A 0.5-50 GHZ ON-WAFER, INTERMODULATION, LOAD-PULL AND POWER MEASUREMENT SYSTEM

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ABSTRACT

A novel on-wafer, intermodulation, load-pull and power measurement system for characterizing devices and circuits for frequencies up to 50 GHz has been developed. The two-tone intermodulation measurement capabilities were added to an existing power and harmonic load-pull measurement system using the 50 GHz spectrum analyzer HP8565. Fundamental power levels and all measured intermodulation (IM) products are vector corrected to the probe tips of the DUT. A key feature of the described system are the vector corrected IM measurements and the capability to study the effects of load impedance on intermodulation.

INTRODUCTION

The successful development and design of low intermodulation distortion amplifiers require therefore the study of the origins of amplifier distortion with an appropriate measurement system [1]. Conventional intermodulation measurement systems use either a power meter or spectrum analyzer [2, 3] and have only scalar correction. In [4] a network analyzer is used to measure the load impedance at the output, while a spectrum analyzer measures the intermodulation products. We use the network analyzer for vector corrected measurements of power and reflection coefficients [5], which are used to correct the spectrum analyzer measurements of intermodulation distortion for higher measurement accuracy. The new system also allows to investigate the effect of fundamental and harmonic load impedances on intermodulation. Therefore, the trade-off between intermodulation and efficiency can be investigated.

We validated intermodulation measurements by comparing them to the intermodulation behavior expected from power-series analysis. IM measurements were performed at different fundamental frequencies with different frequency spacing. The mm-wave capabilities of the system are demonstrated by an intermodulation measurement performed at 38 GHz. In addition intermodulation measurements at 28 GHz at different load impedances were performed to generate an IM distortion contour plot.

MEASUREMENT SYSTEM

Figure 1 depicts the block diagram of the two-tone intermodulation measurement system implemented in the load-pull system [5]. A network analyzer measures the vector corrected input and output power levels at the two excitation frequencies. Sampler a_1 of the 50 GHz four-channel frequency converter is used for constant phase lock, while sampler a_2 measures both a_1 and a_2 power using a PIN switch.

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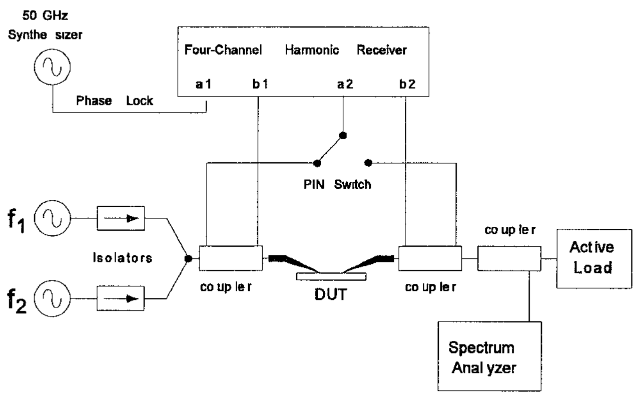

Fig. 1: Block diagram of the intermodulation measurement system.

The two synthesizers, each followed by an isolator, generate the two excitation frequencies and were controlled separately to guarantee the same input power levels at the device terminals during IM measurements. To measure the intermodulation products with the 50 GHz spectrum analyzer, the software was developed for highest dynamic range and lowest intermodulation products generated by the instrument itself [6, 7]. To improve measurement accuracy and speed, the frequency span is set to 1 kHz and averaging capabilities are used if necessary. The active load at the output of the measurement system is used to study the effects of the load impedance on intermodulation distortion.

The vector calibration procedure of. the load-pull measurement system was enhanced to allow the calibration in multi frequency segments, along with a standard broad band calibration, to cover the frequency points of interest for the IM measurements. The fundamental output power levels are measured with the spectrum analyzer and the network analyzer. A key feature of our measurement system is the vector correction of the intermodulation products to the probe tip of the DUT.

