laboratory to determine their large signal characteristics, and suitability for proposed use in the front end receiver of the OVLBI earth station in Green Bank.

1 Introduction

The OVLBI Earth Station project will require two receivers, one for X-band, covering 7.2-8.5 GHz, and one for Ku-band, covering 14.2-15.4 GHz. State-of-the-art low-noise amplifiers have been designed and built at NRAO's Central Development Laboratory for the VLBA project, covering the bands 8-8.8 GHz (X-band) and 14.2-15.4 GHz (Ku-band). These amplifiers were designed to optimize the small signal performance of the LNA, since radio telescope receivers must be sensitive only to the very small-signals arriving from astronomical sources. However, for the OVLBI project, the large signal performance of the LNA's must be considered due to the fact that earth station transmitters will implement a two-way timing link and supply the spacecrafts with a clock signal.[1] In particular, this report is concerned with the measurement of the 1 dB gain compression and 3rd order intermodulation products of the LNA's. Two prototype Ku-band amplifiers were built and tested as development for the VLBA project,[2] and it has been proposed to use them in the Ku-band front end of the OVLBI Earth Station. The amplifiers are three stage, using Fujitsu FHR01FH HEMT devices. They were designed to operate over a 14.4-15.4 frequency band, but will operate as low as 14.2 GHz as needed for the OVLBI front end with only slightly degrade performance. Over the design bandwidth, the prototypes yielded a gain of 25-29 dB and average noise temperature of 22.8 K and 22.5 K for amplifiers U-1 and U-2, respectively. The Ku-band VSOP transmitter will likely be at 15.3 GHz, while the VSOP data downlink is at 14.2 GHz. The current estimate is that a 30 mW (14.8 dBM) transmitter will be required.[3] The data downlink channel will be isolated from the transmitter by a narrowband circulator and a narrow-band-reject filter centered at the transmitter frequency. Anticipating transmitter interference, our purpose is to determine at what signal level the LNA's will be driven into gain compression, and at what level spurious intermodulation products will be created.

2 Nomenclature

Some nomenclature will be explained that is introduced to keep this report easier to read. Two amplifiers were measured, U-1 and U-2. Two temperature were considered, room temperature (around 300°K), and the temperature inside a helium-cooled dewar (around 20°K). Three frequencies were measured: 14.2 GHz, 14.75 GHz, and 15.3 GHz. Finally, the bias levels were adjusted to see what the effect would be on gain compression and intermodulation. For each amplifier, there were nominal bias levels, adjusted for lowest-noise operation, at both 300°K and 20°K. From those nominal levels, the bias levels to the third stage was increased in several instances to see what effect this would have on the measured results. A measurement can be described, then, by the device under test, the temperature, and the bias level. The designation, U1T300BN, stands for amplifier U-1 at 300°K, with nominal low-noise bias. The designation, U2T20BA, stands for amplifier U-2 at 20°K, with an adjusted bias level. Any other designations can be deduced from these examples. The actual bias conditions for all measurements will be listed in a single table.

3 Equipment Setup and Calibration

The general setup that was used for gain compression measurements is shown in Figure 1. All attenuators used were calibrated at the three frequencies, except for the one within the dewar, which was assumed to be 20 dB at all frequencies. The input power was read directly from the power readout on the sweeper after this scale was calibrated. The 30dB attenuator on the output was used if the output power exceeded the maximum rating of the sensor. The measurement procedure was simple, manually increase the input power, recording output power at each setting. This had to be done, of course, for input power high enough to drive the LNA into compression.

