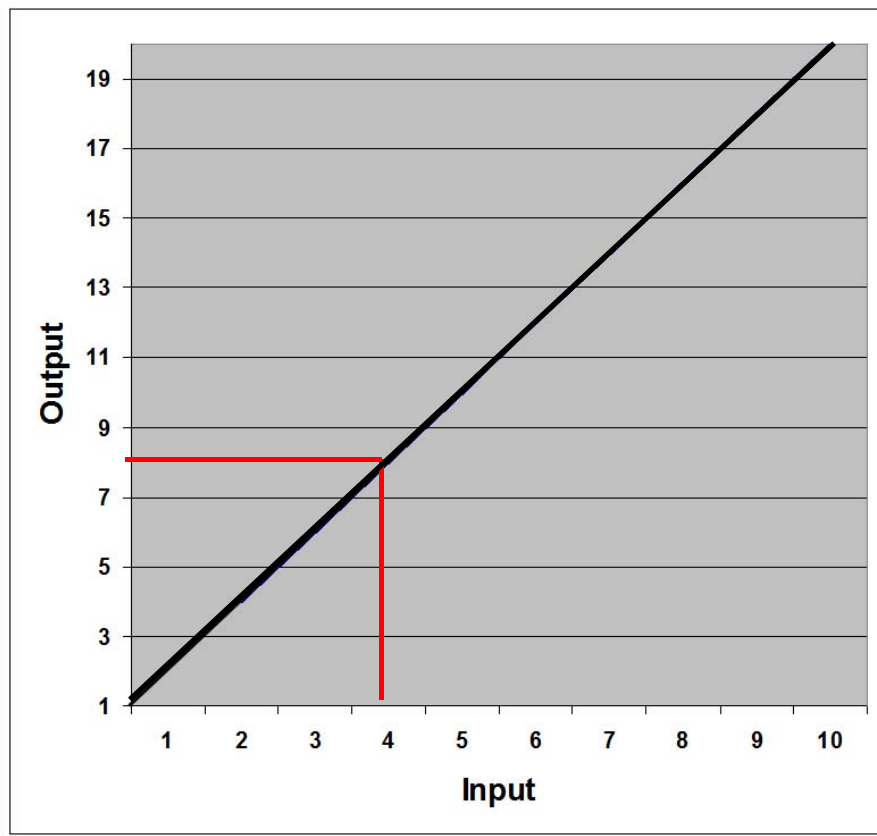

Ricevitore e componenti non lineari

Pierfrancesco Lombardo

Linear Gain

$$S_1(t) \longrightarrow y_1(t)$$
$$S_2(t) \longrightarrow y_2(t)$$

$$a_1 S_1(t) + a_2 S_2(t) \longrightarrow a_1 y_1(t) + a_2 y_2(t)$$

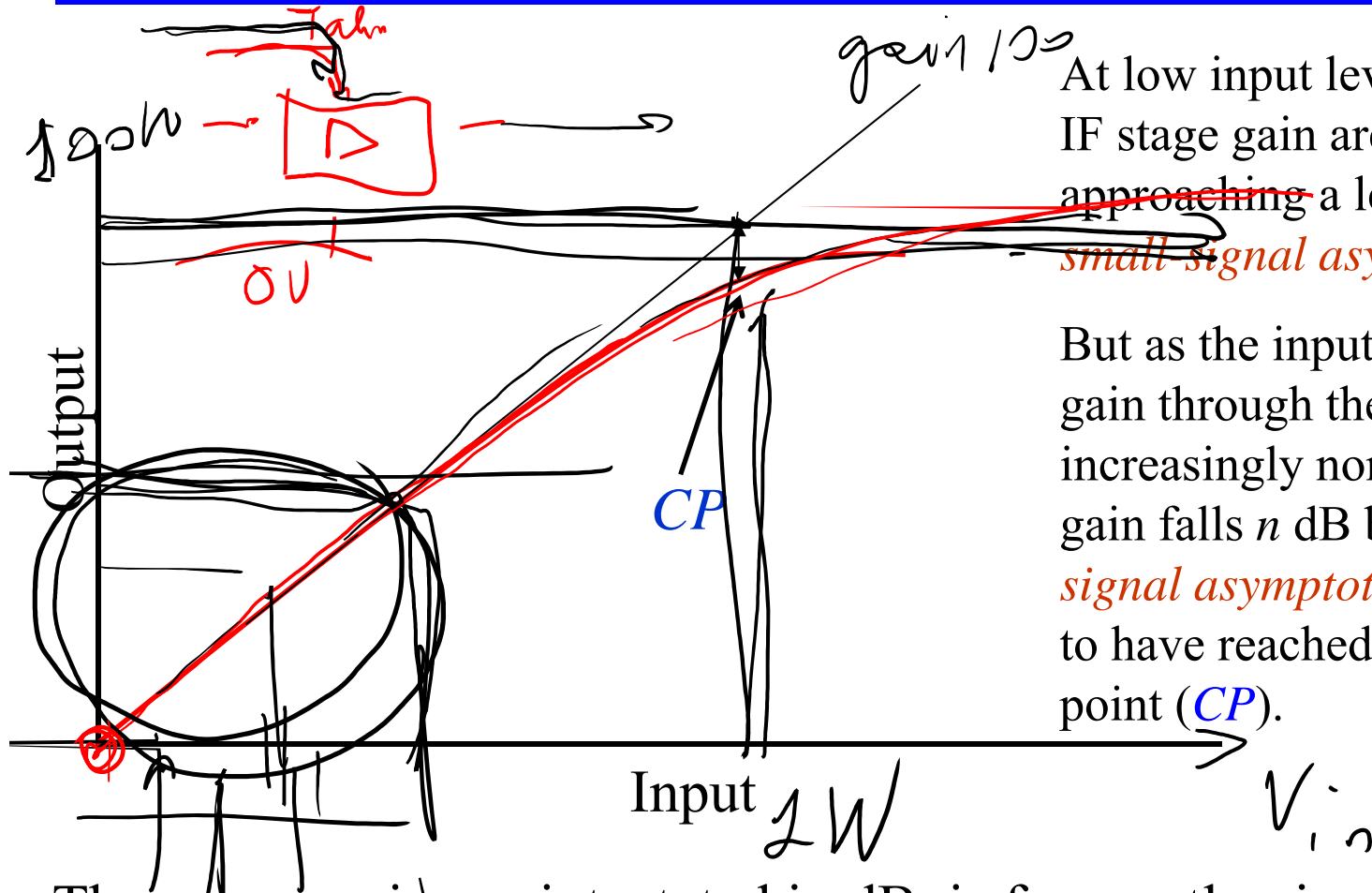


Linear gain in a circuit is normally represented by a straight line.

The scale on the Input and Output axis reflect the gain through the circuit. In this example, a gain of 2:1.

However, all RF & IF circuits are inherently nonlinear.

Gain and the Compression Point



At low input levels, receiver RF and IF stage gain are generally linear—~~approaching~~ approaching a level called the *small-signal asymptotic value*.

But as the input level increases, gain through the stage becomes increasingly nonlinear. When the gain falls n dB below the *small-signal asymptotic value*, it has said to have reached its compression point (**CP**).

The compression point, stated in dB, is frequently given as either 1 dB or 3 dB below the small-signal asymptotic value.

Why it is called 3rd order

$$a_1 s_1(t) + a_2 s_2(t)$$

$$\rightarrow A_2 a_1^2 s_1^2(t) + A_2 a_2^2 s_2^2(t)$$

$$\downarrow A_2 2 a_1 a_2 s_1(t) s_2(t)$$

The performance of an ideal amplifier can be represented by the transfer function:

$$V_{out} = A_0 + A_1 V_{in}$$

An amplifier with some distortion due to **nonlinearities** can be expressed by a transfer function in the form of a power series expansion:

$$V_{out} = A_0 + A_1 V_{in} + A_2 V_{in}^2 + A_3 V_{in}^3 + A_4 V_{in}^4 \dots$$

descrive

An input signal with two frequencies ω_1 and ω_2 may be shown as:

