2 Nonlinear distortions

In a perfect world, communication would be transfer of information across a given medium without any loss or interference to other users. In reality, the communication channels add unwanted signals to the desired information. These signals include random noise and distortion. Random noise is not correlated with the information, whereas distortion generation is a strong function of the information carrying signal [5]. Distortion can be generated from any part of the communication subsystem e.g., circuit components or from the medium. These subsystems include antennas, amplifiers, mixers, digital-to-analog and analog-to-digital converters. The amplifying device is the heart of electrical communication system. These active devices or amplifiers are usually quasi nonlinear to strongly nonlinear. Distortion generated as a result of the nonlinear characteristics of active devices is the scope of this chapter.

This chapter reviews the relevant results and theories related to the distortions in amplifying devices, especially HEMTs, which were important in the development of this thesis.

2.1 Linearity figure of merit for active devices

Usually the following terms are commonly used as figure of merit for linearity of amplifiers or amplifying devices.

- Gain compression/$P_{-1\ dB}$ point
- Harmonic distortion
- Phase distortion
- Intermodulation distortion

- IP3 /TOI (Third Order Intercept Point).
- ACPR (Adjacent Channel Power Ratio)/ Spectral regrowth.
- EVM (Error Vector Magnitude).

Actually, they are related to each other and will be clarified in the following sections.

2.2 Distortions in amplifying devices

Active devices such as transistors are usually used to amplify electrical signal. In a perfect linear system these devices would amplify the signal with a constant gain up to infinite input power. In reality these devices have a transfer characteristic as shown in fig. 2.1 in comparison to perfect linear amplifier.

As pointed in the figure, gain drops after a certain input or output power. When the gain is 1 dB less than the linear gain the corresponding output power is called P_{-1dB}. In ideal case the output power is considered only at one frequency which is the input signal frequency. Due to the nonlinearity, the amplifier generates additional frequency components at the multiples of this signal frequency are called harmonic distortion.

The input vs. output curve can be expressed by Taylor series as shown in eq. 2.1.

$$V_{out} = a_0 + a_1.V_{in} + a_2.V_{in}^{\ 2} + a_3.V_{in}^{\ 3} + ...a_n.V_{in}^{\ n} + ... \tag{2.1}$$

Let us consider an RF amplifier amplifying a pure sine wave ($x = A \sin \omega_1 t$). The output signal consists of the amplified signal and higher harmonics. The nearest harmonic product occurs at the double of the signal frequency and thus can be filtered out easily.