The general setup for the 3rd order intermodulation measurement was as shown in Figure 2. Here the input power levels and the 90° hybrid were not calibrated. Rather, the input power was adjusted so that the output power of the fundamental frequencies was the same (3rd order products are then also equal to each other). The output spectrum was measured on the spectrum analyzer, and the third order products, P_{3rd-dB}, were measured relative to the fundamentals. One of the sources was then turned off and the output power, $P_{fund-dB}$, measured directly with the power meter. These two measurements allowed for the calculation of the 3rd order intercept, in dB (the hypothetical power level at which the 3rd order intermodulation product would become equal to the power in the fundamental signals) from Equation 1.

$$P_{3rd\ order\ intercept} = P_{fund-dB} + \frac{P_{fund-dB} - P_{3rd-dB}}{2} \quad (1)$$

The theory of intermodulation distortion will not be covered here, but it should suffice to say that when the LNA is driven at large enough signal levels begin to generate third harmonics, spurious mixer products appear as discrete sidebands to the two input signals, separated in frequency from them by an amount equal to their difference in frequency. A short discussion of gain compression and intermodulation distortion is given in Gonzalez.[4] He also includes the interesting statement that if the transient voltage response of the LNA includes only

[1] "OVLBI Timekeeping with the VLBA Formatter", L. R. D'Addario, August 1, 1990. See also OVLBI memos #3,7,9, and 10

[2] "Design and Performance of Cryogenically-Cooled 14.4-15.4 GHz HEMT Amplifier", M. Pospieszalski and W. Lakatosh, NRAO Internal Report No. 278, August, 1988

[3] Z. Yamamoto, FAX message dated 5-19-91, including VSOP uplink and dowwnlink power budgets calculated at ISAS, Japan

[4] Guillermo Gonzalez, Microwave Transistor Amplifiers, Prentice Hall, 1984, pp. 174-180

quadratic and cubic terms, then the third order intermodulation intercept will be 10 dB greater than the 1dB gain compression point. In other words if the 1dB gain compression occurs at +5 dBm, then the 3rd order intercept is at +15 dBm.

4 Measurement Results

First, the bias settings for each of the measurements is listed in Table 1. The table also lists an identification number showing that six sets of data were taken. The measurements of amplifier U-1 were done at 294°K and 20°K, and amplifier U-2 was done also at both temperatures, but also with the bias adjusted to the third stage for both cases.

Results of these measurements, including 1 dB compression points at 14.2 GHz, 14.75 GHz, and 15.3 GHz, and the third order intermodulation intercepts are included in Table 2.

Note that for both amplifiers, the 1 dB gain compression was worse at 20° K than at 294° K, and that the degree to which it was worse was higher at 15.3 GHz than it was at 14.2 GHz (Compare Series 1 and 2, and Series 3 and 5). One would have expected the 3rd order intercepts to decrease by the same amount, and this did occur for amplifier U-2, but not for amplifier U-1. We are not sure of the reason for this, perhaps it is due to there not being a simple cubic response of output to input voltage in the amplifier. Two cases were measured in which the bias was increased to the third stage of the LNA, Series 4 and 6. For Series 4, the bias was greatly increased and there was a dramatic improvement in the distortion figures, with 1 dB gain compression at 12.6 dBm and third order intercept at 20.4 dBm. This was at 294° K. Thus it may be possible to adjust the bias to improve the distortion performance. If this were to be pursued, we would have to study the effect in more detail. However, it is worth noting that adjusting the bias will inevitably degrade the noise performance of the amplifier and so may not be advisable.

The accumulated data is presented in tabular form, gain vs. input power, in Tables 3–6, and in graphical form, output power vs, input power, in Figures 3–6. In each case, the Series number correponding to Table 2 is noted.

5 Conclusion

These measurements were made to investigate the effect of an interfering signal from the VSOP or RA transmitter in one of our receivers. A conservative estimate would be that a transmitter signal present in the receiver channel could start to compress an LNA at an output power of around +5 dBm. The lowest input power at which this occurred was for U-2 at 14.2 GHz and $P_{in} = -28$ dBm. At 15.3 GHz, the amplifier compressed at $P_{in} = -22$ dBm. The power levels may be somewhat higher for U-1, which had lower gain, but the measurements of U-2 were done more carefully and methodically, and I suggest that we draw the conclusion that power levels be kept below -30 dBm, and design band-reject filters with a 10 dB safety margin to limit transmitter power at the LNAs to -40 dBm. The intermodulation products should not be a problem if this is done.

