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Measurement and simulation of non-linear microwave amplifiers operating in digital transmission systems

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Abstract

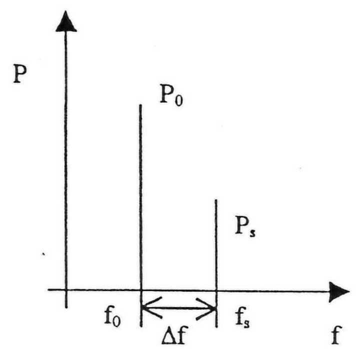
The objective of this work is the measurement and simulation of microwave amplifiers of high-speed digital transmission systems, in the non-linear region. Data characterizing the non-linearity of microwave amplifier devices are most important parameters in both in case of Subcarrier Multiplexed Optical transmission systems and of radio links operating in GHz region. The goal of this analysation is the detailed disclosure of the effects of amplifiers characterized by the AM-compression and AM-to-PM conversion on the quality of the digital transmission (BER, EVM).

Introduction

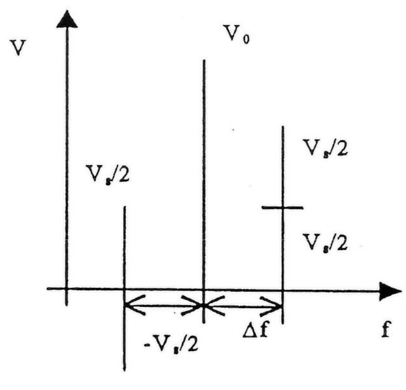
In the case of microwave-optical transmission systems the non-linear behavior of the optical sources and receivers has a deep influence on the quality of the signal. There are several possibilities to test the non-linearity of two port circuits. The large signal behavior of microwave amplifiers can be generally characterised by the 1-dB Compression Point and by the Third Order Intercept Point. In addition, the non-linearity can be tested utilising the spectrum measurement method. It applies two input signals, one of them is much smaller than the other one. The high power large signal is used to drive the circuit into the non-linear regime and the small signal is used to get information about the non-linearity.

AM Compression and AM-PM conversion

The small signal can be considered as a sideband of the large signal. The large signal has a power of P_0 and frequency f_0 , while the small signals power is P_s and its frequency is f_s. The frequency difference between them is $\Delta f=f_s-f_0$, Figure 1.



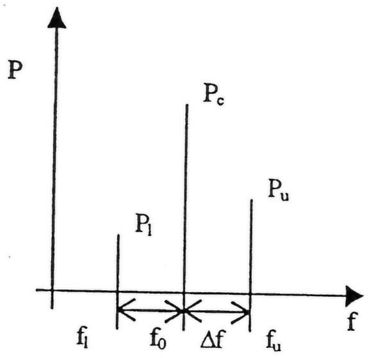
1. Figure: Input signals



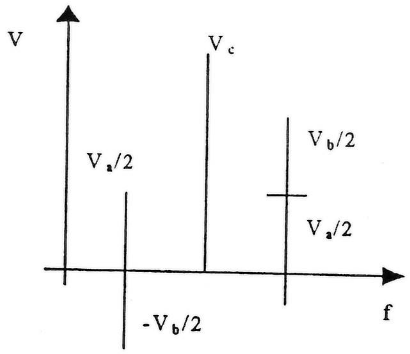
2. Figure: AM and PM at the input

The voltage signals are shown in Figure 2. The large signal is represented by the vector V_0 rotating with an angular frequency ω_0.

The small signal is superimposed on the large signal and is represented by the vector V_s rotating around the end of vector V_0 with the difference angular frequency $\Delta\omega$.
The rotating V_s vector represents both amplitude and phase modulations. It is assumed that there are $V_s/2$ and $-V_s/2$ voltage amplitudes at the other sideband. This way both amplitude modulation (AM) and phase modulation (PM) are encountered.
Due to the non-linear transfer of the two port circuit the input signal will be distorted during the transmission and three signals will appear at the output as shown in Figure 3.



