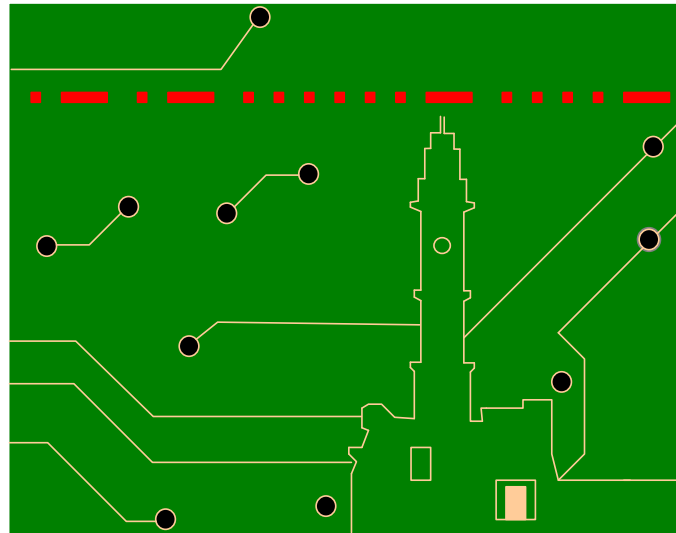


# ΤΗΛ412 Ανάλυση & Σχεδίαση (Σύνθεση) Τηλεπικοινωνιακών Διατάξεων

## Διάλεξη 5



Άγγελος Μπλέτσας

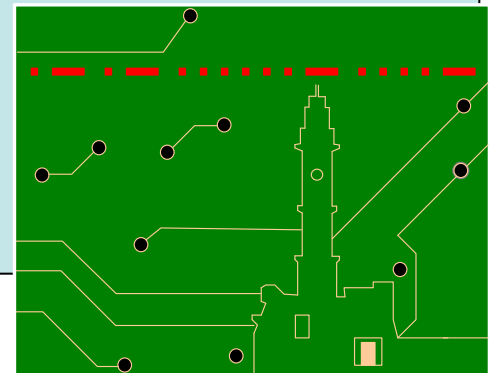
ΗΜΜΥ Πολυτεχνείου Κρήτης, Φθινόπωρο 2014

# Lecture 6 – Receiver Architectures (cont'd)

Previous lecture: Filter Quality Factor  $Q$ ,  
Heterodyne Receivers.

Today,

- Homodyne Receiver (and disadvantages)!
- Example of SuperHeterodyne (SuperHet) Receiver!
- Subsampling and Digital-IF Receiver.
- Dynamic Range of ADC.



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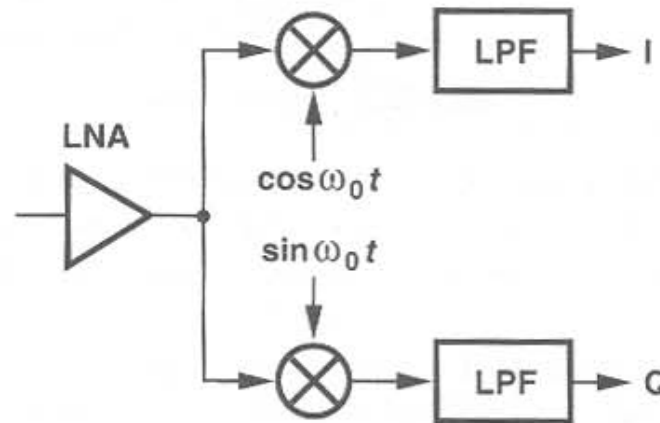
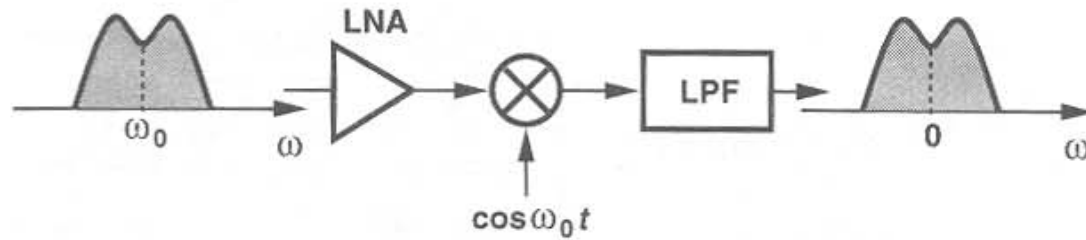
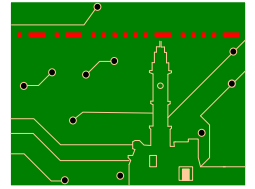
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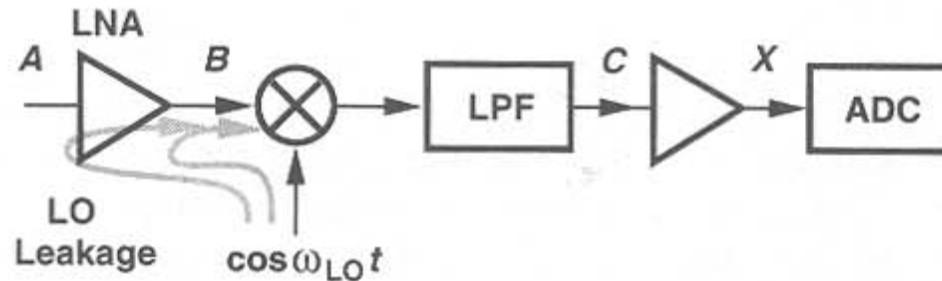
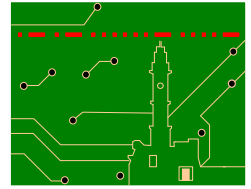
1934 advertisement for Radio Engineering as a lucrative job!