1. U1T300BN			
	V_{ds}	$I_{ds}(mA)$	V_{gs}
Stage 1	2.61	10.1	-.44
Stage 2	2.61	9.54	-0.43
Stage 3	2.63	9.9	-0.80
2. U1T20BN			
	V_{ds}	$I_{ds}(mA)$	V_{gs}
Stage 1	3	5.3	-0.74
Stage 2	3	7.6	-0.51
Stage 3	4.0	12.3	-1.02
3. U2T300BN			
	V_{ds}	$I_{ds}(mA)$	V_{gs}
Stage 1	2.61	10.3	-0.44
Stage 2	2.61	10.1	-0.55
Stage 3	2.63	9.8	-0.60
4. U2T300BA			
	V_{ds}	$I_{ds}(mA)$	V_{gs}
Stage 1	2.61	10.3	-0.44
Stage 2	2.61	10.1	-0.55
Stage 3	4.50	21.0	-0.49
5. U2T20BN			
	V_{ds}	$I_{ds}(mA)$	V_{gs}
Stage 1	3	5.3	-0.74
Stage 2	3	7.6	-0.51
Stage 3	4	12.3	-1.02
6. U2T20BA			
	V_{ds}	$I_{ds}(mA)$	V_{gs}
Stage 1	3	5.3	-0.74
Stage 2	3	7.6	-0.51
Stage 3	5.03	12.0	-1.24

Table 1: Bias parameters for Measurement Series 1–6

1 dB Compression Point					Third Order Product	
Series Number		14.2 GHz	14.75 GHz	15.3 GHz	Freq. (GHz)	Intercept (dBm)
1	U1T300BN	8.9	9.0	10.1	14.4	14.9
2[5]	U1T20BN	7.7	8.4	5.1	15.3	15.2
3	U2T300BN	5.9	7.3	8.0	14.2	15.3
4	U2T300BA	12.6	—	—	14.2	20.4
5[6]	U2T20BN	5.0	6.1	5.7	14.2-15.3	14.25
6	U2T20BA	3.6	7.1	9.2	14.2-15.3	14.25

Table 2: Results of Measurements of Gain Compression and Third Order Intermodulation on Ku-band Amplifiers under Test. F1: 14.2 GHz, F2: 14.75 GHz, F3: 15.30 GHz

[5] The 1 dB compression figures for amplifier U-1 at 20°K were arrived at after eliminating the first row of Table 4, which appears to be a bad data point to to a source calibration error

[6] The frequency at which the intermodulation measurement was made in Series 5 and 6 was not recorded, but it did fall within the band of interest

