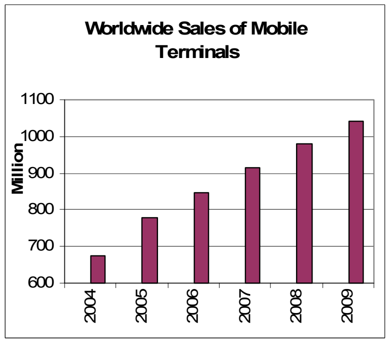
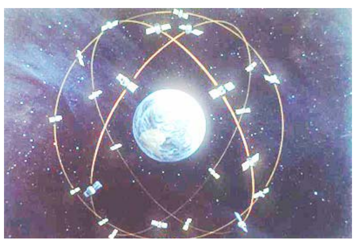
Introduction to RF and Wireless

- **Wireless is everywhere …**

Cellphones:

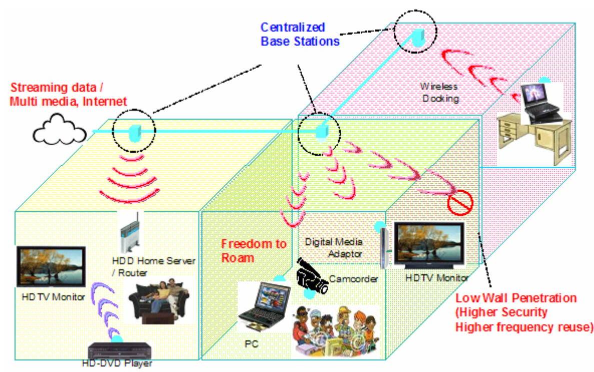


GPS:



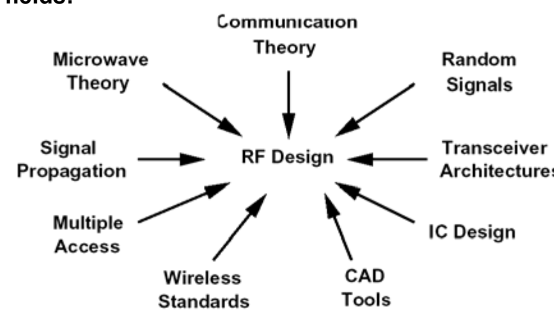
RFIDs:

Wireless Home:

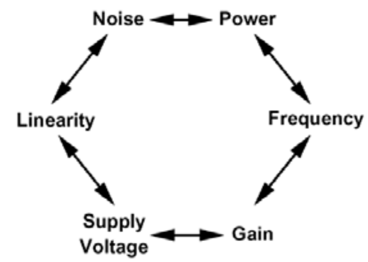


- **Wireless design is challenging …**

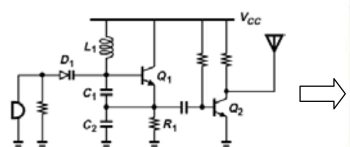
- Draws upon many fields:

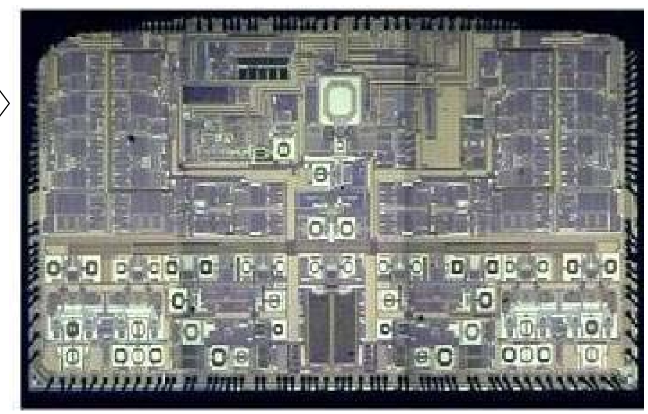


- Competitors must push for: cost, talk time, sensitivity, functions, size, weight, …



- **Wireless has come a long way …**





[A. Behzad et al, ISSCC07]

2x2 802.11a/b/g/n (18 mm^2)