# Homodyne (zero-IF) Receiver



- Directly convert to DC ( $\omega_{LO} = \omega_{in} = \omega_1$ ,  $\omega_{IF} = \omega_2 = 0$ ).

# Basic Problems with zero-IF Receivers: DC Offset



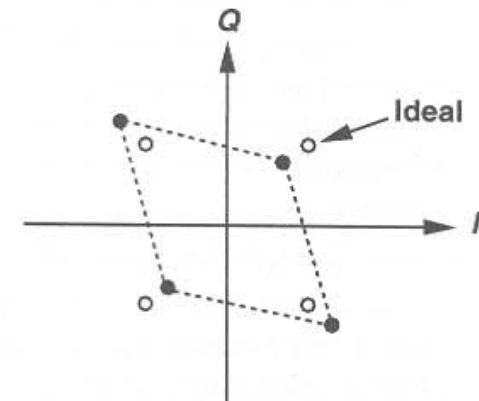
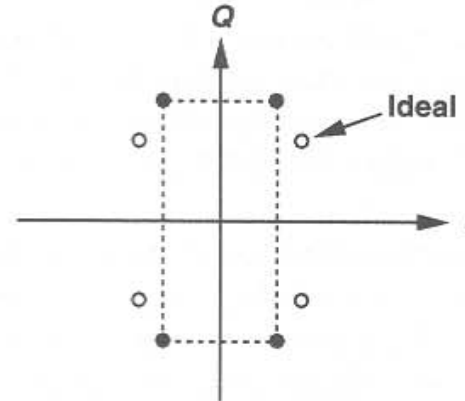
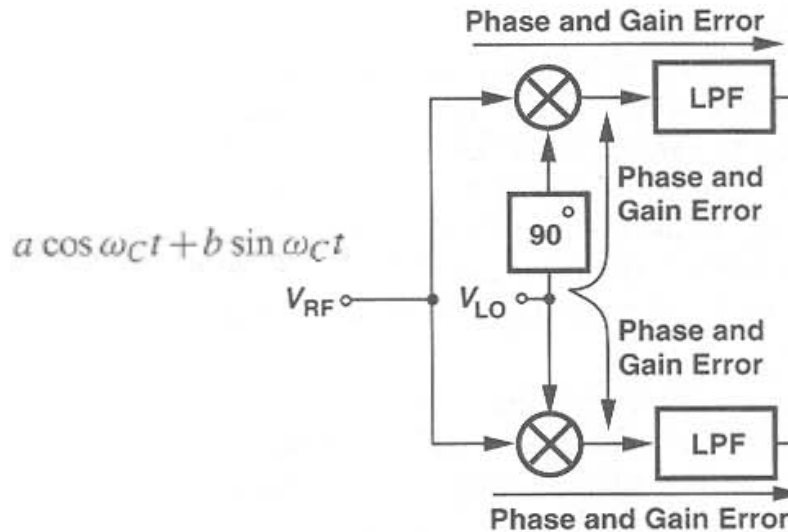
- Big Problem: LO leakage due to capacitive and substrate coupling (or bond wire coupling if LO is provided through an external wire).
- The higher the frequency, the more obvious the effect.
- leakage  $\Rightarrow$  DC offset  $\Rightarrow$  saturation of following stages!
- possible solutions: DC-free coding or DC-offset removal.

# Basic Problems with zero-IF Receivers: IQ Mismatch

$$\cos \theta \cos \varphi = \frac{\cos(\theta - \varphi) + \cos(\theta + \varphi)}{2}$$

$$\sin \theta \sin \varphi = \frac{\cos(\theta - \varphi) - \cos(\theta + \varphi)}{2}$$

$$\sin \theta \cos \varphi = \frac{\sin(\theta + \varphi) + \sin(\theta - \varphi)}{2}$$



$$x_{LO,I}(t) = 2 \left(1 + \frac{\epsilon}{2}\right) \cos \left(\omega_c t + \frac{\theta}{2}\right)$$

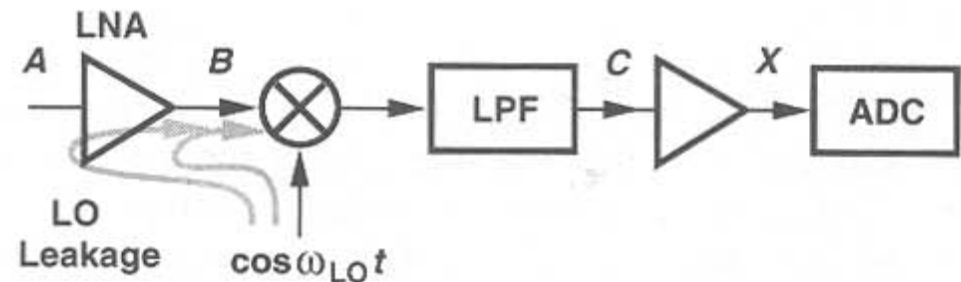
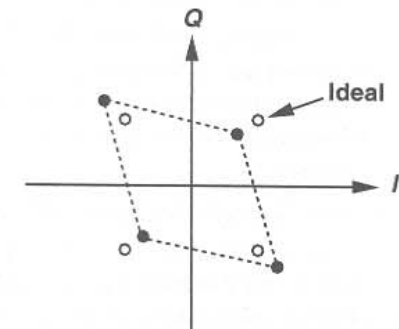
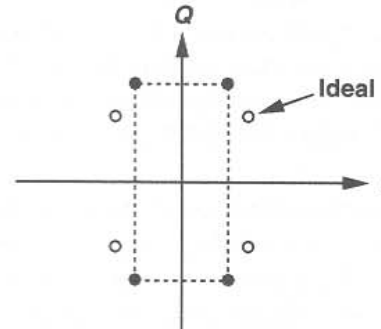
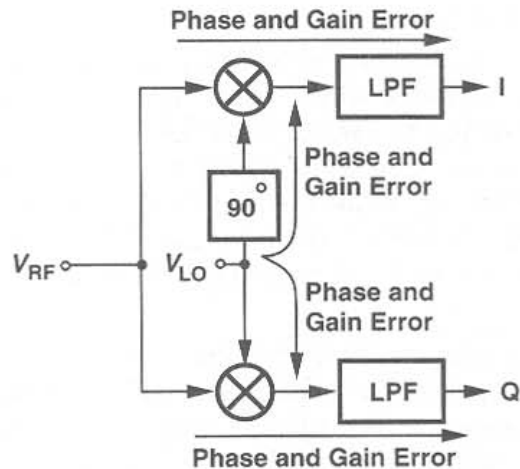
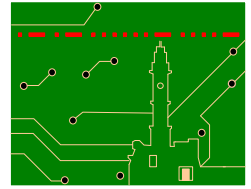
$$x_{LO,Q}(t) = 2 \left(1 - \frac{\epsilon}{2}\right) \sin \left(\omega_c t - \frac{\theta}{2}\right)$$