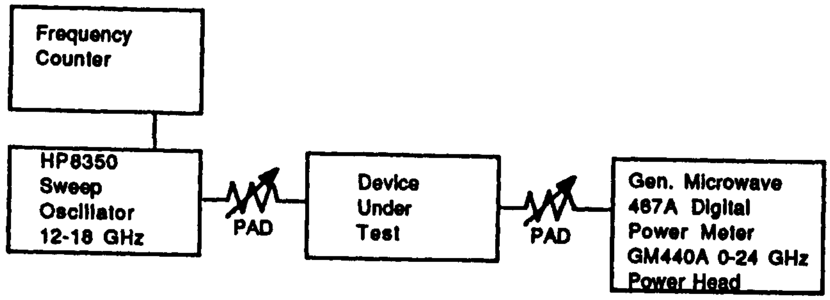

Figure 1: Gain Compression Measurement Setup

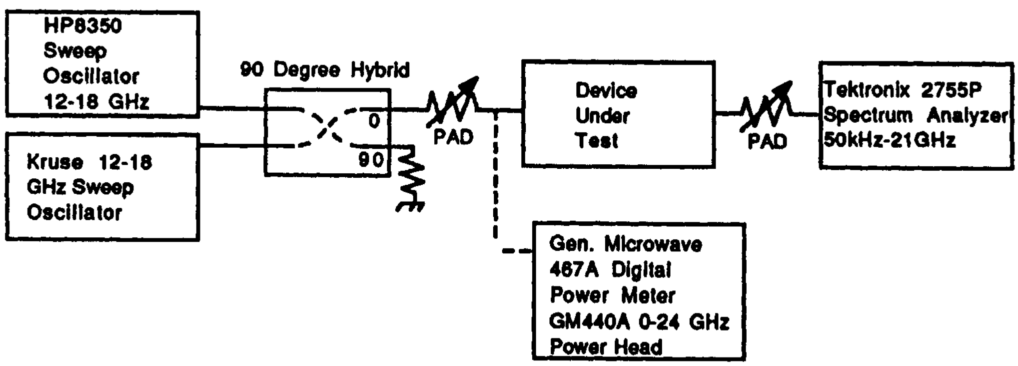

Figure 2: Third Order Intermodulation Measurement Setup

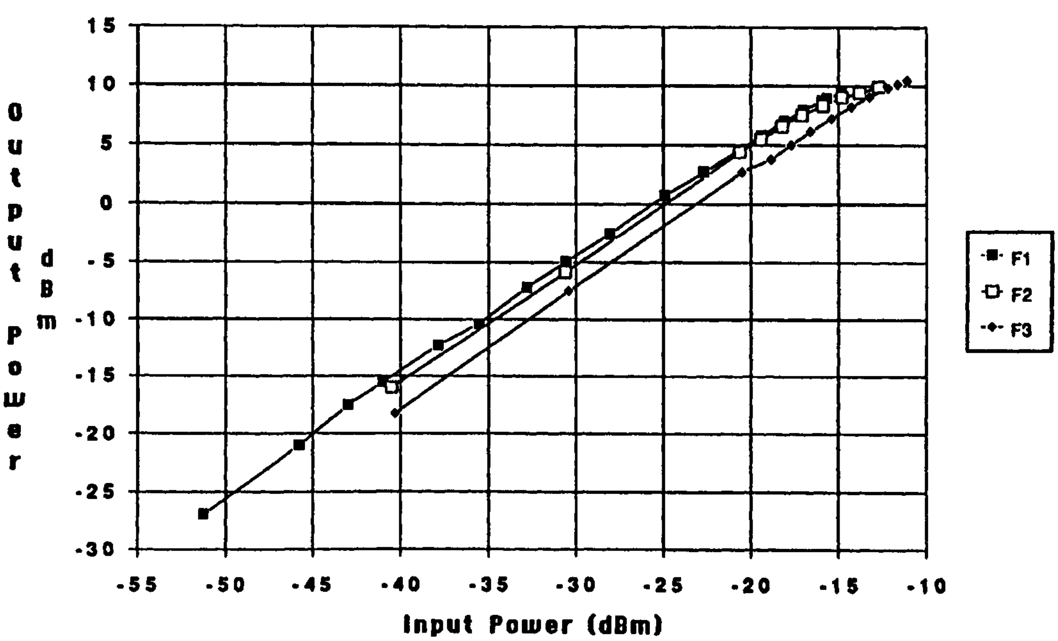

Figure 3: Output power vs. input power for U1 at $T = 294^\circ K$ at three frequencies: F1=14.2 GHz, F2=14.75, F3=15.3 GHz. Corresponds to Series 1 and Table 3

Freq.=14.2 GHz		Freq.=14.75 GHz		Freq.=15.3 GHz	
P_{in}	Gain(dB)	P_{in}	Gain(dB)	P_{in}	Gain(dB)
-41	25.5	-40.5	24.5	-40.3	22.05
-30.6	25.6	-30.6	24.7	-30.4	22.9
-20.5	25.0	-20.6	24.9	-20.5	22.8
-19.35	25.2	-19.4	24.8	-18.9	22.7
-18.1	25.1	-18.2	24.7	-17.7	22.7
-17.0	24.9	-17.1	24.5	-16.6	22.7
-15.9	24.7	-15.9	24.2	-15.4	22.7
-15.6	24.6	-14.8	23.8	-14.3	22.5
-14.9	24.3	-13.8	23.2	-13.3	22.3
		-12.7	22.6	-12.2	22.0
				-11.7	21.8