$$V_{in} = V_1 \cos(\omega_1 t) + V_2 \cos(\omega_2 t)$$

The **first** order term $A_0 + A_1 V_{in}$ gives the fundamental products

$$V_{out} = A_0 + A_1 V_1 \cos(\omega_1 t) + A_1 V_2 \cos(\omega_2 t)$$

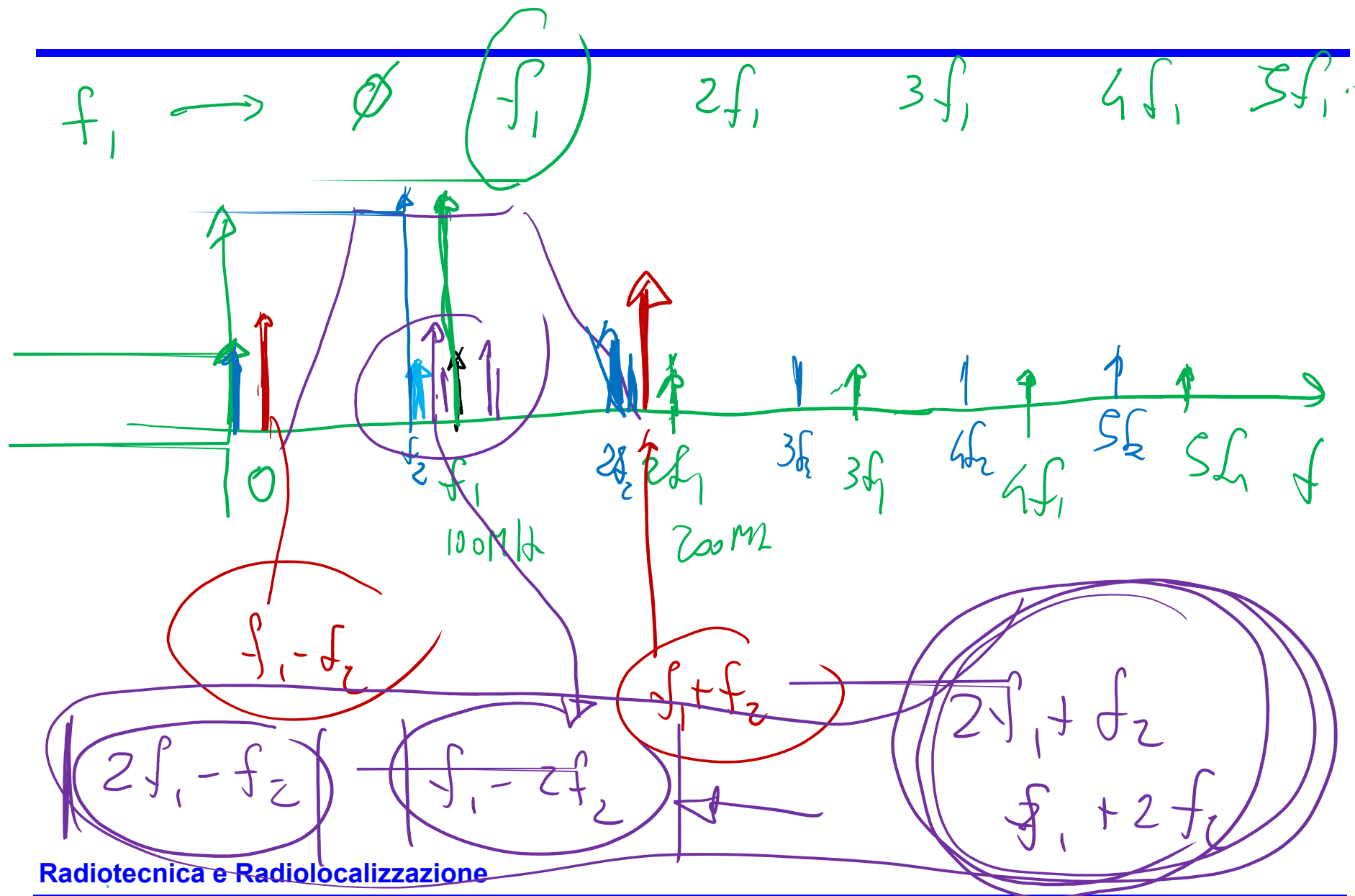
The **second** order term $A_2 V_{in}^2$ determines the second order products:

$$A_2 V_{in}^2 = \frac{A_2 V_1^2}{2} + \frac{A_2 V_2^2}{2} + \frac{A_2 V_1^2}{2} \cos(2\omega_1 t) + \frac{A_2 V_2^2}{2} \cos(2\omega_2 t) + \frac{A_2 V_1 V_2}{2} [\cos(\omega_1 t + \omega_2 t) + \cos(\omega_1 t - \omega_2 t)]$$

DC terms

2nd harmonic terms

2nd order IMD terms



$$V_1 = V_2$$

Why it is called 3rd order (cont'd)

$$A_1 V_1$$

$$A_1 V_2$$

The **third** order term $A_3 V_{in}^3$ determines the third order products:

$$A_3 V_{in}^3 = \frac{3A_3}{2} \left[V_1 V_2^2 + \frac{V_1^3}{2} \right] \cos(\omega_1 t) + \frac{3A_3}{2} \cos \left[V_1^2 V_2 + \frac{V_2^3}{2} \right] \cos(\omega_2 t) +$$

Fundamental frequency terms

$$\frac{A_3 V_1^3}{4} \cos(3\omega_1 t) + \frac{A_3 V_2^3}{4} \cos(3\omega_2 t) +$$

3rd harmonic terms

$$\frac{3A_3 V_1^2 V_2}{4} [\cos(2\omega_1 t + \omega_2 t) + \cos(2\omega_1 t - \omega_2 t)] + \frac{3A_3 V_1 V_2^2}{4} [\cos(2\omega_2 t + \omega_1 t) + \cos(2\omega_2 t - \omega_1 t)]$$

$$\frac{3A_3 V_1^3}{4}$$

3rd order IMD terms – The troublemakers

Nonlinearity and Intermodulation Distortion

- Nonlinearity in RF and IF circuits leads to two undesirable outcomes: harmonics and intermodulation distortion.
- Harmonics in and of themselves are not particularly troublesome.
- For example, if we are listening to a QSO on 7.230 MHz, the second harmonic, 14.460 MHz is well outside the RF passband.
- However, when the harmonics mix with each other and other signals in the circuit, undesirable and troublesome intermodulation products can occur.

Intermodulation Distortion Products: Example (I)

(1)	Fifth-Order	$3f_1-2f_2$	7.218
(2)	Third-Order	$2f_1-f_2$	7.221
(3)	Signal One	f_1	7.224
(4)	Signal Two	f_2	7.227
(5)	Third-Order	$2f_2-f_1$	7.230
(6)	Fifth-Order	$3f_2-2f_1$	7.233

Intermodulation Distortion Products: Example (II)