MEASUREMENT RESULTS

Intermodulation measurements are shown in figures 2 to 5 for PHEMT MMIC amplifiers measured at different fundamental frequencies using different frequency spacings. The broad band 0.25 μm PHEMT amplifiers are a 2 to 50 GHz traveling wave amplifier (HMMC-5040) and a 20 to 40 GHz four stage medium power amplifier (HMMC-5025) [8].

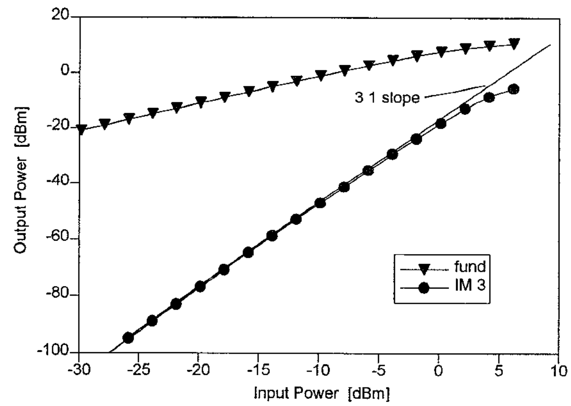

Fig. 2: Third order IM measurement of 2 to 50 GHz PHEMT TWA at 5 GHz, with 10 MHz frequency separation.

Figure 2 and 3 show intermodulation measurements with tones 10 MHz and 1 MHz apart. Both measurements are at a fundamental frequency of 5 GHz for a 2 to 50 GHz TWA. In the described measurements this load impedance was set to 50 Ω.

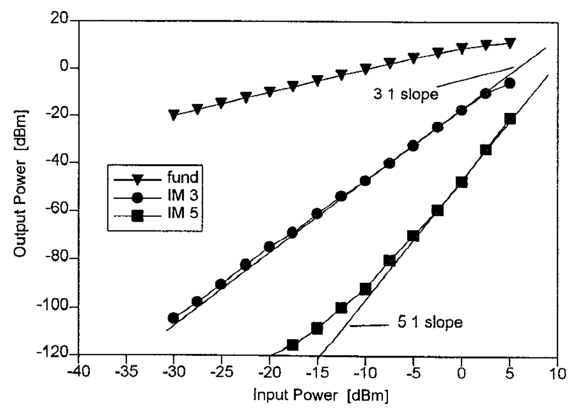

Fig. 3 IM measurement up to the fifth order for a 2 to 50 GHz TWA at 5 GHz, with 1 MHz frequency separation.

The third-order IM products are independent of their frequency spacing. It is also clearly observed that the third- and fifth-order IM products vary by 3 dB and 5 dB, respectively, with 1 dB input power level variation, as expected from power-series analysis [9].

An intermodulation measurement at 20 GHz for a 20 to 40 GHz four stage PHEMT amplifier, with tones 10 MHz apart, is shown in figure 4.

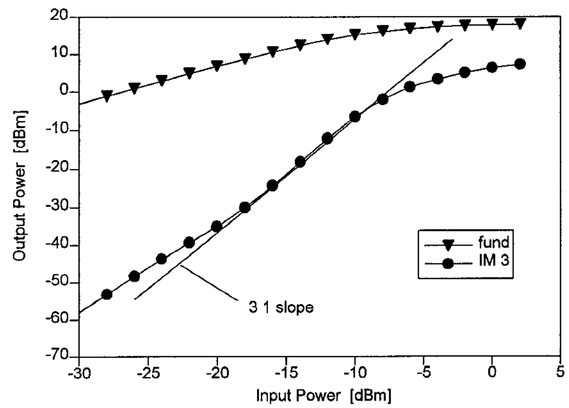

Fig. 4: IM measurement for a 20 to 40 GHz four stage PHEMT amplifier at 20 GHz, with 10 MHz frequency separation (no isolators).

The IM products measured at lower input power levels (< -17 dBm) are affected by the poor isolation between the two signal sources, because no isolators were used for the measurement. However, the expected 3:1 slope in the third-order IM product is observed at higher input power levels.

To demonstrate the mm-wave capabilities of our system an intermodulation measurement at 38 GHz was performed for the 20 to 40 GHz four stage PHEMT amplifier as shown in Figure 5.

