

Microwave Amplifier Figure of Merit Measurement

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In this paper, the figure of merit of microwave amplifiers is measured. They are gain, 1 dB compression point and two tone third-order intercept products. The measurement setup as well as the method of measurement are shown. The measured amplifier can be used for student laboratory exercise as well as for appropriate scientific research.

Keywords: microwave amplifier, figure of merit, gain, third-order intercept point, 1db compression point

1. INTRODUCTION

THE AMPLIFIER is a device commonly used in radiofrequency technologies such as transmitter (Fig.1), as a final stage before transmitting the modulated signal.

The amplifier chain consists of cascaded gain stages with power gains in the range of 6 to 20 dB [1].

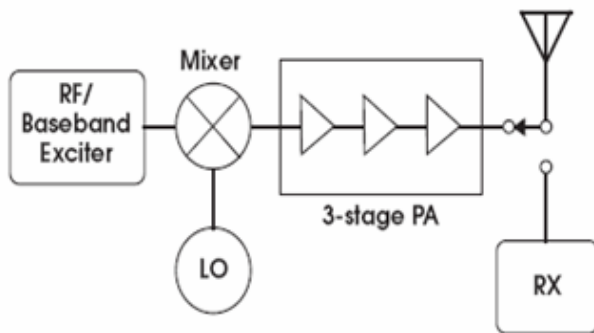


Fig.1 Amplifier commonly used in transmitter.

Radio frequency power amplifiers utilize a wide variety of active devices, including bipolar-junction transistors (BJTs), MOSFETs, JFETs (SITs), GaAs MESFETs, HEMTs, pHEMTs, and vacuum tubes.



Fig.2 Amplifier under test.

Amplifiers can operate in classes A, B, AB, C, D, E and F [2]. We tested class A amplifier made by „Microwave Power Devices“, Model: LWA 4690-1/1837, based on bipolar devices (Fig.2). Usually, 1dB compression point, gain and two-tone third-order intercept point are measured as the amplifier figure of merit. As specified by manufacturer, the frequency range of the amplifier is from 100 MHz to 900 MHz.

2. THEORY & MEASUREMENT SETUP

In the measurement procedure, the most common parameters, which are stated above, were measured. For the measurements we used HP 8657A Signal generator (0.1-1040 MHz), HP 8640B Signal generator (0.5-1024 MHz), HP 11667A Power splitter (DC-18 GHz) and Anritsu MS 2661C Spectrum Analyzer (9 kHz – 18 GHz).

Gain (forward gain, G). In low-frequency circuits, gain is often thought of in terms of voltage or current gain, such as the ratio of the output voltage across the load to the input applied voltage [4]. At operating frequencies of the measured amplifier it is difficult to directly measure a voltage, so we used a form of power gain. Once the notion of power gain is introduced, there are several definitions of power gain that might be used:

- [1] *Available gain* is the ratio of the amplifier output power to the available power from the generator source. This definition depends on Z_G but is independent of Z_L .
- [2] *Power gain*. This is the ratio of the power dissipated in the load, Z_L , to the power delivered to the input of the amplifier. This definition is independent of the generator impedance, Z_G . Certain amplifiers, especially negative resistance amplifiers, are strongly dependent on Z_G .
- [3] *Exchangeable gain*. This is the ratio of the output exchangeable power to the input exchangeable power. The exchangeable power of the source is defined as (1). For negative resistance amplifiers $P < 0$! Furthermore, this definition is independent of Z_L .

$$P = \frac{|V|^2}{4R\{Z_G\}}, R\{Z_G\} \neq 0 \quad (1)$$

- [4] *Insertion gain*. This is the ratio of the output power to the power that would be dissipated in the load if the

amplifier were not present. There is a problem in applying this definition to mixers or parametric upconverters where the input and output frequencies differ.

- [5] *Transducer power gain.* This is the ratio of the power delivered to the load to the available power from the source. This definition depends on both Z_G and Z_L . It gives positive gain for negative resistance amplifiers as well. Since the characteristics of real amplifiers change when either the load or generator impedance are changed, it is desirable that the gain definition reflects this characteristic. Thus the transducer power gain definition is found to be most useful [4].

The measured power gain is specified in the small signal, linear gain region. The setup for the gain measurement is shown in Fig.3.



Fig.3 Gain and 1 dB compression point measurement setup.

