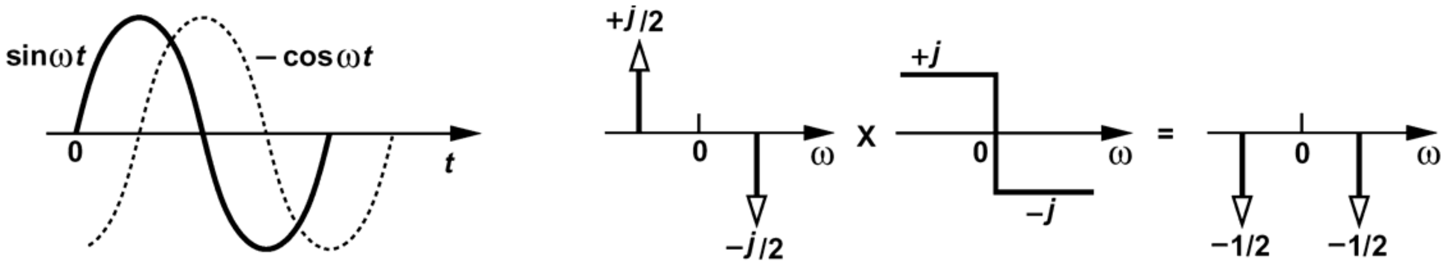
Transceiver Architectures (III)

Image-Reject Receivers

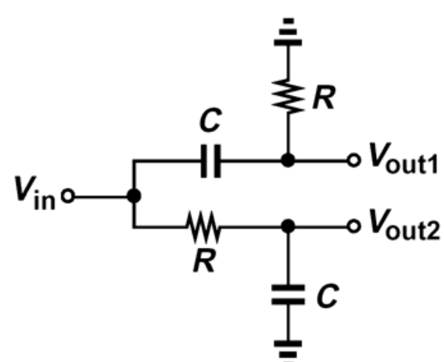
Since the image and the signal lie on the two sides of the LO frequency, it is possible to architect the RX so that it can distinguish between the two and reject one (hopefully the image).

• 90^o Phase Shift
How do we shift a modulated signal by 90 degrees?



In general, for a narrowband signal:

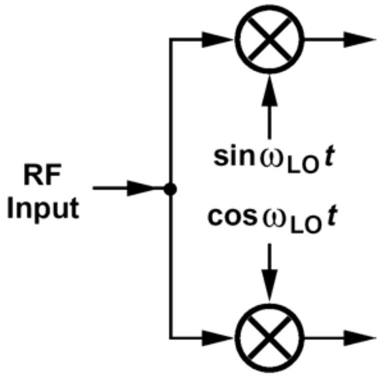
Thus, Hilbert transform distinguishes between positive and negative frequencies. The phase shift can be realized by an RC-CR network:



Example: Plot the spectrum of Acos ωt + jAsin ωt.

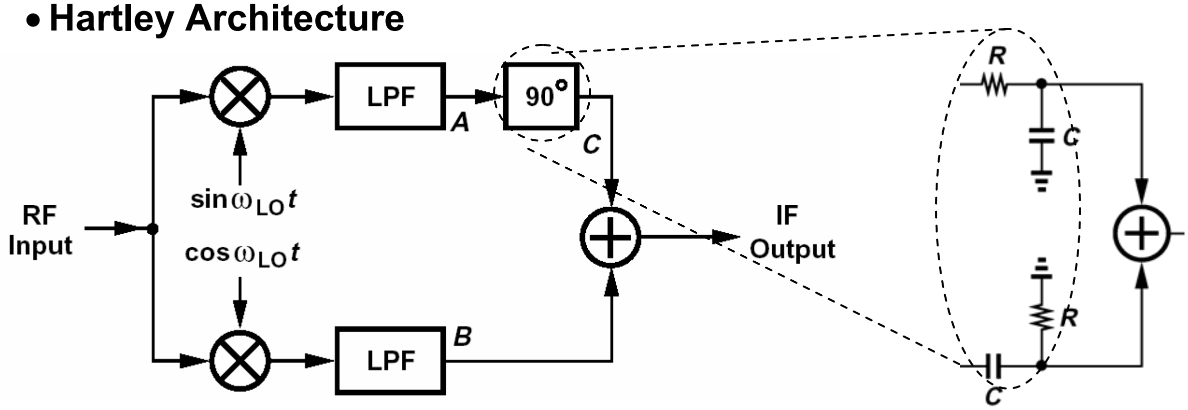
Exercise: A narrowband signal I(t) with a real spectrum is shifted by 90^o to produce Q(t). Plot the spectrum of I(t)+jQ(t).

