Cross modulation

If the interferer is amplitude modulated, the distorted modulation from the interferer will be impressed on the desired signal (in the presence of nonlinearities).

One additional contribution to dynamic range has to do with the quality of the local oscillator(s). LOs are not pure tones but
contain noise sidebands.

\[ dB \text{ magnitude} \uparrow \quad \uparrow \quad dB \text{ mag.} \uparrow \quad \uparrow \quad dB \text{ magnitude} \]

Desired (ideal) \quad Actual LO characteristic
LO characteristic

Strong signals (interferers) may affect the desired signal via mixing with the noise sidebands of the oscillator.
Test setup for measuring dynamic range properties:

Consider some uses of this circuit.

Desensitization - Only 2 signals are used.
Use S1 as the desired signal and S2 as the desensitizing signal.

Steps:
1) Set S2 at a predetermined frequency away from that of S1.
2) Set S2 output = 0 and set S1 for S/N (SINAD) of about 13dB.
3) Increase S2 output until S/N (SINAD) is decreased by 3dB.
4) Shift S2 in frequency and repeat the above steps to obtain sensitization deselectivity curve (if needed).
Intermodulation distortion

For n=2 components 2 tones (S1 and S2) are varied in frequency with frequency difference maintained at a desired value. For both tones must stay several channels away from the desired frequency so that the fundamental component doesn't substantially influence the measurement. Adjust a tone outputs to be equal in amplitude,
and vary the output amplitudes so that the receiver output level achieves a specified minimum value.

For \( n = 3 \) the 2 tones are set to, for example, 3 channels away and 6 channels away and the measurements are repeated.

**Spurious Outputs**

These are signals that may be produced by the receiver without any signals being input.
They affect the dynamic range and are a result of various synthesizer, LO, power supply, amplifier parasitic oscillation, and IF subharmonic effects. Oftentimes they may be observed as one listens for quieting on certain frequencies as the receiver is tuned over a band.

Gain control

Gain control circuitry can affect the dynamic range of a receiver and caution
is necessary to ensure that the effects are not detrimental. Gain control is used to ensure that information quality is maintained over a wide range of input signal levels.

Two primary types of gain control:

1) AGC (automatic gain control)Designed to keep the output signal level constant as input signal strength is varied. Important for AM receivers.
2) Limiting (for angle and frequency modulation).

This circuitry is used to reduce effect of AM to PM conversion.

This concludes our introduction to the most important receiver characteristic namely sensitivity, selectivity and dynamic range.
Receiver System Planning

Now let's begin to look at the receiver in terms of its functional blocks. One of the first decisions that must be made is the number and positions of IF conversions. Next the frequency range of each LO must be determined since this establishes the locations of the spurious responses of the various orders. There
are two choices for each LO frequency, defined by the equation $|f_s \pm f_{IF}| = f_{LO}$. These selections are dependent on the number of RF bands chosen and their frequencies, and on the availability of stable, fixed bandwidth filters at potential IFs.

Another important decision is the gain distribution throughout the system since this determines the NF and
the signal levels at various points in the system. For best NF, adequate gain is required prior to the first mixer stage, since mixers tend to have poor NFs, and mixers with low spurious products often have a loss. However, minimum IM product levels occur when the level is as low as possible prior to the final channel bandwidth selection. Usually this implies
a minimum gain prior to the final IF amplifier, where channel bandwidths are likely to be established. Minimization of the signal level at the mixer input also reduces the level of spurious responses. In some systems it may be necessary to accept lowered sensitivity to avoid high spurious response and IM levels. In such cases the preselection filter outputs may be fed
directly to the mixer, without rf amplification, and filter and mixer losses prior to the first IF amplifier must be minimized.

Receiver planning is largely a cut-and-try process centered around the receiver level diagram. (Fortunately, system-level simulation packages are available to assist in the planning.) Initial selections are made; the NF, IP3, and
levels of spurious responses closest to the rf are evaluated and compared to specific goals. This can then be reworked for the initial stages. Additional stages are then added and the receiver level diagram can be brought up with increasing detail. An example of the level diagram is given in Fig. 3.1 of the text.
Before the level diagram can be built up we need to know how to account for the affect of each block on the particular parameter of interest. So let's consider that first.

**Contribution of Noise Figure**

For some types of components, e.g., op amps and low frequency r.f. transistors, the noise contributions may be specified in terms of equivalent voltage...
and current sources. For example:

\[ V_s \quad R_g \quad E_n \quad \text{Noise, Flicker, etc.} \]

At the system level we generally work with noise figures for individual blocks and determine the overall noise figure for the system.