$$x_{BB,I}(t) = a \left(1 + \frac{\epsilon}{2}\right) \cos \frac{\theta}{2} - b \left(1 + \frac{\epsilon}{2}\right) \sin \frac{\theta}{2}$$

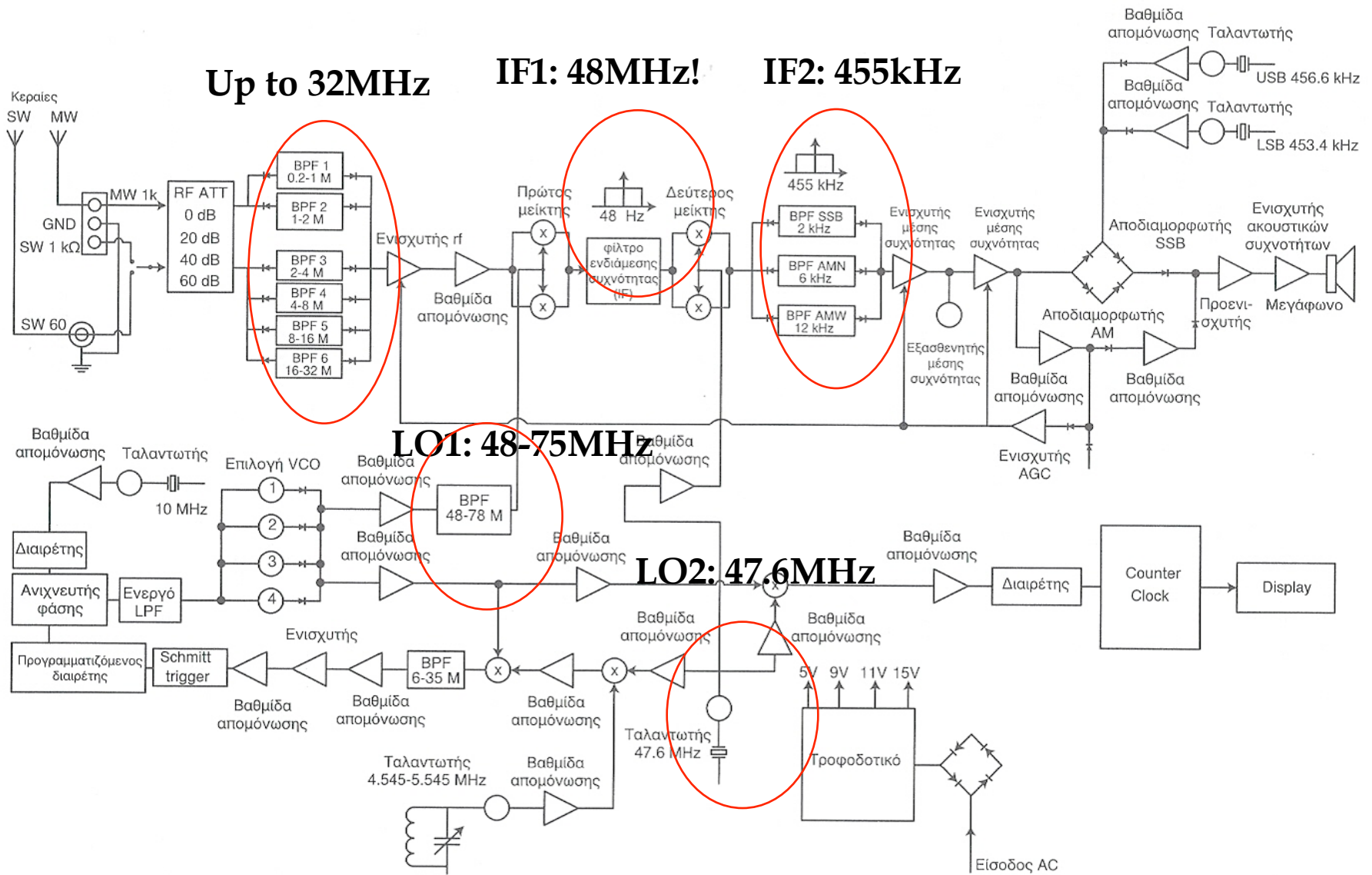
$$x_{BB,Q}(t) = -a \left(1 - \frac{\epsilon}{2}\right) \sin \frac{\theta}{2} + b \left(1 - \frac{\epsilon}{2}\right) \cos \frac{\theta}{2}$$

- Remember: The higher the (LO) frequency, the higher the parasitics (that is why this problem is smaller in heterodyne recs).