Nonlinearity and Distortion

Linearity and Time Variance

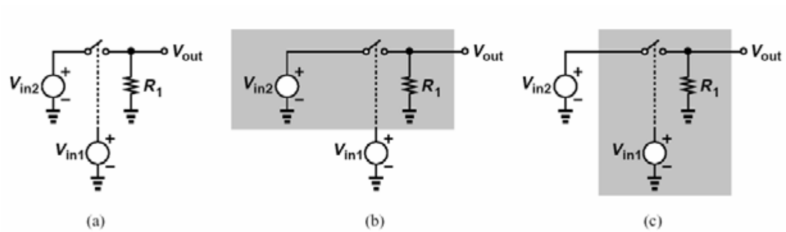
- A system is linear if it satisfies the superposition principle:

$$x_1(t) \to y_1(t), \;\; x_2(t) \to y_2(t)$$
$$ax_1(t) + bx_2(t) \to ay_1(t) + by_2(t)$$

- A system is time-variant if $x(t) \to y(t)$, then $x(t-\tau) \to y(t-\tau)$

Example:

If the switch turns on at the zero crossings of Vin1, is the system



nonlinear or time-variant?

- A linear system can generate frequency components that do not exist in the input:

$$V_{out}(f) \;=\; V_{in2}(f) * \sum_{n=-\infty}^{+\infty} \frac{\sin(n\pi/2)}{n\pi}\delta(f - \frac{n}{T_1})$$

Graphically:

Classes of Systems

- Memoryless vs. Dynamic Systems: A memoryless ("static") system produces an instantaneous output, i.e., the output does not depend on past values:

$$y(t) = \alpha x(t)$$

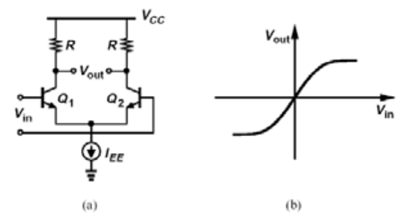
A dynamic system produces an output that may depend on past values. A linear dynamic system satisfies the convolution integral:

$$y(t) = h(t) * x(t)$$

- For a static, nonlinear system, we can approximate the input/output relationship by a polynomial:

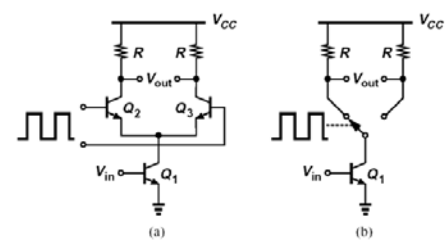
$$y(t) = \alpha_0 + \alpha_1 x(t) + \alpha_2 x^2(t) + \alpha_3 x^3(t) + \cdots$$

Most types of nonlinearity encountered in practice are "compressive:



- For a dynamic, nonlinear system, one may need to resort to Volterra series or "harmonic balance" techniques.

Example:



Effects of Nonlinearity

Nonlinearity introduces "harmonic distortion," "gain compression," "desensitization," "intermodulation," etc.

- **Harmonic Distortion**

If a sinusoid is applied to a nonlinear time-invariant system, the output contains components that are integer multiples of the input frequency: If

$$x(t) = A\cos\omega t$$

then

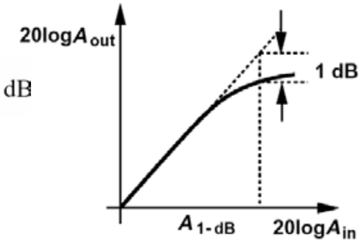
$$y(t) = \alpha_1 A\cos\omega t + \alpha_2 A^2\cos^2\omega t + \alpha_3 A^3\cos^3 t$$

- **With "odd symmetry," even harmonics are absent.**
- **Amplitude of nth-order harmonic is roughly proportional to A^n.**
-

- **Gain Compression**

In compressive systems, the small-signal gain (slope of the charac.) falls at high input levels. This is quantified by the "1-dB compression point:"

$$20\log|\alpha_1 + \frac{3}{4}\alpha_3 A_{1-\mathrm{dB}}^2| = 20\log|\alpha_1| - 1\ \mathrm{dB}$$