The idea of gain measurement is to measure output power (P_{out}) for known input power (P_{in}). The input power is the power displayed on signal generator minus loss in the cable. The output power is the power measured on the spectrum analyzer plus loss in the cable. Cable loss (P_L) is measured by directly connecting signal generator and spectrum analyzer by the cable. Then, if we assume that the losses in spectrum analyzer and signal generator are negligible, the difference between the power measured on spectrum analyzer and the power displayed on signal generator is cable loss. The gain is then defined as (2).

$$G = 10 \log \frac{P_{out} + P_L}{P_{in} - P_L} \quad (2)$$

The **two-tone third-order** intercept point must be measured if we want to know how the amplifier responds to modulated signals. The presence of two or more tones in a non-linear device generates intermodulation products. These products are the sum and difference of multiples of the fundamental tones. Equation (3) shows the series expansion of multiplying two monotonics f_1 and f_2 . The order is characterized by the sum of the fundamental factors [5].

$$\begin{aligned} P_{out} &= a_1 f_1 + a_2 f_2 + && \leftarrow \text{Fundamentals} \\ &+ a_3 (f_1 \pm f_2) + && \leftarrow 2^{nd} \text{ Order Products} \\ &+ a_4 (f_1 \pm 2f_2) + a_5 (2f_1 \pm f_2) + && \leftarrow 3^{rd} \text{ Order Products} \\ &+ a_6 (2f_1 \pm 2f_2) + && \leftarrow 4^{th} \text{ Order Products} \\ &+ \dots + a_\infty (\infty f_1 \pm \infty f_2) && \leftarrow \text{etc.} \end{aligned} \quad (3)$$

As we can see (3), if f_1 and f_2 are the frequencies of the two signals arriving at the input, the amplifier generates inter-modulation products at its output due to inherent nonlinearity, in the form:

$$\pm m a_x f_1 \pm n a_y f_2 \quad (4)$$

Here m and n are positive integers, which can assume any value from 1 to infinity. The order of the inter-modulation is defined as $m + n$. Accordingly, $2xf_1 - f_2$, $2xf_2 - f_1$, $3xf_1$ and $3xf_2$ are third-order products by definition. The first two products are called two-tone third-order products as they are generated when two tones are applied simultaneously at the input. Two-tone third-order products are very close to the desired signals and are very difficult to filter out. In the linear region, third-order products decrease/increase by 3 dB for every 1 dB decrease/increase of input power, and output signal power decreases/increases by a dB for every dB of input power (Fig.4) [6]. Output intercept point, IP3 (dBm) can also be calculated using (5).

$$IP3(dBm)_{out} = P_{out}(dBm) + \frac{A}{2} \quad (5)$$

Where P_{out} (dBm) is the output power of each tone in dBm and A is the difference of output power and intermodulation level in dB. Input intercept point is obtained by substituting P_{in} (dBm) for P_{out} (dBm) in the above equation.

As we stated above, many of the spurious tones are out-band and they cause no problem. The third-order difference tones are closest to the fundamentals. They very likely fall in-band and add non-linearity and distortion to the output. Fig.5 illustrates intermodulation products and their relative frequency.

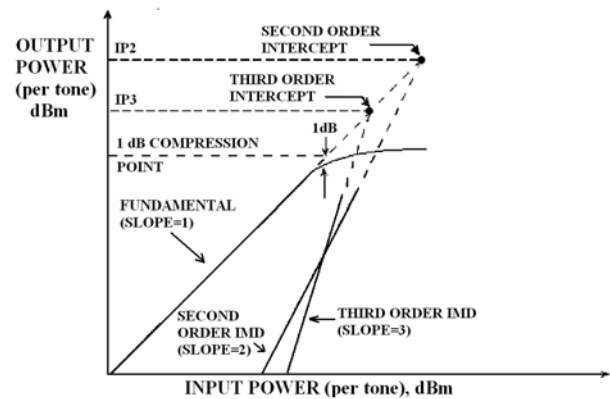


Fig.4 Definition of Intercept Points and 1-dB Compression Points for Amplifiers.

Intermodulation products increase at rates that are multiples of the fundamentals. If not for the output power saturating limit, intermodulation products would overtake the fundamentals, as shown in Fig.4. IP3 is the point where 3rd-order products would overtake fundamentals in output power [5].