Table 3: Gain vs. input power for amplifier U1 at $T = 294°K$. Corresponds to Series 1 and Figure 3

Freq.=14.2 GHz		Freq.=14.75 GHz		Freq.=15.3 GHz	
P_{in}	Gain(dB)	P_{in}	Gain(dB)	P_{in}	Gain(dB)
-27.9	30.9	-33.5	30.0	-33.6	26.5
-25.0	30.1	-30.3	29.4	-30.3	25.9
-22.7	29.9	-28	29.3	-28	25.5
-20.3	29.8	-25.1	29.0	-22.8	25.2
-22.1	29.5	-22.7	28.5	-21.6	25.2
-21.5	29.2	-20.4	28.4	-20.5	25.0
		-20	28.4	-19.2	24.8
		-19.8	28.3	-18.1	24.7
		-19.2	28.1	-17.1	24.8
				-16.0	24.7

Table 4: Gain vs. input power for amplifier U1 at $T = 20°K$. Corresponds to Series 2 and Figure 4.

	15.3 GHz	14.75 GHz	14.2 GHz	14.2 GHZ*
P_{in}	Gain(dB)	Gain(dB)	Gain(dB)	Gain(dB)
-42.7	24.1	25.5	27.2	
-40.3	24.0	25.3	27.3	
-38.1	23.8	25.7	27.3	
-35.1	23.9	25.3	27.0	
-32.8	23.9	25.3	27.0	27.2
-30.1	24.0	25.1	27.1	27.3
-28.0	24.2	25.3	27.3	27.5
-25.0	24.1	25.3	27.1	27.4
-23.8	24.1	25.2	26.9	27.3
-22.7	24.0	25.1	26.8	27.2
-21.5	23.9	24.8	26.6	27.2
-20.3	23.9	24.9	26.2	27.1
-19.1	23.8	24.8	25.8	27.0
-18.0	23.7	24.6	25.2	27.0
-17.0	23.5	24.3	24.7	26.9
-15.9	23.2	23.8	23.9	26.8
-14.8	22.8	23.2	22.9	26.7
-13.8	22.3	22.6		26.4
-12.7	21.6	21.8		25.5

Table 5: Gain vs. input power for amplifier U2 at $T = 297°K$. Column with * - V_d bias was increased to 3rd stage. Corresponds to Series 3 and 4 and Figure 5