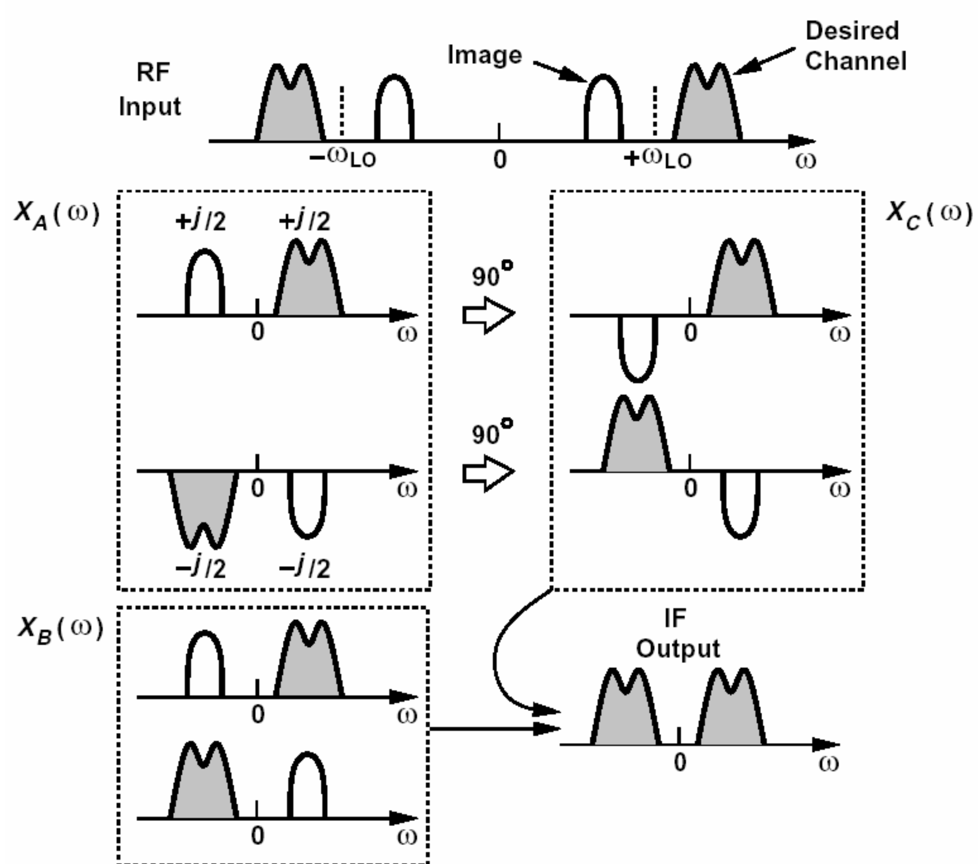
Another 90° shift circuit: "Quadrature downconverter"



Exercise: Repeat the above analysis for low-side injection.

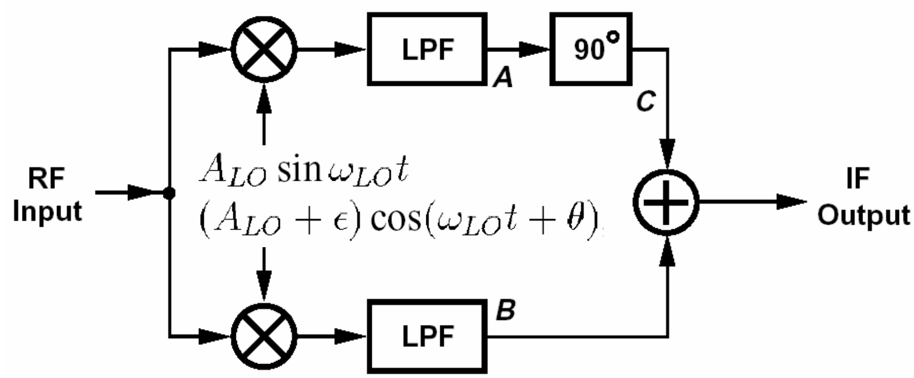
• Hartley Architecture





Exercise: An engineer constructs the above topology but uses high-side injection. Explain what happens and why the engineer probably graduated from the other school across town.

- Effect of Mismatches:



$$x_{sig}(t) = \frac{(A_{LO}+\epsilon)A_{RF}}{2}\cos[(\omega_{LO}-\omega_{RF})t+\theta] + \frac{A_{LO}A_{RF}}{2}\cos(\omega_{LO}-\omega_{RF})t$$
$$x_{im}(t) = \frac{(A_{LO}+\epsilon)A_{im}}{2}\cos[(\omega_{LO}-\omega_{im})t+\theta] - \frac{A_{LO}A_{im}}{2}\cos(\omega_{LO}-\omega_{im})t.$$

Compute the image-to-signal ratio at the ouput and divide it by the image-to-signal ratio at the input:

$$\mathrm{IRR} = \frac{(1+\epsilon)^2 + 2(1+\epsilon)\cos\Delta\theta + 1}{(1+\epsilon)^2 - 2(1+\epsilon)\cos\Delta\theta + 1}$$

Exercise: Prove that for $\epsilon \ll A_{LO}$ and $\theta \ll 1$ rad

For example, an IRR of 60 dB requires a phase mismatch of 0.1 degree. Typical IRR is around 30-35 dB.

- Other issues in Hartley architecture: (1) voltage addition at the output; (2) amplitude imbalance in the RC-CR section at frequencies away from 1/(RC); (3) variation of RC with process and temperature.