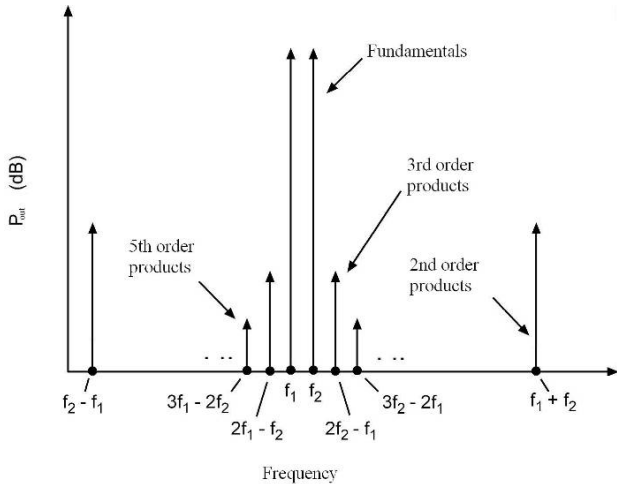


Fig.5 Intermodulation products and their relative frequency.

The measurement of the third-order products was made by using measurement setup displayed in Fig.6.

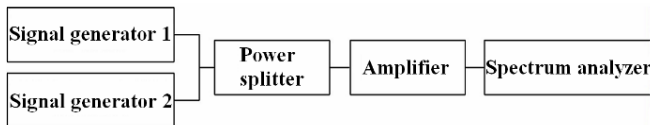


Fig.6 Third-order intercept point measurement setup.

IP3 can be determined by applying 2 equal power monotonies and measuring a fundamental power and a 3rd-order power (either 2f₂-f₁ or 2f₁-f₂) at the output. Then apply these measured values to (6).

$$IP3 = \frac{3}{2} P_{1st} - \frac{1}{2} P_{3rd} \quad (6)$$

As always, it is important to ensure that unwanted spurious harmonics do not land on the 3rd-order or fundamental frequencies. Also, the measurements should be made in a region clear of output compression. Fig.7 shows a typical measurement of the third-order intercept point.

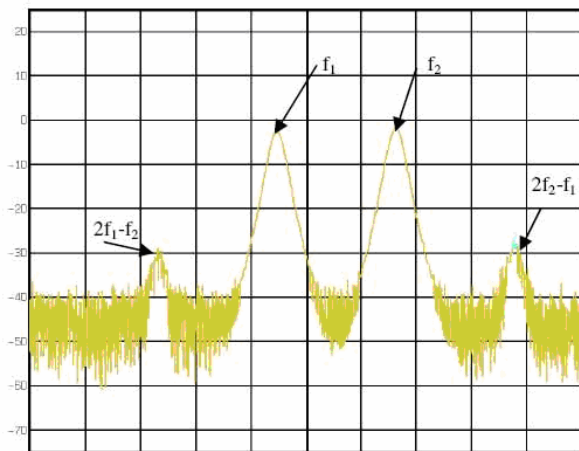


Fig.7 Typical measurement of the third-order intercept point.

The **1 dB compression point** of an amplifier is the input power required to reduce the gain to 1 dB below its small-signal value. This value can be measured by supplying a constant-frequency, ramped-power input signal to the amplifier and measuring the output power as a function of available input power. We used the spectrum analyzer as a calibrated, tuned power meter (Fig.3). The signal source was set at frequency of 500 MHz and the power level at -20 dBm. Next, the spectrum analyzer's reference level was 30 dB to protect the input from excessive power. In 1 dB steps, we increased the signal generator power, and measured the output power as shown on the spectrum analyzer. We assumed that the loss in the adapter is negligible compared to the loss in the cables, and that the loss in each cable is the same.

3. RESULTS

We measured the gain for Pin power levels of -30dBm (1 μW) and -5 dBm (0.32 mW) for frequency range from 100 MHz up to 1100 MHz in steps of 10 MHz. Figure 8 shows the results of gain measurement for input power level of -30dBm. Fig.9 shows the result of gain measurement for input power level of -5dBm.

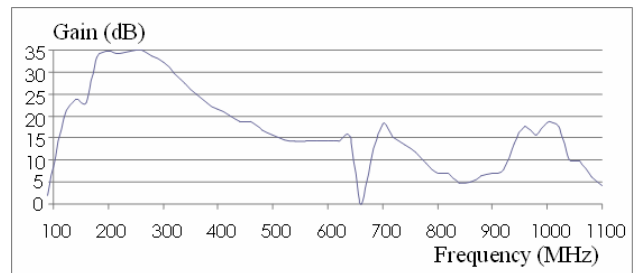


Fig.8 Gain measurement result for input power level of -30 dBm.