3. Figure: Output signals



4. Figure: AM and PM at the output

The lower sideband with a power of P_l can also be observed beside the large signal with a power of P_c and the upper sideband signal with a power of P_u. That means a change both in the amplitude modulation and in the phase modulation. The voltage amplitudes at the output are presented in Figure 4., where V_a is the magnitude of the amplitude modulation and V_b is the magnitude of the phase modulation. Based on the before going the time function of the input signal is:

$$V_{in}(t) = \mathrm{Re}\left\{V_0 e^{j\omega_0 t} + \frac{1}{2}V_s\left[e^{j(\omega_0+\Delta\omega)t} + e^{j(\omega_0-\Delta\omega t)}\right] + \frac{1}{2}V_s\left[e^{j(\omega_0+\Delta\omega)t} - e^{j(\omega_0-\Delta\omega)t}\right]\right\}$$

In this equation the first term represents the large signal, the second term is the amplitude modulation and the third term gives the value of the phase modulation. The amplification of the two port circuit is A. Due to the non-linear transfer both the amplitude and the phase modulation are changed. The time function of the output signal is:

$$V_{out}(t) = \mathrm{Re}\left\{V_c e^{j\omega_0 t} + \frac{1}{2}V_a\left[e^{j(\omega_0+\Delta\omega)t} + e^{j(\omega_0-\Delta\omega t)}\right] + \frac{1}{2}V_b\left[e^{j(\omega_0+\Delta\omega)t} - e^{j(\omega_0-\Delta\omega)t}\right]\right\}$$

V_c is the amplitude of the large signal, V_a is the amplitude of the AM, and V_b is the amplitude of the PM at the output. Using the spectrum method the powers of the signals are measured related to the large signal power. If the reference characteristic impedance is the same for every signals the voltages can be used.
The AM compression as a result of the degradation of the transfer at large signals is the ratio of the input and output amplitude modulation depth, so it can be used to characterise the non-linear behaviour of the circuit.

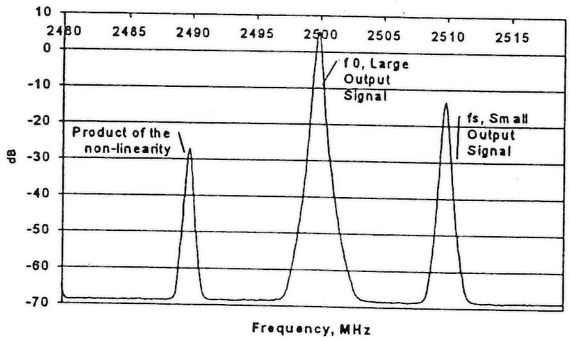
$$cp = \frac{m_{AM}^{(in)}}{m_{AM}^{(out)}}$$

The modulation depth at the input and at the output:

$$m_{AM}^{(in)} = \frac{V_s}{\cdot\cdot} \qquad m_{AM}^{(out)} = \frac{V_a}{\cdot\cdot} = \frac{V_u}{\cdot\cdot} + \frac{V_l}{\cdot\cdot}$$

In the practice this phenomenon had been investigated by measurements both on a distributed amplifier operating in an optical receiver and in case of power amplifiers usable in optical-wireless transmission links. Let us see the AM-compression, investigated in the case of a 1-7GHz distributed amplifier

with a 1dB- compression point at 3dBm input power.
This measurement is illustrated in Figure 5., the two higher signals are the input signals modified by the system, and the third is the product of the non-linearity. Measuring the power of the two sideband signals related to the large signal power, made us able to calculate the output modulation depth. In the case of our distributed amplifier this AM compression at 6dBm input power was 1.408dB, so the modulation depth at the output is smaller than the one at the input.



5. Figure: AM compression at the output

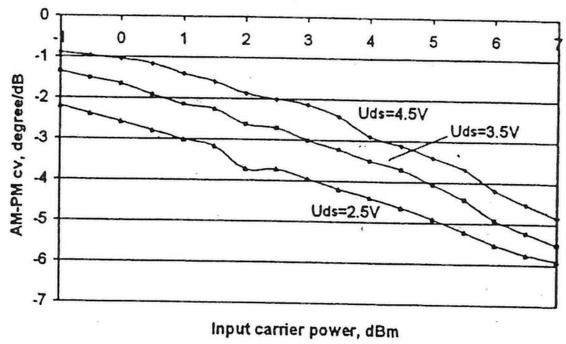
There is another measure to characterise the non-linearity, the AM-PM conversion. This effect is encountered when the reactances or susceptances in the two port circuit are dependent on the drive power. The AM-PM conversion is defined as the additional phase shift - in degree - caused by 1dB change in the input power. With the spectrum method the AM-PM conversion can also be determined by using the same measurement results. The phase shift at the output is:

$$\mathrm{tg}\,\varphi = \frac{V_b}{V_c} \qquad \varphi \cong \frac{V_b}{V_c} = \frac{V_u}{V_c} - \frac{V_l}{V_c}$$

For small φ values: tanφ ≅φ.
According to the definition the input signal has to be increased by 1dB, in our case V_s=0.12V_0. For V_s=0.12V_0, the phase deviation is 0.12 rad or 6.88° at the input. When the 1 dB amplitude change is kept, the additional phase shift is called AM-PM conversion and described by the following expression:

$$cv = \frac{180}{3.14}\left(\frac{V_u}{V_c} - \frac{V_l}{V_c}\right) - 6.88\left[{}^{\circ}\!/_{dB}\right]$$