Exercise: Try 90-degree phase shift in RF path. What happens if sine and cosine are swapped?

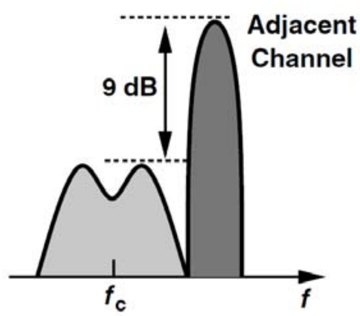
- **Weaver Architecture**

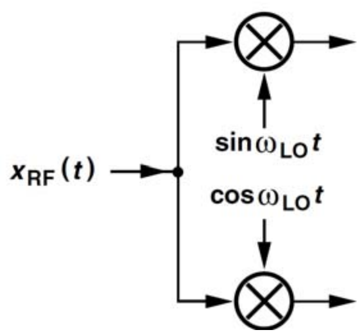
Operation is similar to Hartley (refer to textbook) but the architecture is rarely used.

Low-IF Receivers

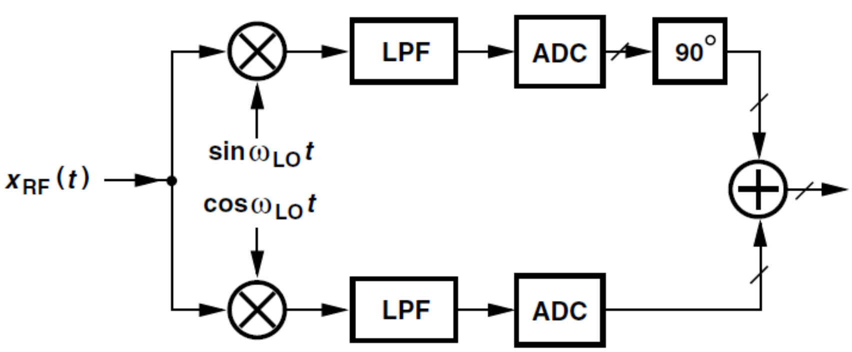
Direct conversion presents two issues in GSM applications: (1) high flicker noise in baseband, and (2) difficulty in offset removal. "Low-IF" receivers overcome these issues by exploiting the relaxed adjacent channels spec of GSM.

In GSM, the adjacent channel can be only 9 dB higher than the desired channel.





Can perform image rejection in the digital domain:



Other low-IF receivers choose a higher IF so that an analog filter can perform both image rejection and channel selection. Such a filter is called a "polyphase filter." But then,

(1) The image is no longer in the adjacent channel and hence quite large;
(2) Baseband ADCs must digitize a broad bandwidth, consuming high power;
(3) Polyphase filters are generally quite power hungry.

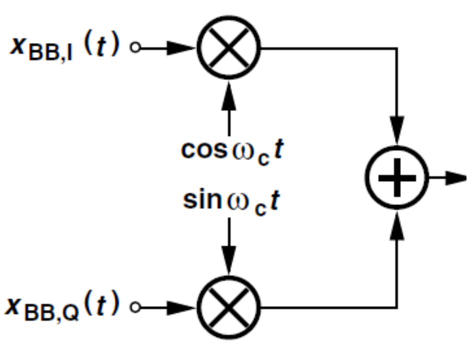
Implementations using polyphase filters are not very common today.

Exercise: which one of direct-conversion issues are serious in low-IF receivers as well?

Transmitter Architectures

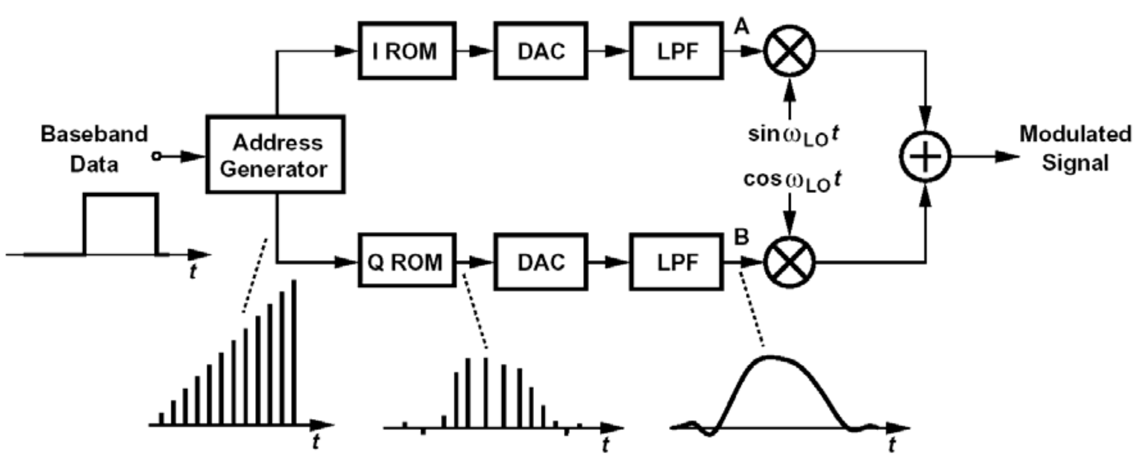
- **Need to modulate (and amplify):**

$$x(t) = A(t)\cos[\omega_c t + \phi(t)]$$
$$= A(t)\cos\omega_c t\cos[\phi(t)] - A(t)\sin\omega_c t\sin[\phi(t)]$$