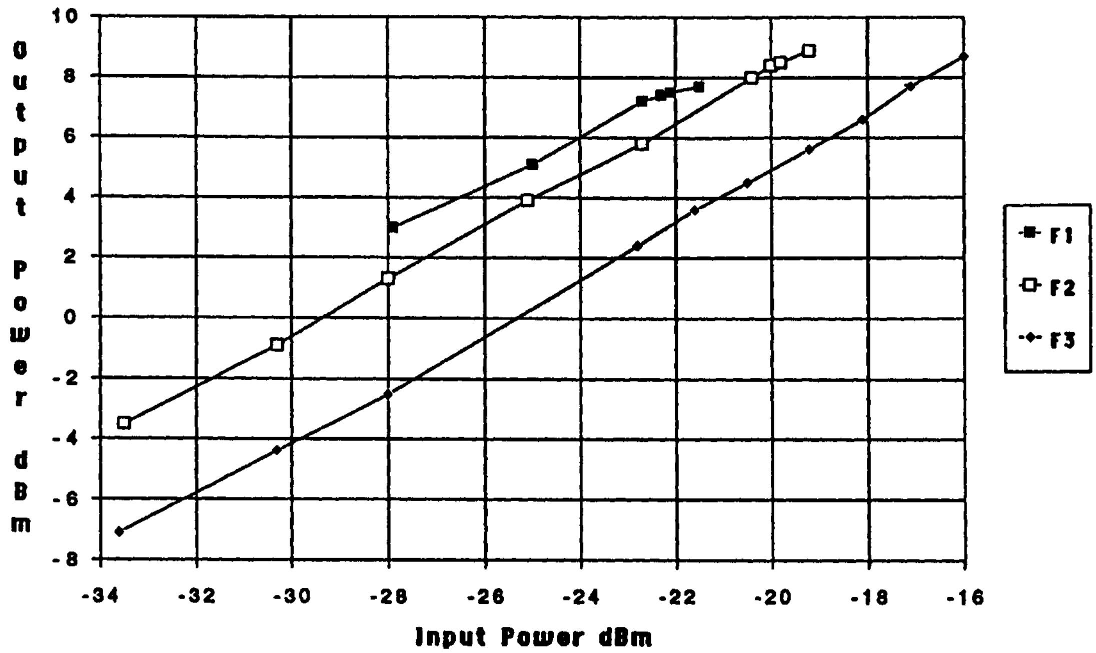

Figure 4: Output power vs. input power for U1 at $T = 20°K$ at three frequencies: F1=14.2 GHz, F2=14.75, F3=15.3 GHz. Corresponds to Series 2 and Table 4

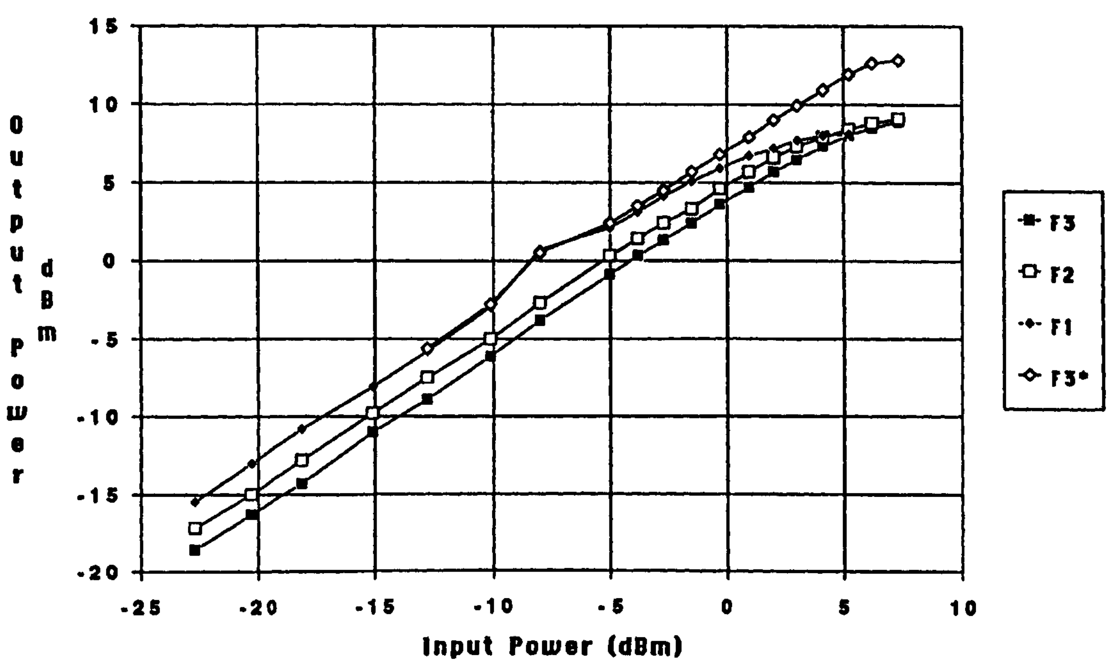

Figure 5: Output power vs. input power for U2 at $T = 297°K$ at three frequencies: F1=14.2 GHz, F2=14.75, F3=15.3 GHz. Both bias conditions for 14.2 GHz are shown. Corresponds to Series 3 and 4 and Table 5