# Basic Problems with zero-IF Receivers



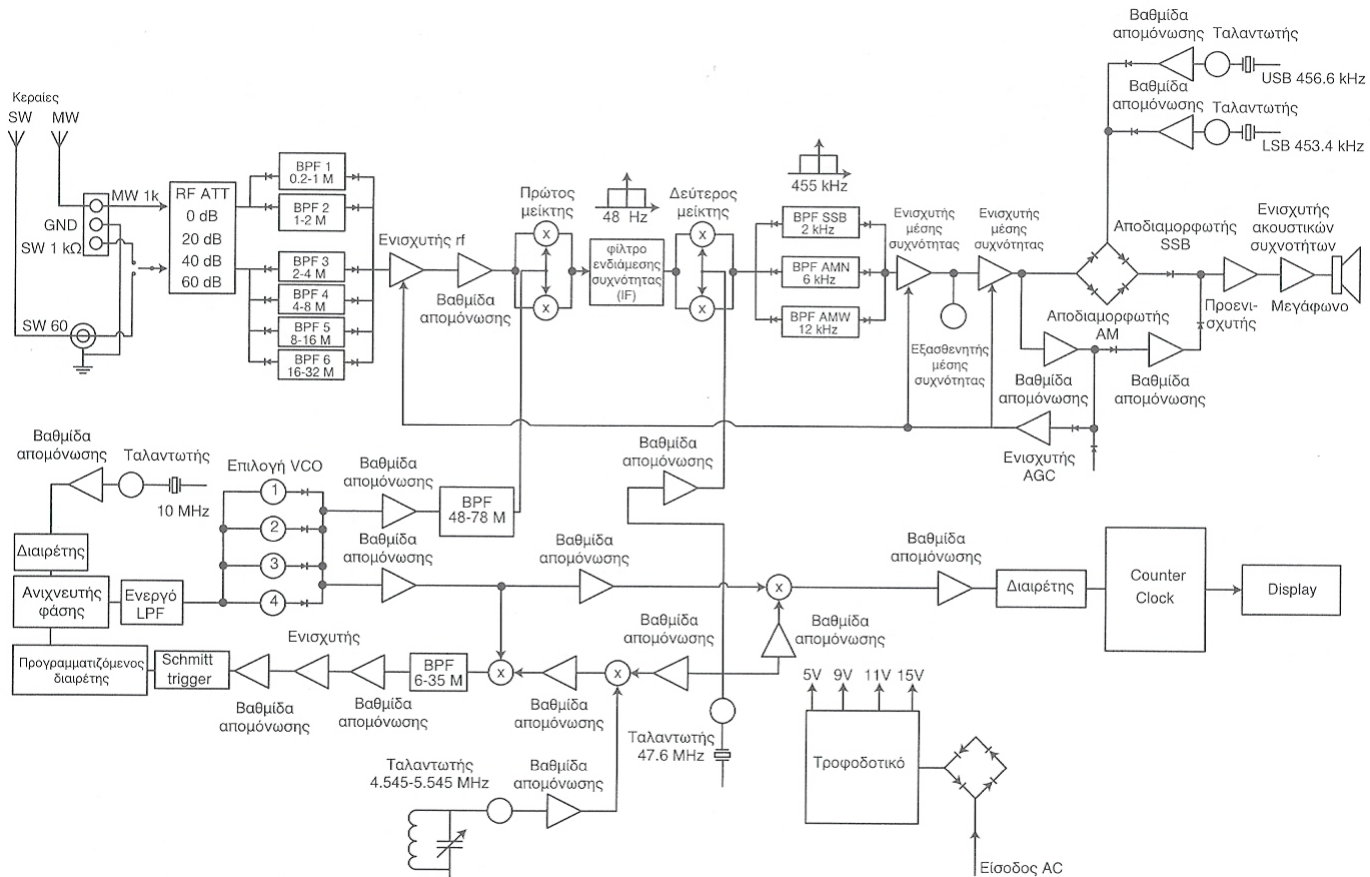
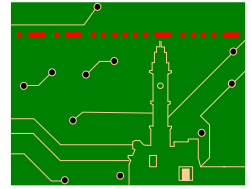
- Additional problems in zero-IF receivers: flicker ( $1/f$ ) noise and even order distortion (close to DC).