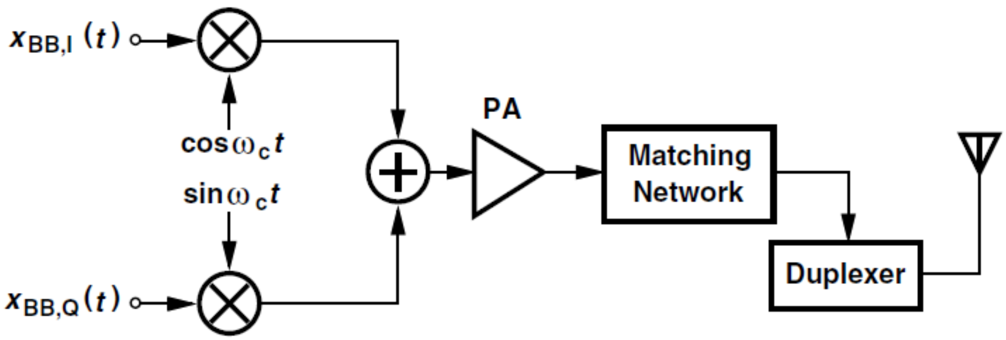


Also known as: quadrature modulator, vector modulator, single-sideband mixer

- **How do we generate the baseband signals?**



• Direct-Conversion TX



- Effect of I/Q Mismatch

Apply two quadrature tones to baseband inputs and find the undesired sideband magnitude:

$$\begin{aligned} V_{out}(t) &= V_0(1+\varepsilon)\cos\omega_{in}t\cos(\omega_c t+\Delta\theta) - V_0\sin\omega_{in}t\sin\omega_c t \\ &= \frac{V_0}{2}[(1+\varepsilon)\cos\Delta\theta+1]\cos(\omega_c t+\omega_{in})t \\ &\quad - \frac{V_0}{2}(1+\varepsilon)\sin\Delta\theta\sin(\omega_c+\omega_{in})t \\ &\quad + \frac{V_0}{2}[(1+\varepsilon)\cos\Delta\theta-1]\cos(\omega_c-\omega_{in})t \\ &\quad - \frac{V_0}{2}(1+\varepsilon)\sin\Delta\theta\sin(\omega_c-\omega_{in})t. \end{aligned}$$

The ratio of desired sideband to undesired sideband is a measure of I/Q matching:

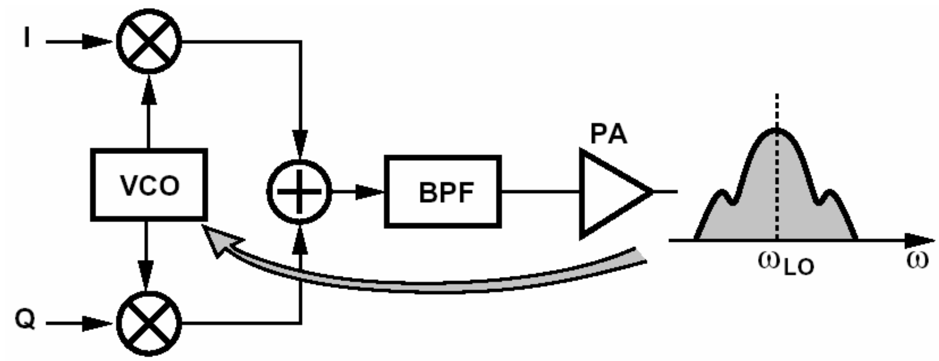
$$\frac{P_+}{P_-} = \frac{1-(1+\epsilon)\cos\theta+\epsilon}{1+(1+\epsilon)\cos\theta+\epsilon}$$

Exercise: Prove that this equation is the same as that obtained for IRR of receivers.

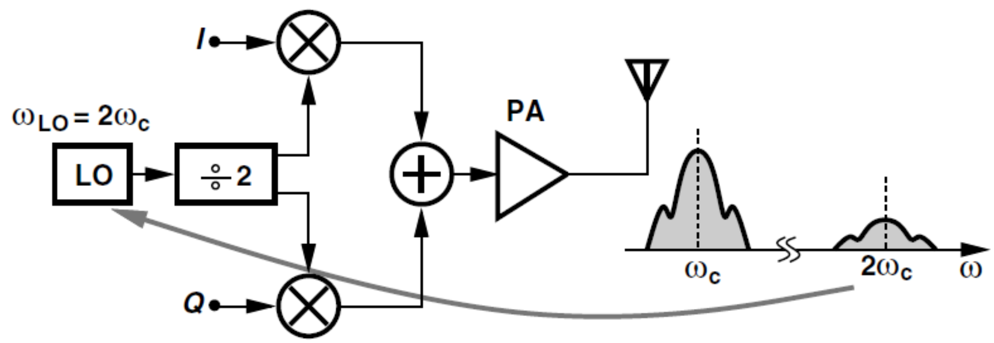
In practice, the tolerable mismatches for a given modulation scheme are determined by detailed simulations.