Consider a cascaded circuit with several noise blocks:
\[ N = \frac{kTB}{-} \]

\[ \text{Block 1} \quad \text{Gain} = G_1 \]

\[ \text{EE5331} \quad \text{Noise Free} \]

\[ \text{Block 2} \quad \text{Gain} = G_2 \]

\[ \text{Noise Free} \]

\[ N_{\text{excess}_1} = (F_1 - 1)kTB \]

\[ N_{\text{excess}_2} = (F_2 - 1)kTB \]

\[ \text{Block 3} \quad \text{Gain} = G_3 \]

\[ N_{\text{excess}_3} = (F_3 - 1)kTB \]

We'd like to refer the noise back to the input of the entire system. So we have
So, the total noise factor (referred to the input) is calculated as:

$$ F_{\text{total}} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} $$
For the following calculate NF.

\[ F_{total} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3} \]

\[ = 8.92 \quad \text{or} \quad NF_{total} = 9.5 \text{dB} \]
Noise Figure

General comments

1) For devices having primarily resistive loss, attenuation is \(\equiv\) noise figure.

2) Matching between circuit blocks impacts NF.
(See Chpt. 3)

Intercept Points
(See Fig. 2.21)
Intercept Points

How do we calculate these?

Consider the case of cascading elements that contribute to the generation of intermodulation products. Consider the case of cascading 2 amplifiers with known voltage gains, and know 2nd- and 3rd-order intercept points.
Amp 1  Amp 2
\[ V \rightarrow \downarrow \rightarrow \downarrow \rightarrow \text{output} \]

Voltage \( G_{V1} \quad G_{V2} \quad G_{V1}G_{V2}V \)

Gain

2nd-order \( V_{I21} \quad V_{I22} \quad V_{d12} + G_{V2}V_{d21} \)

IP

3rd-order \( V_{I31} \quad V_{I32} \quad V_{d22} + G_{V2}V_{d31} \)

IP

Focus on 2nd-order products first. Notice that we have (output)

\[ V_{d12} + G_{V2}V_{d21} \]

\[ \text{2nd-harmonic response of Amp 1} \]

\[ \text{2nd-harmonic response of Amp 2 to } V \]
Referring the 2nd-harmonic output back to the input we have

\[ V_d = \frac{G_{u_2} V_d_{21} + V_d_{22}}{G_{u_1} G_{u_2}} \]

\[ = \frac{V_d_{21}}{G_{u_1}} + \frac{V_d_{22}}{G_{u_1} G_{u_2}} \]

Notice at the second-order IP that the second harmonic and fundamental have the same output power (voltage). We can then write

\[ V_d_1 = V_{IP_2} = a \hat{V} \quad \text{fundamental} \]

\[ V_d_2 = V_{IP_2} = b \hat{V} \quad \text{2nd harmonic} \]
Comparing the 2 expressions we find
\[ \hat{y} = \frac{V_{IP2}}{a} \Rightarrow V_{IP2} = b \left( \frac{V_{IP2}}{a} \right)^2 \]

So, \[ \frac{a^2}{V_{IP2}} = b \]

and \[ V_{d2} = a^2 \left( \frac{V}{V_{IP2}} \right) \]

Voltage gain through the amplifier stage.

At the output we had \[ G_{v2} V_{d2} + V_{d2a} \]

and that, referred back to the input gave
\[ V_d = \frac{V_{d2}}{G_{v1}} + \frac{V_{d2a}}{G_{v1} G_{v2}} \]
Using the expression
\[ Vd_2 = a^2 \left( \frac{V^2}{V_{IP_d}} \right) \]
we can write
\[ Vd = \frac{(G_{r_1} V)^2}{V_{IP_21}} \frac{(G_{r_1} G_{r_2} V)^2}{V_{IP_22}} + \frac{V_{IP_22}}{G_{r_1} G_{r_2}} \]
\[ = V^2 \left( \frac{G_{r_1}}{V_{IP_21}} + \frac{G_{r_1} G_{r_2}}{V_{IP_22}} \right) \]
Referring to the input
we have \[ Vd = \frac{V^2}{V_{IP_2 total}} \]
such that
\[ \frac{1}{V_{IP_2 total}} = \frac{G_{r_1}}{V_{IP_21}} + \frac{G_{r_1} G_{r_2}}{V_{IP_22}} \]