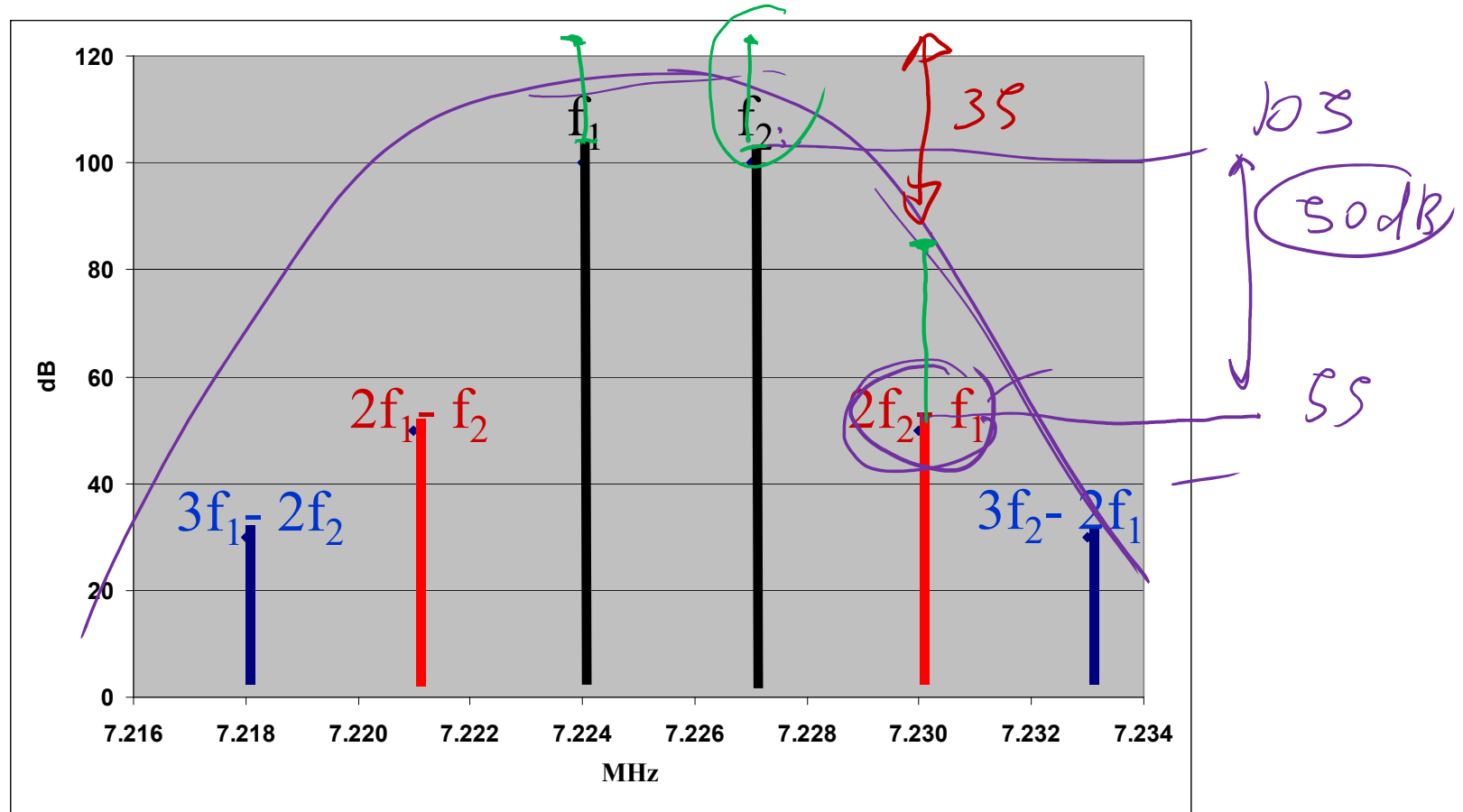
- (1) Fifth-Order $3f_1 - 2f_2$ 7.218
- (2) Third-Order $2f_1 - f_2$ 7.221
- (3) **Signal One**
- (4) **Signal Two**
- (5) Third-Order
- (6) Fifth-Order

$2f_1 = 2 \times 7.221 = 14.442$
$f_2 = \quad \quad \quad 7.227$
—
$14.442 - 7.227 = 7.221$