B. Razavi

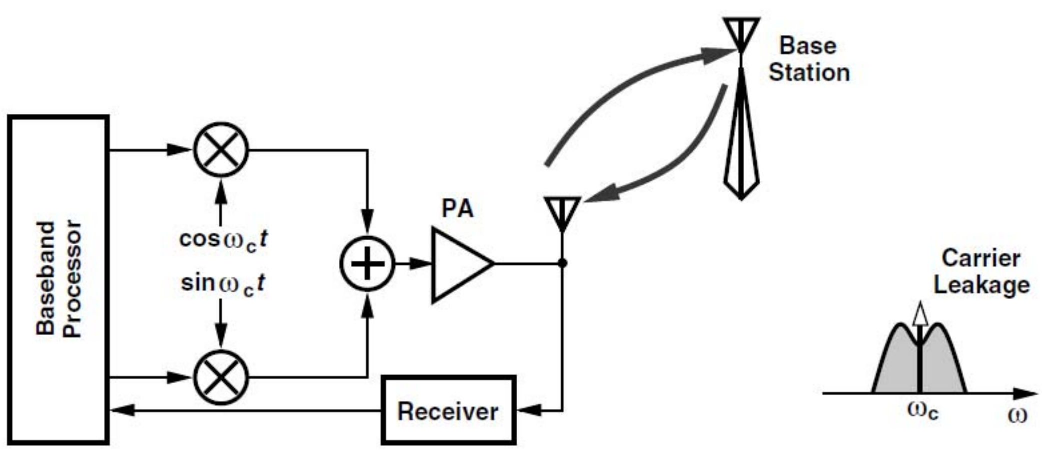
- Problem of "Pulling"



Common Solution:



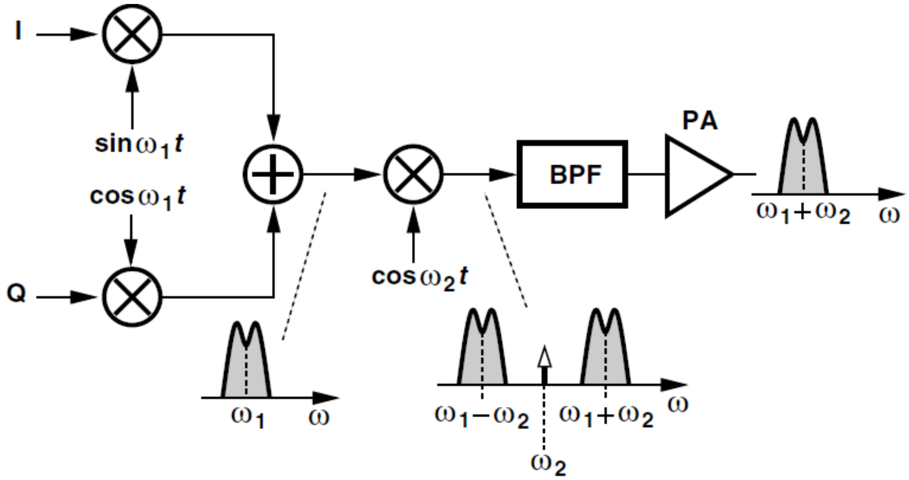
- Problem of Carrier Feedthrough
DC offsets in baseband lead to carrier feedthrough in RF.



How do we deal with this?