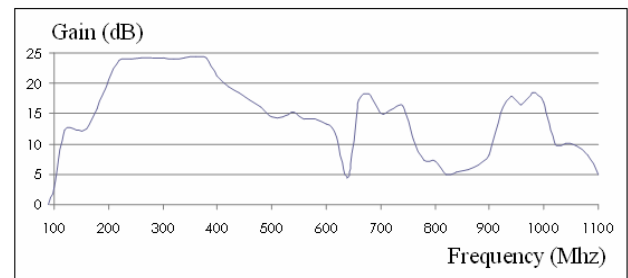


Fig.9 Gain measurement result for input power level of -5 dBm.

For the **third-order intercept point measurement**, the frequencies were set to be 699.9 MHz and 700.1 MHz, and the power level of both sources to -20 dBm. The spectrum analyzer was set to a center frequency of 700 MHz and a span of 600 kHz to include the signals and the responses induced by circuit non-linearities.

For input powers from -20 dBm to -8 dBm in 1 dBm steps, we found the output power as well as the intermodulation products. The two-tone, third-order intercept point (IP3) was gained by interpolation, and the result is shown in the Fig.10. It is at app 3 dBm of input power (8 dBm output power).

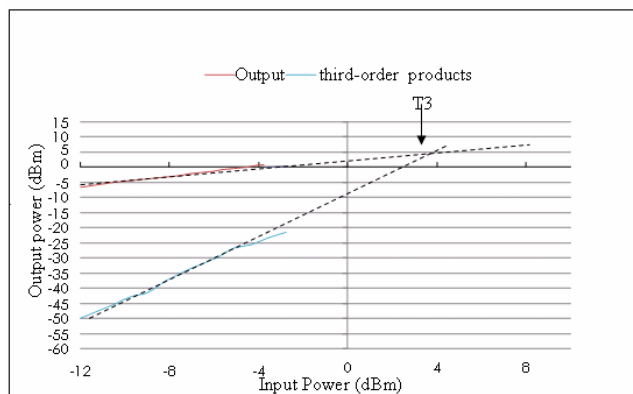


Fig.10 Third-order intercept point.

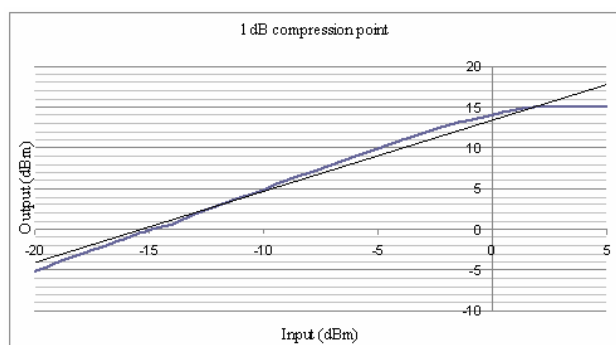


Fig.11 The 1 dB compression point.

For frequency of 500 MHz we had measured gain and increasing input power level as described above. This kind of measurement had given us **1 dB compression point**. Fig.11 shows measurement result for 1 dB compression point.

4. CONCLUSIONS

The measured gain is from 25 (large input signal) to 35 dB (small input signal) in the frequency range from 200 - 400 MHz, and much less at the upper frequencies as shown on Fig.8 and Fig.9. As we can see, the gain characteristic is linear in the frequency range from 200 – 400 MHz while in other displayed frequency range shows high non-linearity. That kind of gain is not appropriate for frequencies that are not in a range from 200 MHz to 400 MHz because of high non-

linearities that could be generated with use out of that frequency range.

In our case, the gain also depends on the input power level, although not considerably.

The **third-order intercept point** is gained by interpolation from the lower power levels. It is approximately at 3 dBm of the input power level (8 dBm output power). This is in a normal range for a class A power amplifiers (Fig.10).

The tested amplifier showed that the **1 dB compression point** appears at the 0 dBm of input power at 500 MHz. The gain is 14 dB, which is 1 dB less than that for a small signal input. This gives us the maximum input power level that we should append to the input to avoid distortion (0 dBm).

The tested amplifier is ideal for laboratory exercises and scientific experiments and should be used in a frequency range stated above. In the recommended range it should be used for frequency and phase modulated signals amplification because the amplifier shows certain gain dependence of the input power level.

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