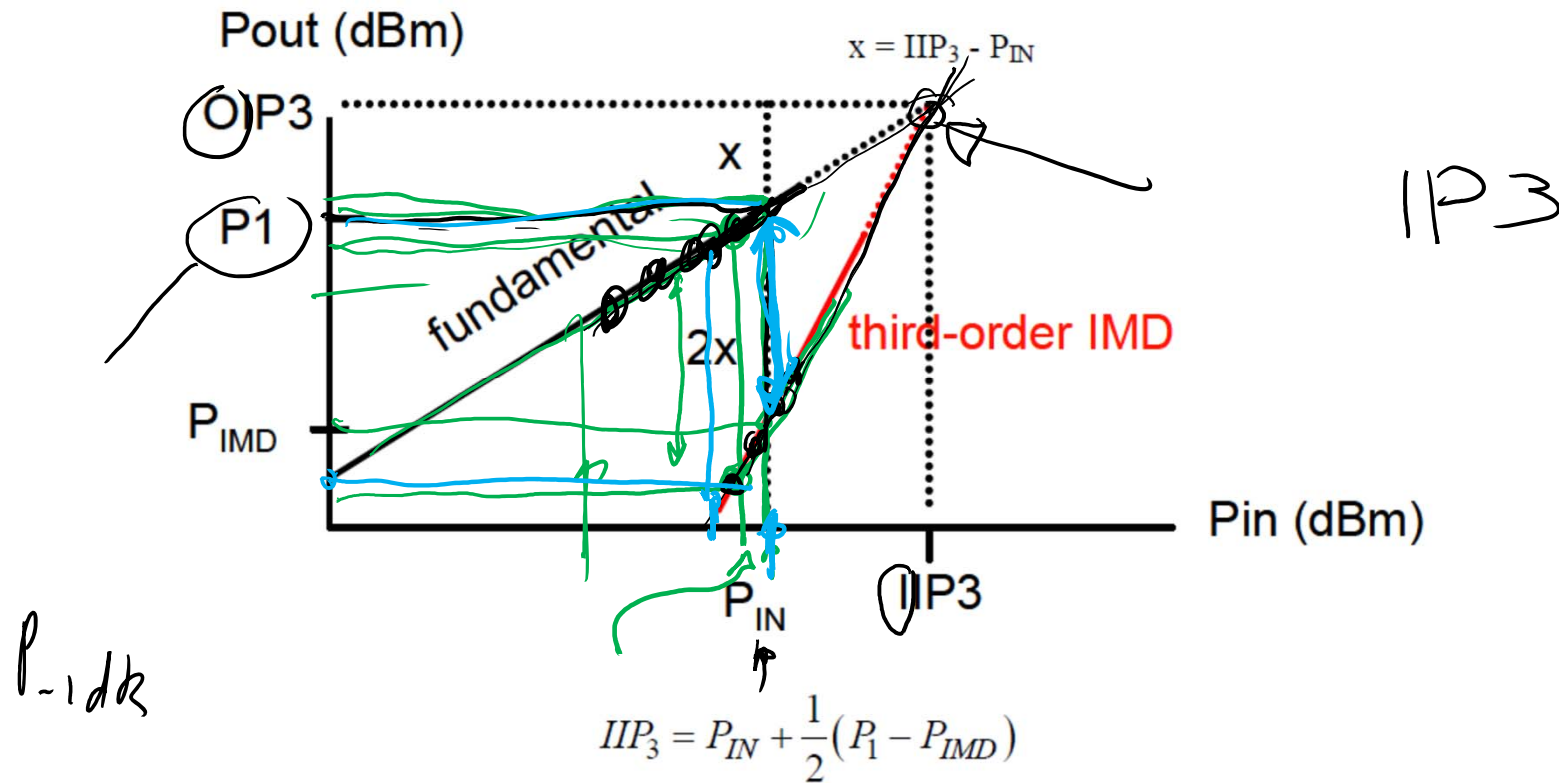
Intermodulation Distortion Products: Example (III)

(1)	Fifth-Order	$3f_1-2f_2$	7.218
(2)	Third-Order	$2f_1-f_2$	7.221
(3)	<u>Signal One</u>	<u>f_1</u>	<u>7.224</u>
(4)	Signal Two	f_2	<u>7.227</u>
(5)	Third-Order	$2f_2-f_1$	7.230
(6)	Fifth-Order	$3f_2-2f_1$	7.233