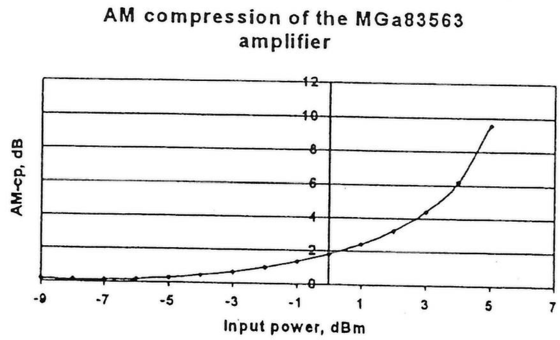
The AM-PM conversion was measured on the microwave distributed amplifier at different input power with variable biasing, Figure 6.



6. Figure: AM-PM conversion at different biasing

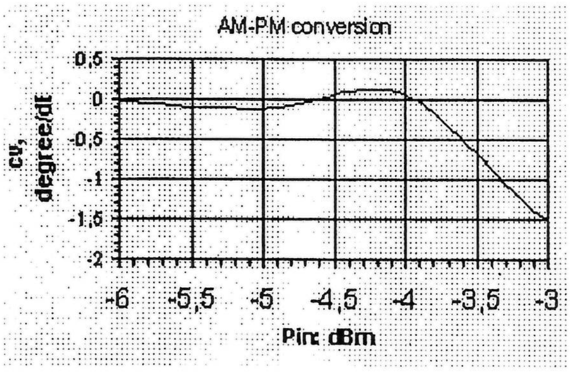
Power amplifiers in optical-wireless digital transmission systems

The non-linear behavior is in case of power amplifiers more remarkable than in case of broadband amplifiers. The AM-compression and the AM-PM-conversion was measured on a MGa83563 power amplifier. Figure 7. shows the results of the measurements.

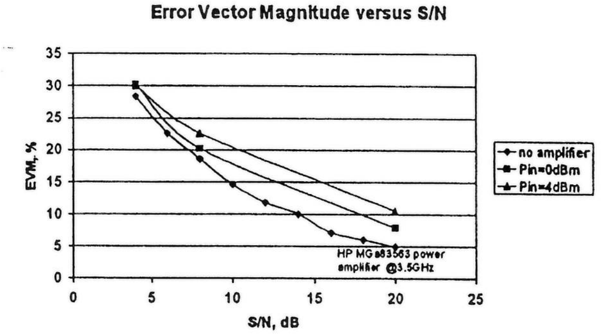


7. Figure: AM-compression of a power amplifier

Figure 8.shows the AM-to-PM conversion of the amplifier.

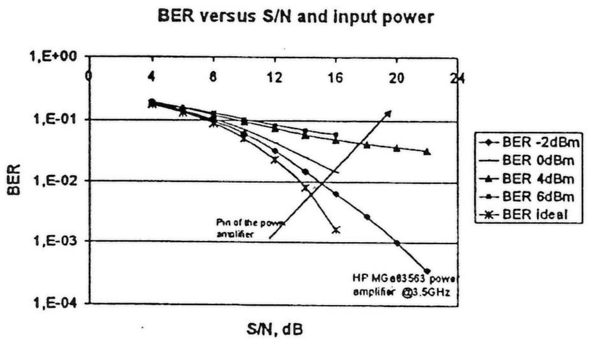


8. Figure:AM-PM conversion of Mga83563



10. Figure: EVM versus S/N

Using this kind of power amplifiers in an digital transmission, we have to investigate the result of the distortions to the chosen modulation. In case of 16QAM modulation the Bit Error Ratio was simulated in an optical-wireless digital transmission link. Bit Error ratios for various input power of the amplifier are depicted in Figure 9.



9. Figure: BER using power amplifier

Increasing the input power the amplifier behavior will be more and more non-linear and in case of large input powers the information transmission is not possible anymore.

There is another option to characterize the results of the non-linearity in the system. The EVM versus signal to noise ratio are shown in Figure 10.

In case of optical subcarrier multiplexed transmission due to the large number of subcarriers, analyzation of the non-linearity and the connection between the distortion results and the data characterizing the non-linearity is mostly important.

In this paper the effects of the amplifiers characterized by AM-compression and AM-to-PM-conversion to the quality of the transmission was investigated. The broadband amplifiers operating in optical receivers and power amplifiers operating in optical-microwave networks were involved to the analysation.

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