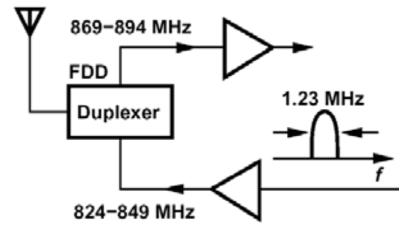
- **Desensitization and Blocking**

If a small signal is accompanied with a large interferer, then:

$$x(t) = A_1\cos\omega_1 t + A_2\cos\omega_2 t$$

$$y(t) = (\alpha_1 A_1 + \frac{3}{4}\alpha_3 A_1^3 + \frac{3}{2}\alpha_3 A_1 A_2^2)\cos\omega_1 t + \cdots$$

The interferer is sometimes called a "blocker."
Example:



- **Intermodulation**

Suppose two interferers are applied to a nonlinear system ("two-tone test"):

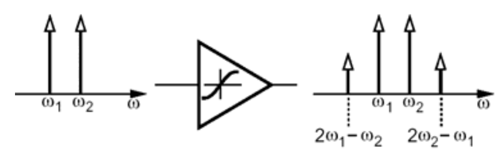
$$x(t) = A_1\cos\omega_1 t + A_2\cos\omega_2 t$$

$$\begin{aligned} y(t) &= \alpha_1(A_1\cos\omega_1 t + A_2\cos\omega_2 t) + \alpha_2(A_1\cos\omega_1 t + A_2\cos\omega_2 t)^2 \\ &+ \alpha_3(A_1\cos\omega_1 t + A_2\cos\omega_2 t)^3. \end{aligned}$$

We therefore have these "intermodulation" (IM) components:

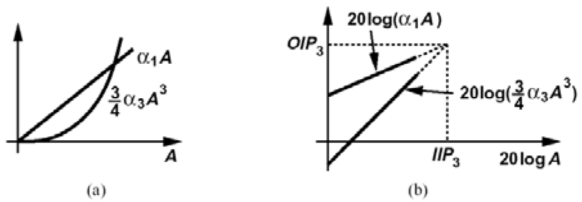
$$\begin{aligned} \omega &= \omega_1 \pm \omega_2 : \alpha_2 A_1 A_2\cos(\omega_1+\omega_2)t + \alpha_2 A_1 A_2\cos(\omega_1-\omega_2)t \\ \omega &= 2\omega_1 \pm \omega_2 : \frac{3\alpha_3 A_1^2 A_2}{4}\cos(2\omega_1+\omega_2)t + \frac{3\alpha_3 A_1^2 A_2}{4}\cos(2\omega_1-\omega_2)t \\ \omega &= 2\omega_2 \pm \omega_1 : \frac{3\alpha_3 A_2^2 A_1}{4}\cos(2\omega_2+\omega_1)t + \frac{3\alpha_3 A_2^2 A_1}{4}\cos(2\omega_2-\omega_1)t \end{aligned}$$

Which ones are troublesome?



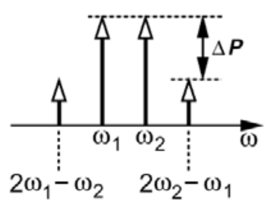
- "Third Intercept Point" (IP3): Two tones with equal amplitudes are applied:

$$y(t) = (\alpha_1 + \frac{9}{4}\alpha_3 A^2)A\cos\omega_1 t + (\alpha_1 + \frac{9}{4}\alpha_3 A^2)A\cos\omega_2 t + \frac{3}{4}\alpha_3 A^3 \cos(2\omega_1 - \omega_2)t + \frac{3}{4}\alpha_3 A^3 \cos(2\omega_2 - \omega_1)t + \cdots$$



Thus, IIP3 is obtained as:

- Shortcut Method:



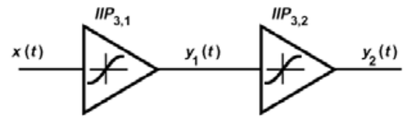
$$IIP_3|_{dBm} = \frac{\Delta P|_{dB}}{2} + P_{in}|_{dBm}$$

- Relationship between IP3 and P1dB:

$$\frac{A_{1-dB}}{A_{IP3}} = \frac{\sqrt{0.145}}{\sqrt{4/3}} \approx -9.6 \text{ dB}$$

Typical receiver IP3 is around -10 dBm.