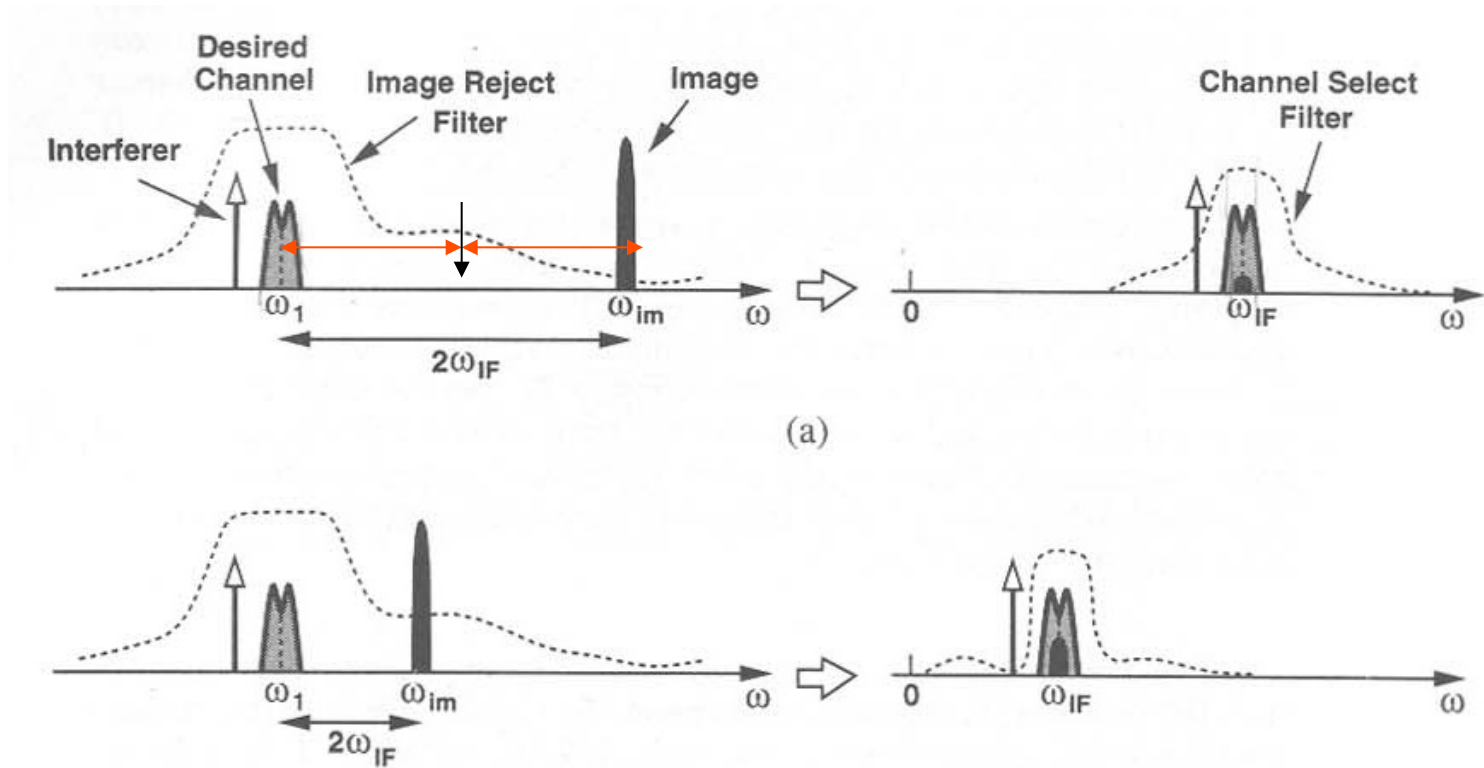
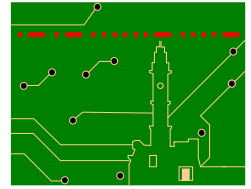
- Superheterodyne architecture:  $IF > \text{signal freq!}$



# What is the advantage of SuperHet?



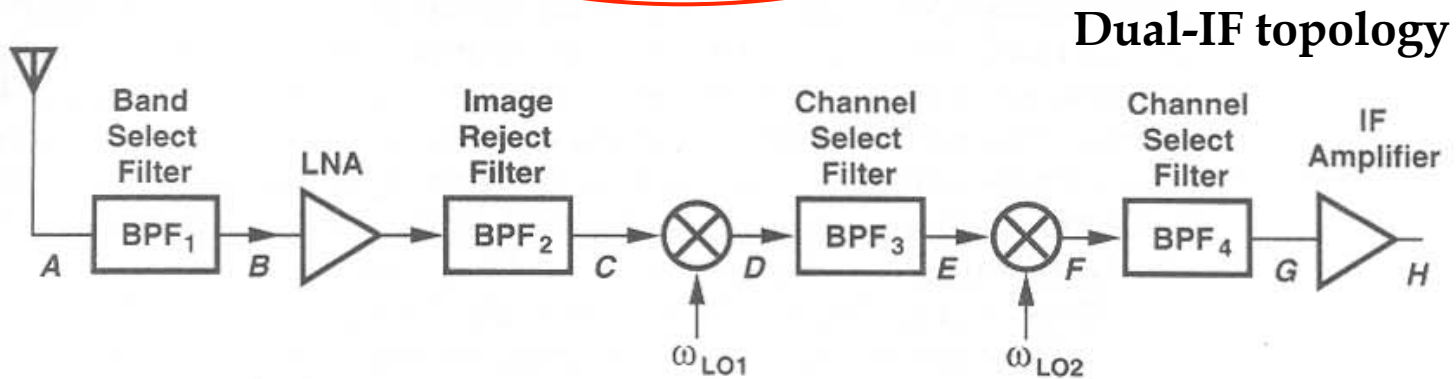
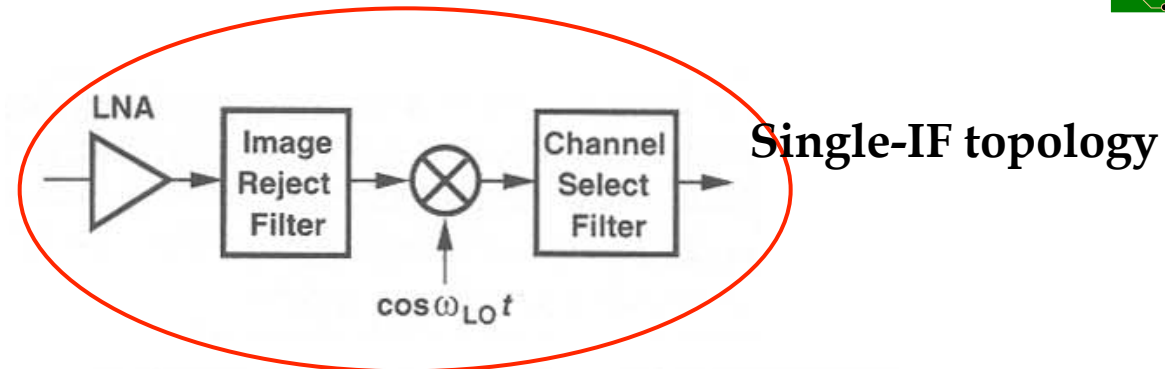
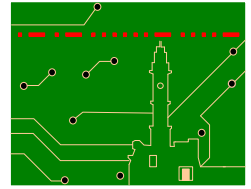
# Heterodyne Receiver: Selectivity vs Sensitivity Tradeoff