B. Razavi

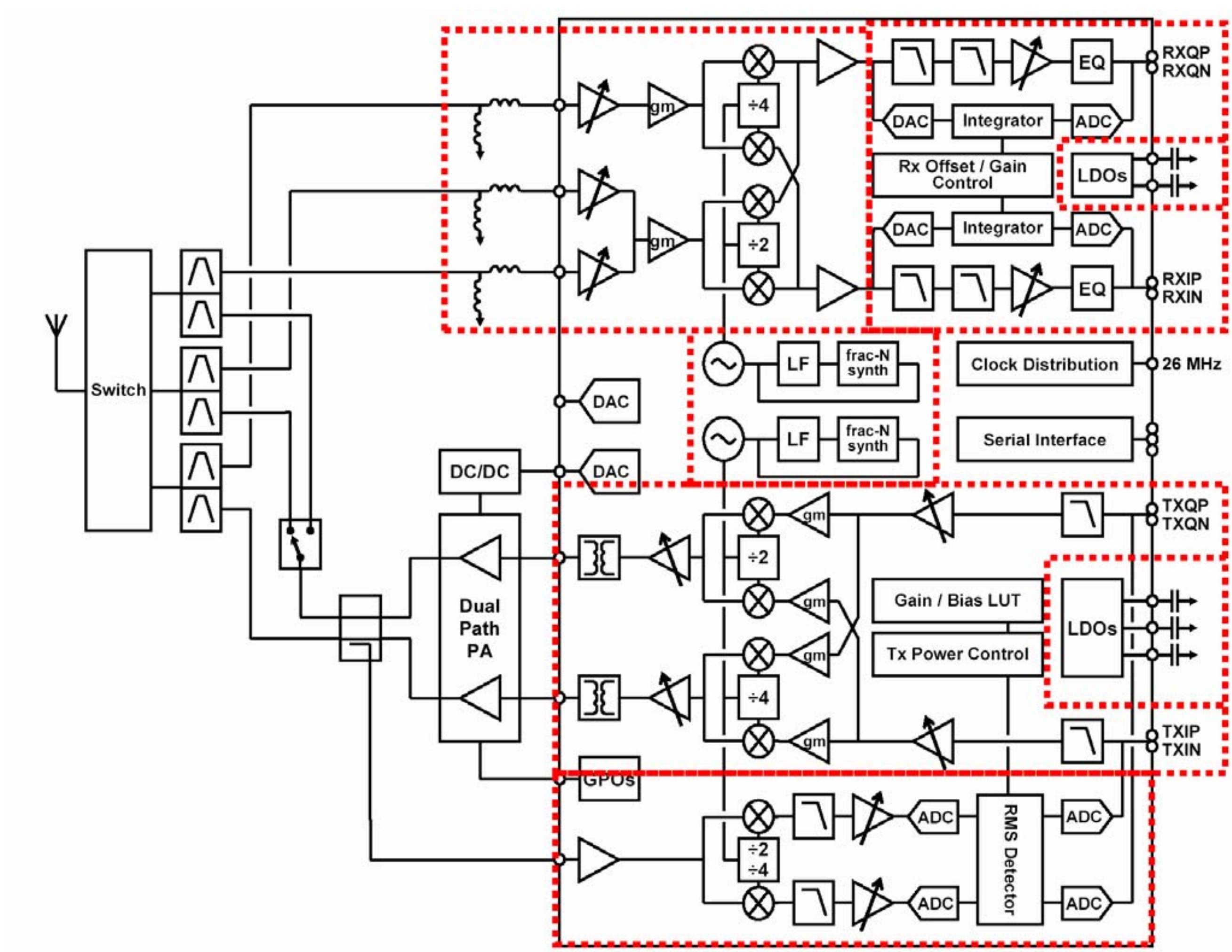
- **Heterodyne Transmitters**



Exercise: How do we avoid two LOs in two-step transmitters?