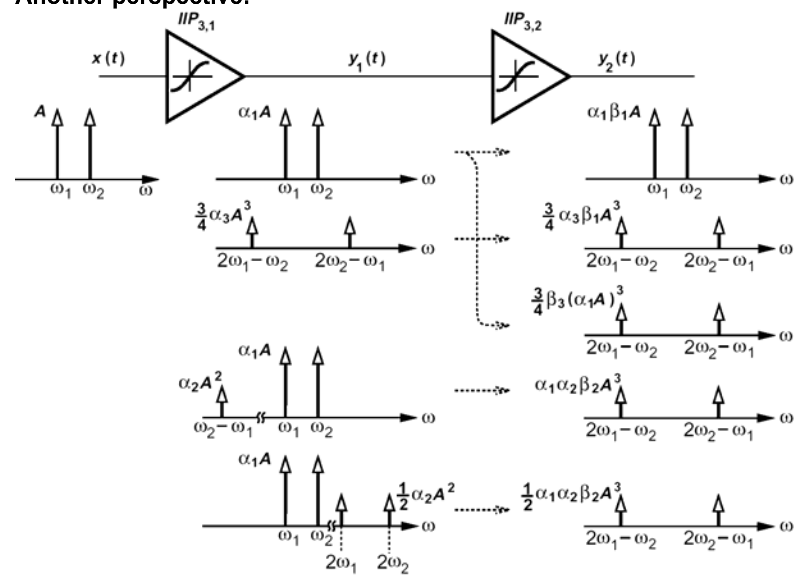
- **Cascaded Nonlinear Stages**



$$y_2(t) = \beta_1[\alpha_1 x(t) + \alpha_2 x^2(t) + \alpha_3 x^3(t)] + \beta_2[\alpha_1 x(t) + \alpha_2 x^2(t) + \alpha_3 x^3(t)]^2 + \beta_3[\alpha_1 x(t) + \alpha_2 x^2(t) + \alpha_3 x^3(t)]^3.$$

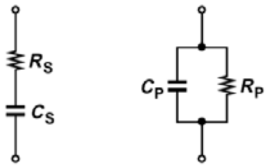
$$\frac{1}{A_{IP3}^2} = \frac{3}{4}\frac{|\alpha_3\beta_1| + |2\alpha_1\alpha_2\beta_2| + |\alpha_1^3\beta_3|}{|\alpha_1\beta_1|} = \frac{1}{A_{IP3,1}^2} + \frac{3\alpha_2\beta_2}{4\beta_1} + \frac{1}{A_{IP3,2}^2},$$

Another perspective:



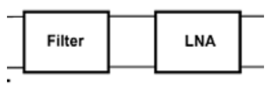
EE101 Concepts

- **Definitions of Q**

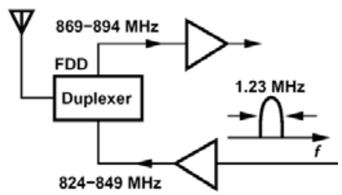


For a second-order tank:

- **Conjugate Matching**



Do we want to have conjugate matching here?



- **dB's and dBm's**

dB is used for <u>dimensionless</u> quantities to make them algebraically manageable:

- Voltage Gain: Vout/Vin → in dB 20log (Vout/Vin)

- Power Gain: Pout/Pin → in dB 10log (Pout/Pin)

Are the voltage gain and power gain equal if expressed in dB?

dBm is used for <u>power</u> quantities is a 50-ohm matched system:

Power P1 in dBm = 10 log (P1/ 1mW)

What do we do in on-50-ohm systems?

- A 50-ohm signal source delivers the specified power only if it is terminated into a 50-ohm load.

- **Other Basics**
  - **Fourier transform of sine and cosine**
  - **Sifting property of impulses**
  - **Trig. Identities: cos a +/- cos b, cos a cos b, cos (a+b), $\cos^2 a$, $\cos^3 a$**