Not so simple, as it looks:

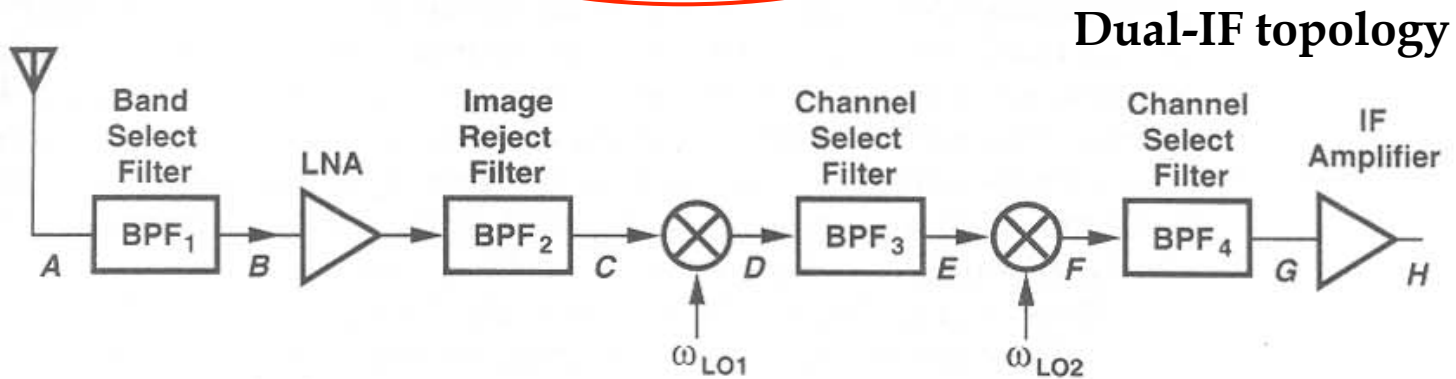
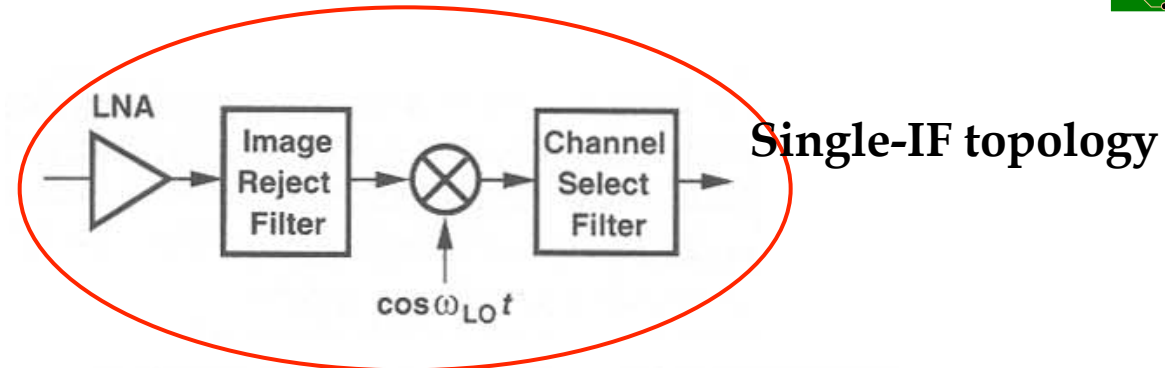
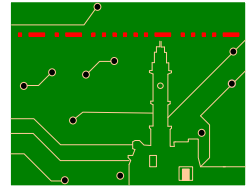
- higher  $\omega_{IF}$  results to better image rejection (better sensitivity)...
- however, higher  $\omega_{IF}$  results to worse channel selection (worse selectivity)!

# Addressing the tradeoff: dual-IF topology



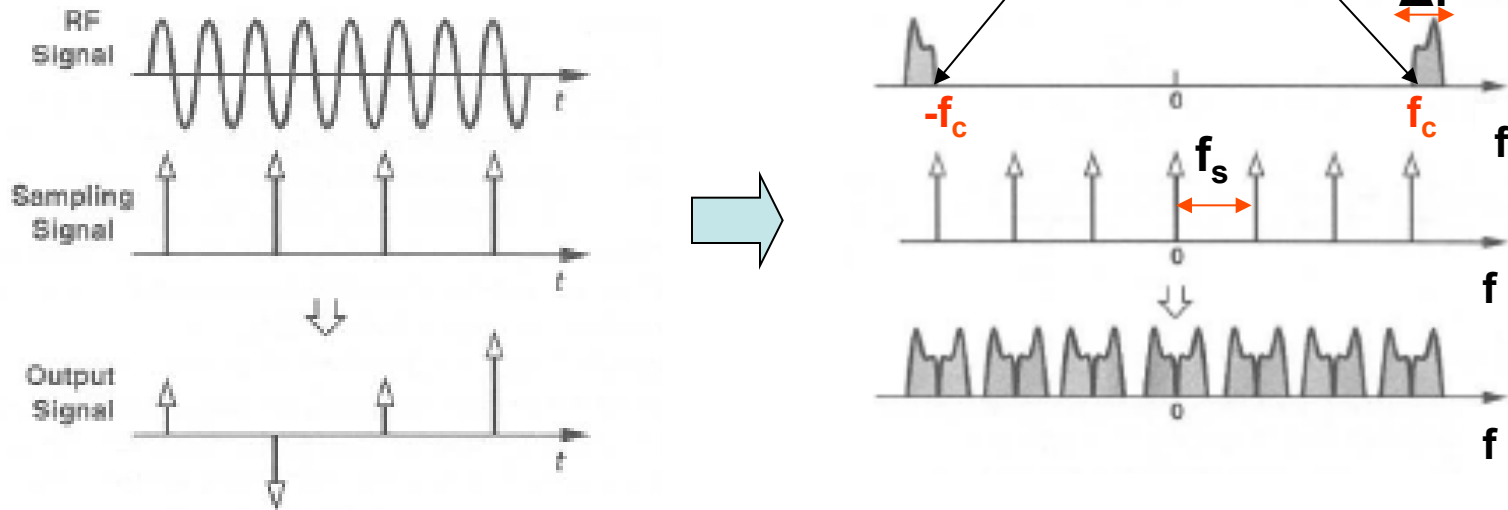
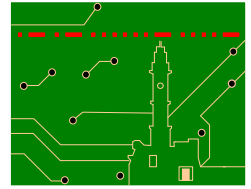
- up conversion: no limit on the IF frequency (as opposed to down conversion)...
- higher IF => better image rejection => better sensitivity...
- second conversion solves the selectivity problem!