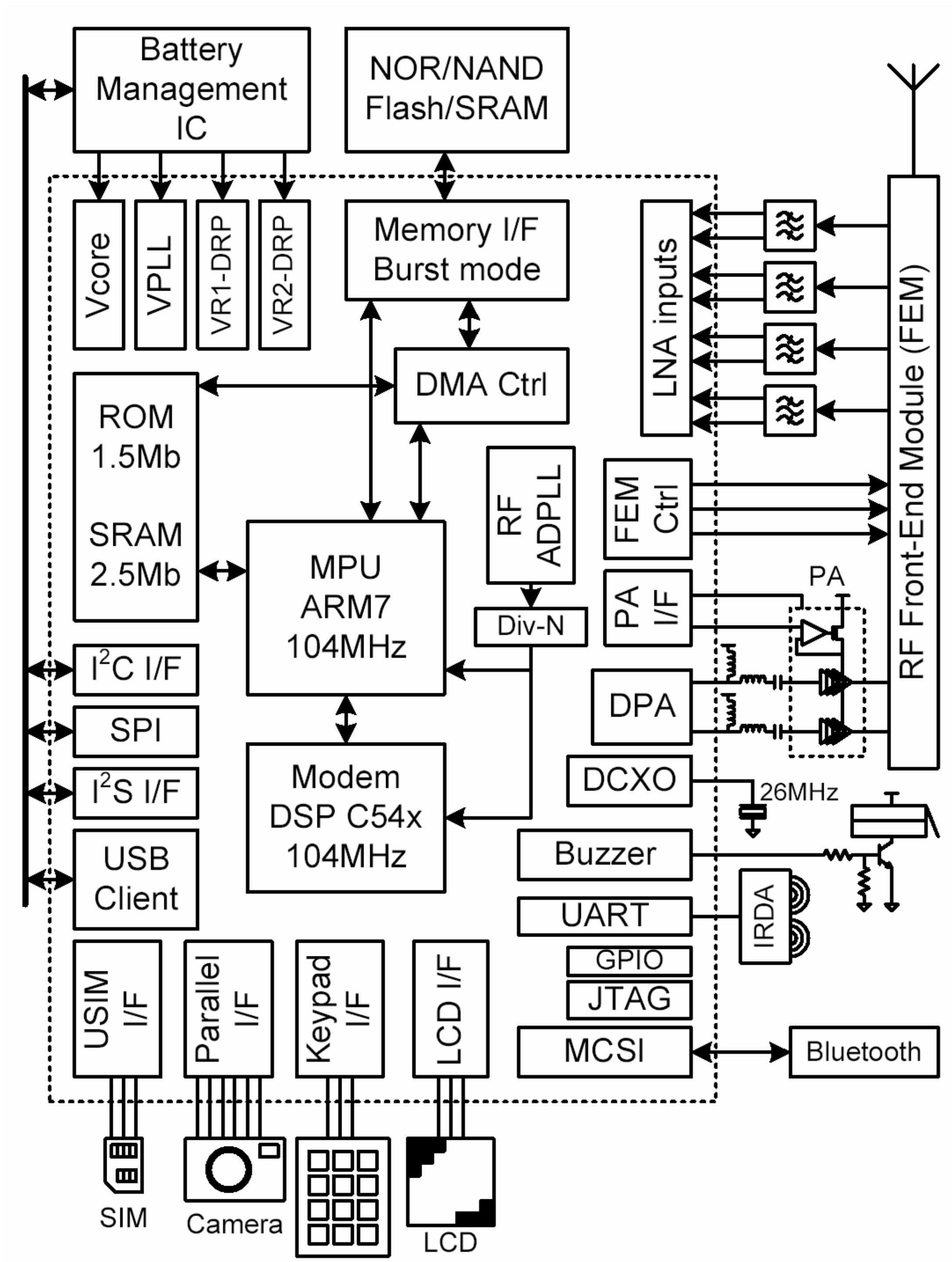
Case Studies

1. Tri-Band WDMA Transceiver: 900 MHz, 2 GHz, 2.5 GHz



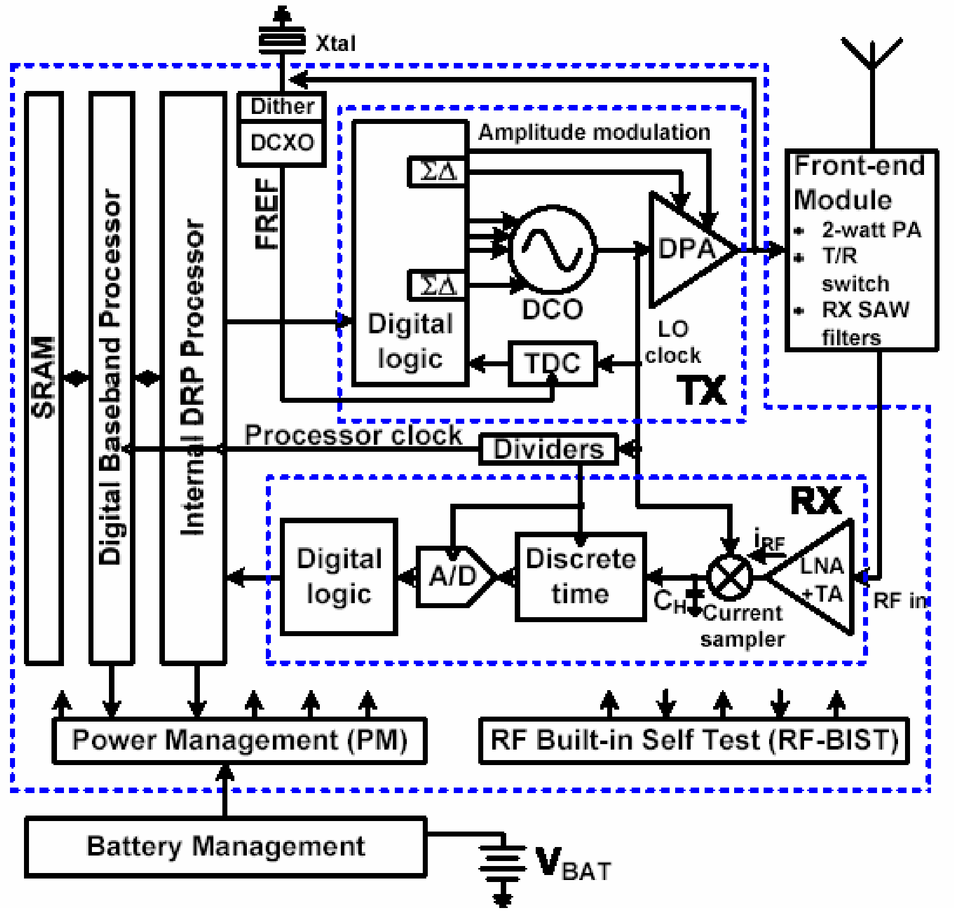
Tenbroek, ISSCC08]