The expected 3 dB/dB variation of the third-order IM products is observed at higher input power levels. For this IM measurement once again no isolators are used at the input side.

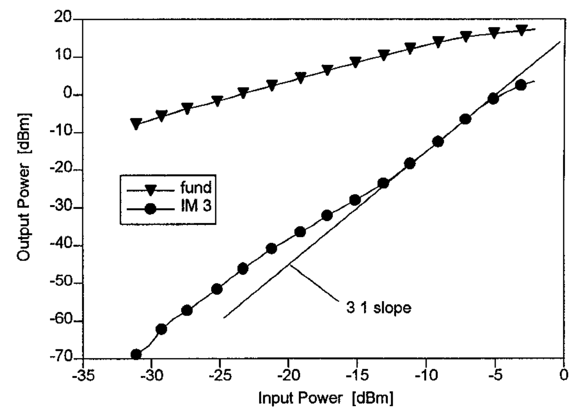

Fig. 5: IM measurement for a 20 to 40 GHz four stage PHEMT amplifier at 38 GHz, with 10 MHz frequency separation (no isolators).

Finally we used the measurement system to perform IM measurements versus load impedance at a fundamental frequency of 28 GHz with a frequency spacing of 1 MHz. Figure 6 depicts the polar chart with the IM distortion contours in the complex load impedance plane Γ_L for a 8x30 μm^2 MODFET (Bias: Vgs=-0.8 V, Vds=5.0 V, Ids= 183 mA/mm). The input power level was set to P_{in}= 8 dBm.

The Third Order Intercept (TOI) points

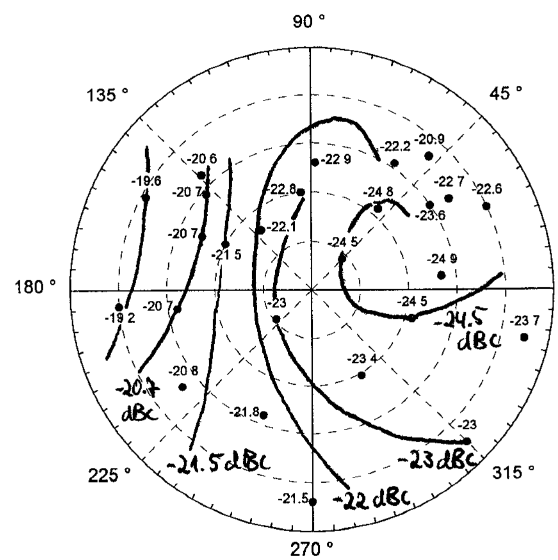

Fig. 6: IM distortion contours of a 6x30 μm^2 MODFET at 28 GHz, with 1 MHz frequency separation (input power= 8 dBm, no isolators used)

were extrapolated from the intermodulation measurements. These TOI values were compared in Table 1 with a rule of thumb known from the literature [10]. This rule of thumb says that the TOI point is approximately the output power at the 1 dB gain compression under single tone excitation plus 9.65 dBm. Table 1 shows that the rule of thumb is accurate to 3 dB for the PHEMT MMIC amplifiers measured in this study.

DUT	f [GHz]	G_0 [dB]	P_{-1dB} [dBm]	TOI [dBm]	TOI rule of thumb
2 to 50 GHz TWA	5	10.2	13.0	23.9	22.6
6x30 μm^2 MODFET	28	9.68	17.2	26	26.9
20 to 40 GHz 4-stage amplifier	20	26.9	19.2	28.2	28.9
	38	23.6	20.4	27.0	30.0

Tab. 1: Comparison of measured and calculated TOI points using the rule of thumb.

CONCLUSION

A novel intermodulation measurement system for frequencies up to 50 GHz is presented. The two-tone intermodulation capabilities were implemented in a present power and load-pull measurement system, which allows for accurate, vector corrected intermodulation measurements. The intermodulation measurements showed the expected behavior from power-series analysis and were demonstrated up to 38 GHz. The active load at the output of the system can be used to study the effects of load impedance on intermodulation.

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