# Addressing the tradeoff: dual-IF topology



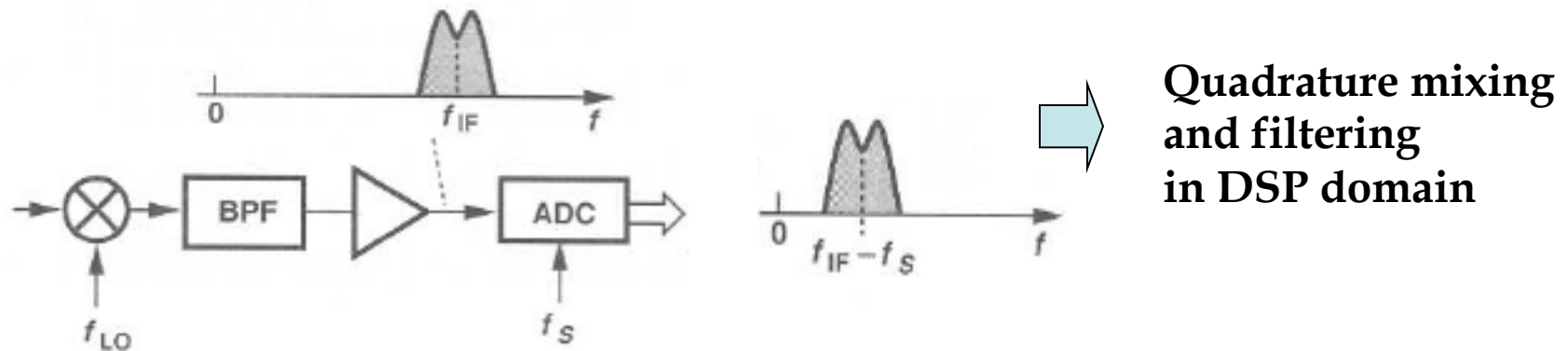
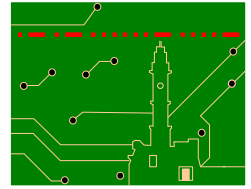
- What about the image of the second IF?
- It exists in a smaller frequency than the LO2 and has been filtered by the first image reject filter or the first band select filter.
- It is also efficiently filtered by the last (low-center freq.) channel select filter!

# Subsampling Receiver



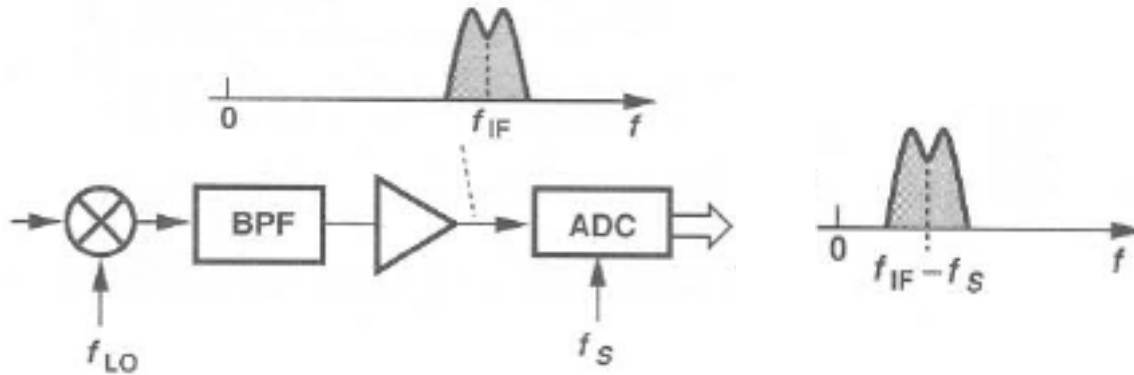
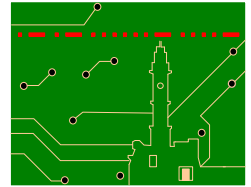
- For signal of passband BW  $\Delta f$ , sample with  $f_s > 2 \Delta f$ .
- Usually,  $f_c = m f_s$  ( $m$  integer)...
- For narrowband signals, simplifies local oscillator design!
- Sampling circuit much simpler than mixer design...
- Major drawback: aliasing of noise  
(down-converted noise is enhanced)!