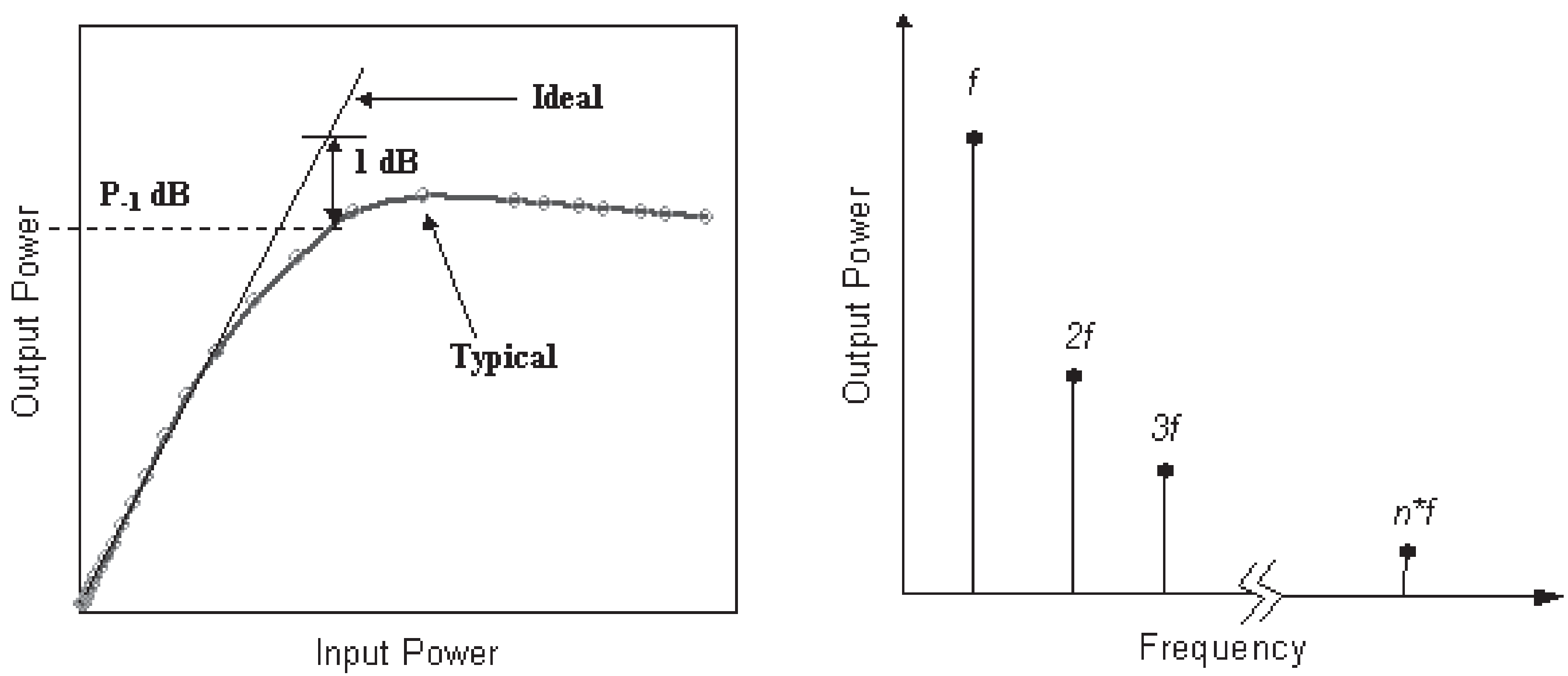

Figure 2.1 Input vs. output curve of a typical non-linear device and corresponding frequency spectrum for monochromatic input signal.

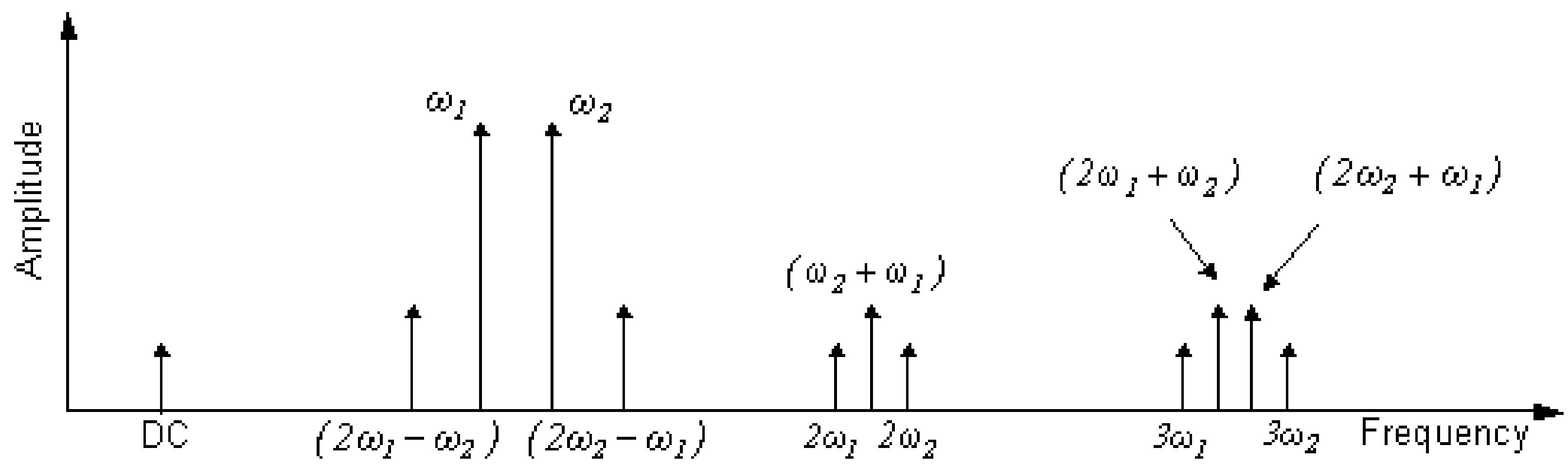

Figure 2.2 The output spectrum of a device excited with a two-tone signal (up to third order mixed products i.e., $n \leq 3$).

TABLE 2.1

LIST OF THE OUTPUT FREQUENCY COMPONENTS OF A NONLINEAR SYSTEM EXCITED BY A TWO-TONE SIGNAL (N≤3)

Frequency Components	Magnitude	Phase
dc	$a_0 + a_1 \;.A^2$	…
ω_1, ω_2	$a_1 A + \frac{9}{4} a_3 \;.A^3$	*Sin*
$2\omega_1, 2\omega_2$	$\frac{1}{2} a_2 \;.A^2$	*-Cos*
$3\omega_1, 3\omega_2$	$\frac{1}{4} a_3 \;.A^3$	*-Sin*
$(\omega_1 + \omega_2), (\omega_2 - \omega_1)$	$a_2 \;.A^2$	*-Cos, Cos*
$(2\omega_1 + \omega_2), (2\omega_2 + \omega_1)$	$\frac{3}{4} a_3 \;.A^3$	*-Sin*
$(2\omega_1 - \omega_2)$	$\frac{3}{4} a_3 \;.A^3$	"*Sin*" if , $\omega_1 > \omega_2$ Otherwise "*–Sin*"
$(\omega_1 + 2\omega_2), (\omega_1 - 2\omega_2)$	$\frac{3}{4} a_3 \;.A^3$	"*Sin*" if, $\omega_2 > \omega_1$ Otherwise "*–Sin*"

* *The phase of a term is defined by its behavior at t=0.*

For a modulated signal, however, this does not work anymore because mixing products are generated which fall in the signal band and it is impossible to filter them out. These mixing products are called intermodulation distortion products. The simplest modulated signal is a two-tone signal ($x = A_1 \sin\omega_1 t + A_2 \sin\omega_2 t$), where ω_1 and ω_2 correspond to two closely spaced frequency components, which is similar to an amplitude-modulated signal.