2. Quad-Band GSM Transceiver



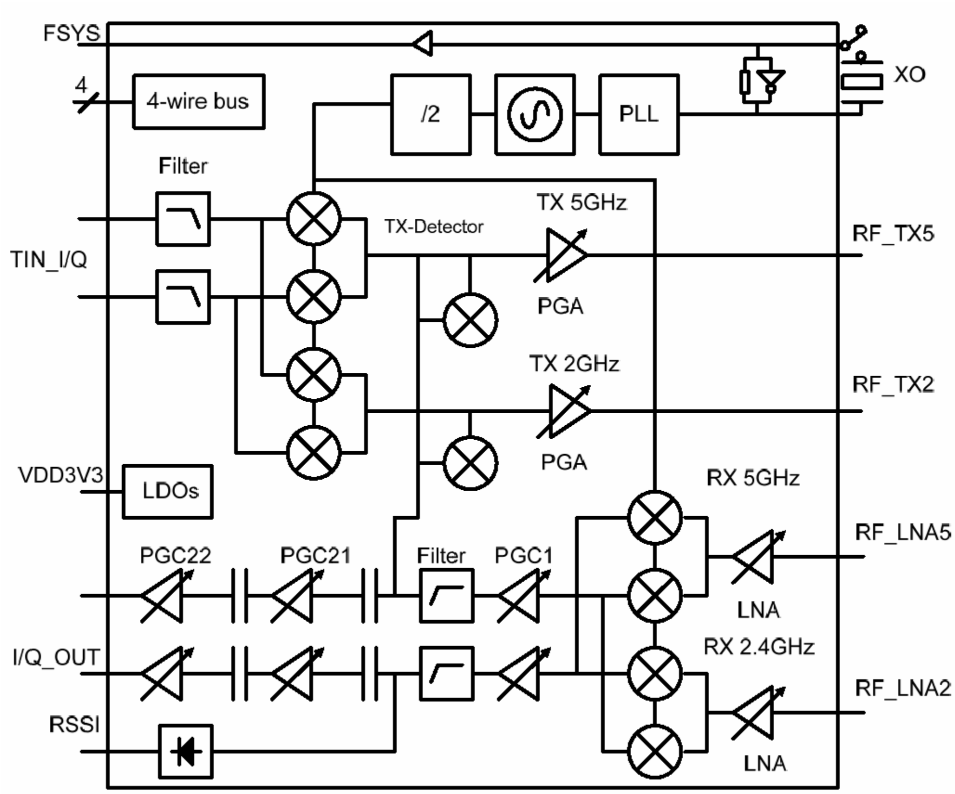
[Staszewiski, ISSCC08]

Detailed architecture for one band:

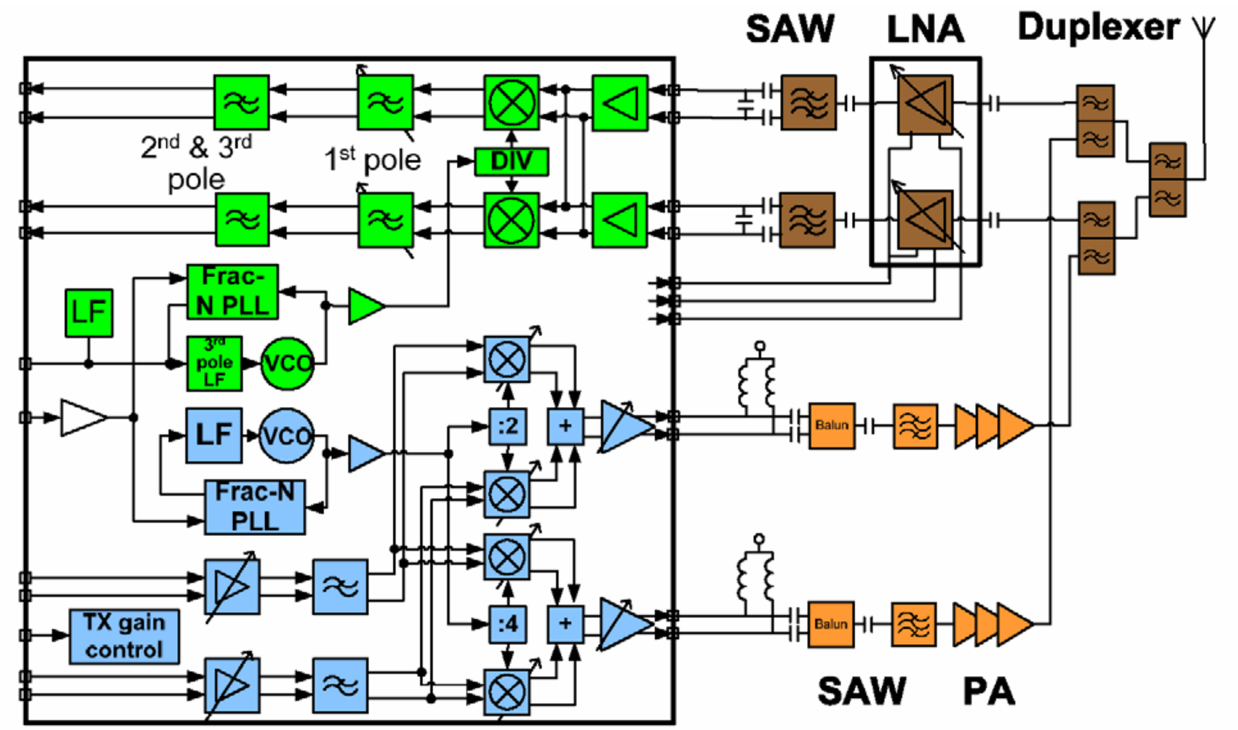


3. 11a/b/g Transceiver

[Simon, ISSCC07]



4. CDMA2000 Transceiver



[Zipper, ISSCC 07]