	Freq.=14.2 GHz		Freq.=14.75 GHz		Freq.=15.3 GHz	
P_{in}	Gain(dB)	Gain(db)*	Gain(dB)	Gain(dB)*	Gain(dB)	Gain(dB)*
-42.7	34.2	31.7	30.1	29.8	28.8	28.5
-38.1	34.3	32.0	29.8	29.6	28.7	28.6
-35.1	33.9	32.1	29.8	29.7	28.6	28.5
-32.8	33.3	32.0	29.2	29.6	28.5	28.4
-30.1	33.3	32.0	29.8	29.5	28.6	28.5
-28.0	33.0	31.6	29.7	29.5	28.7	28.5
-25.0	31.6	30.6	29.4	29.1	28.3	28.2
-23.8	30.9		29.1	29.0	28.1	28.1
-22.7	30.3		28.8	28.9	27.9	28.0
-21.5	29.4		28.5	28.6	27.6	27.9
-20.3	28.3		28.3	28.4	27.4	27.7
-19.0			27.6	27.9	27.3	27.4
-18.0			27.1	27.5	27.2	27.4

Table 6: Gain vs. input power for amplifier U2 at $T = 17°K$ Column with * - V_d bias was increased to 3rd stage Corresponds to Series 5 and 6 and Figure 6

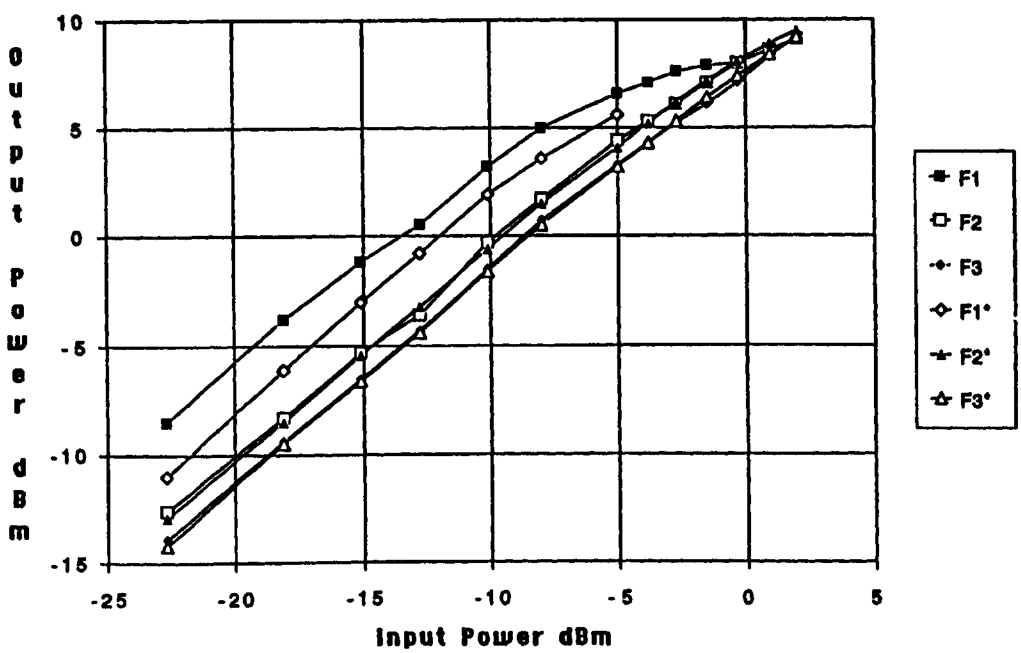

Figure 6: Output power vs. input power for U2 at $T = 17°K$ at three frequencies: F1=14.2 GHz, F2=14.75, F3=15.3 GHz. Corresponds to Series 5 and 6 and Table 6