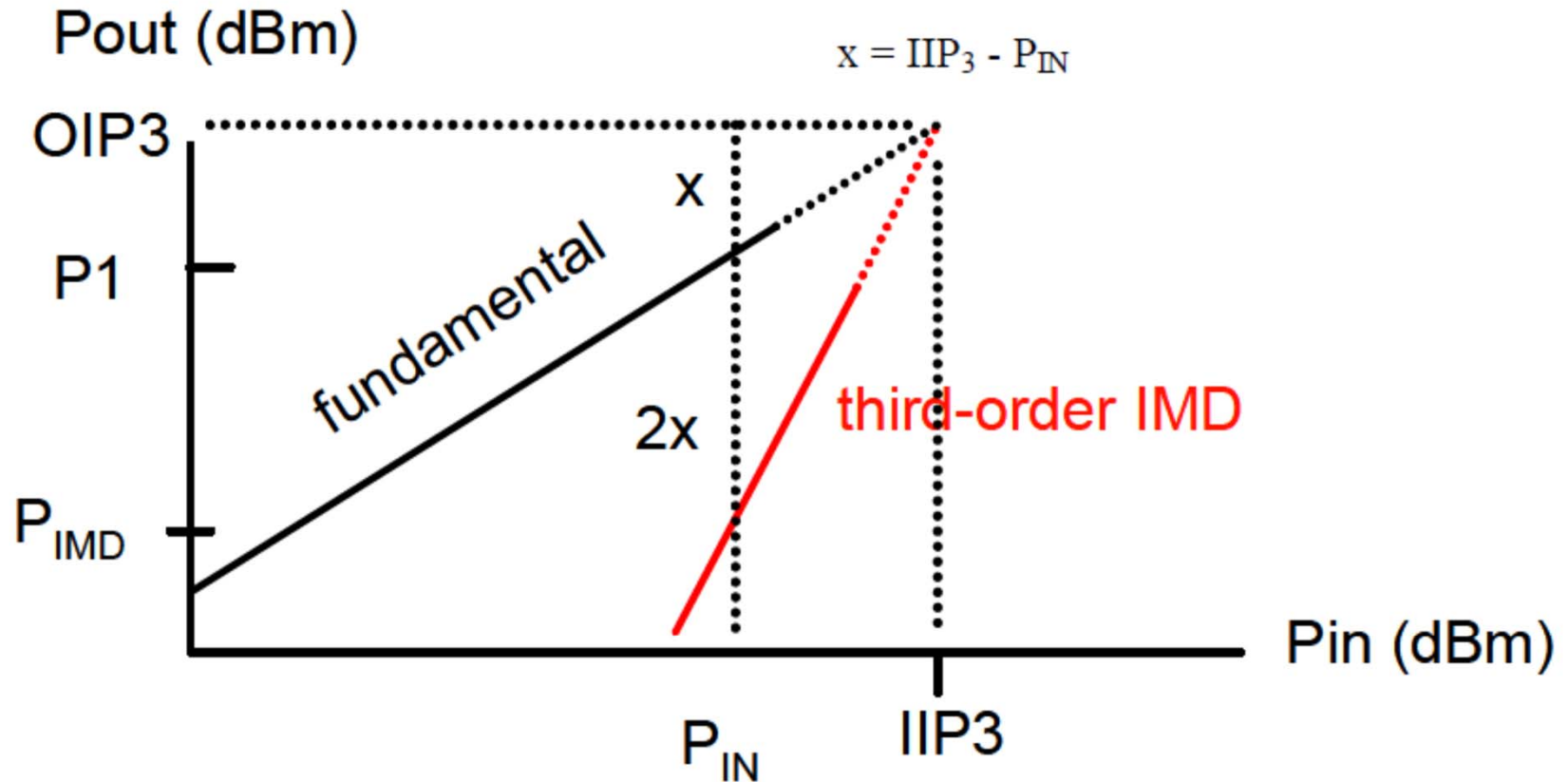
Intermodulation Distortion Products: Example (IV)



Spurious-Free Dynamic Range



Spurious-Free Dynamic Range



IP3 for cascaded system



Figure 12. Cascaded RF functional blocks with known IP_n .

The total gain of a cascaded structure is:

$$G = G_1 \times G_2 \times G_3 \text{ (in linear)}$$

or

$$g = g_1 + g_2 + g_3 \text{ (in dB or dBm)}$$

One can just use the equation, applied for three stages:

$$\left(\frac{1}{OIP_n}\right)_{TOT} = \left(\frac{1}{OIP_{n_1}} + \frac{G_2}{OIP_{n_2}} + \frac{G_2 \times G_3}{OIP_{n_3}}\right)$$