# Digital-IF Receivers (no Signal Aliasing)

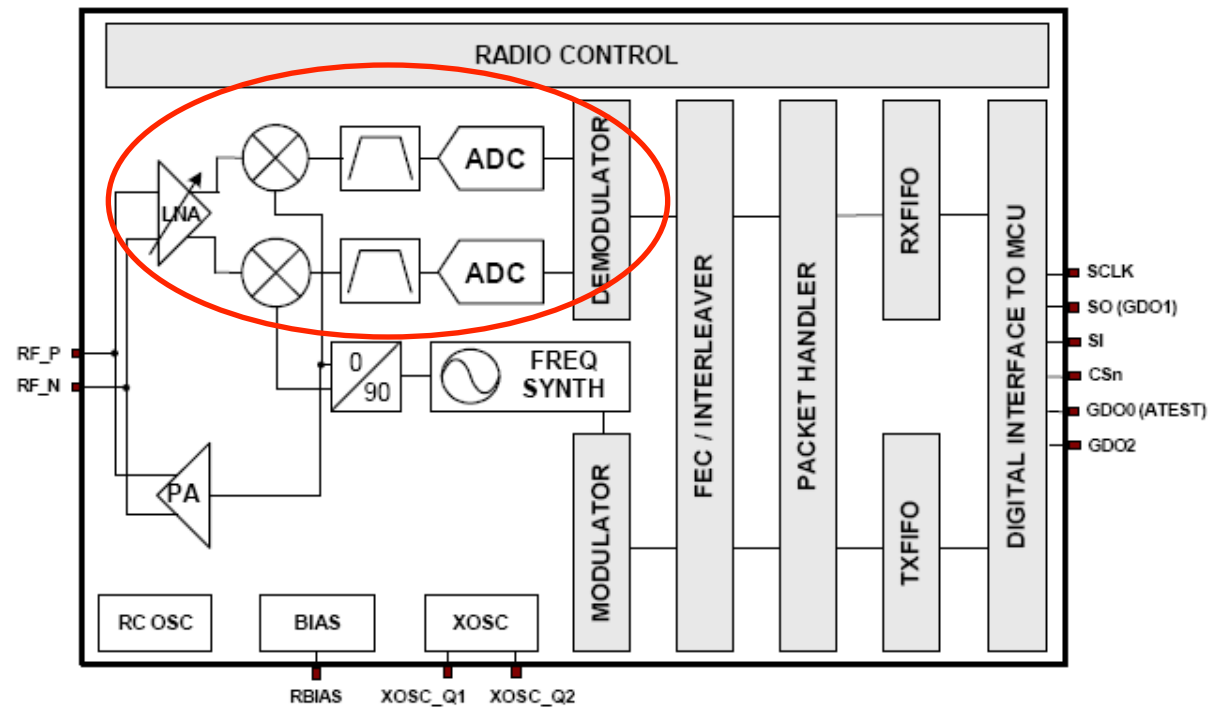


- What if we sample at slightly smaller frequency than the IF?
- ...get rid of Nyquist rate factor of 2 ( $2f_{IF}$ )...
- ...still, sampling rate  $f_s$  is not negligible and requires speed and linearity (intermodulation products due to limited filtering affect performance)
- usually, in base stations where multiple channels need to be processed simultaneously...

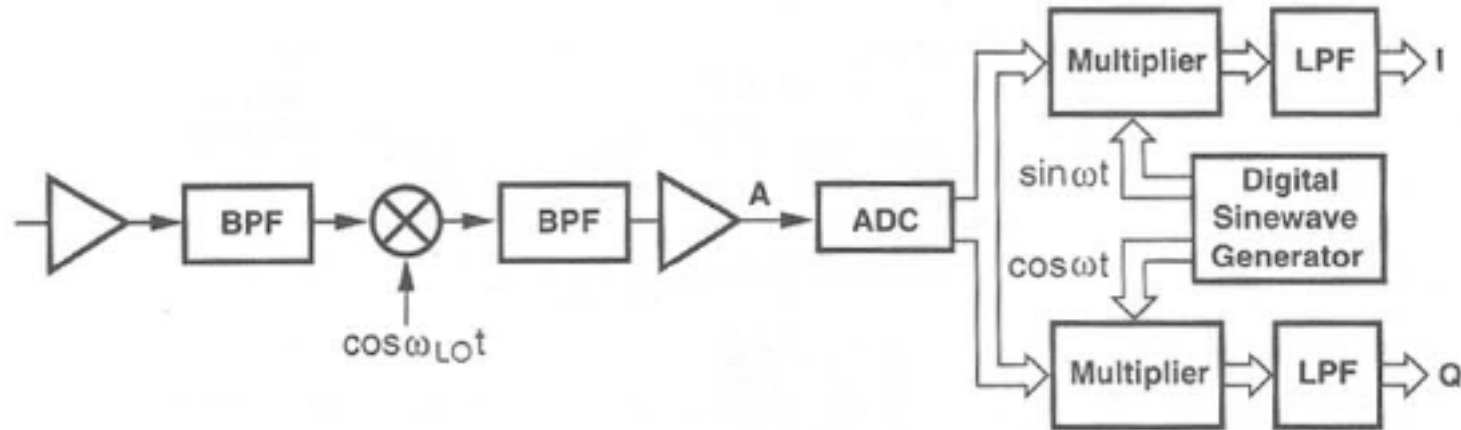
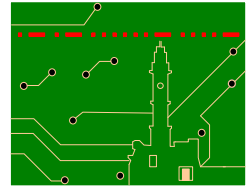
# Ερώτηση: Έχετε χρησιμοποιήσει Digital-IF Receiver?



Απάντηση: cc2500

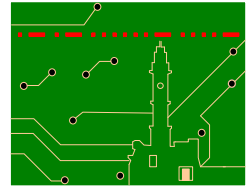


# General Architecture of Digital-IF Receiver

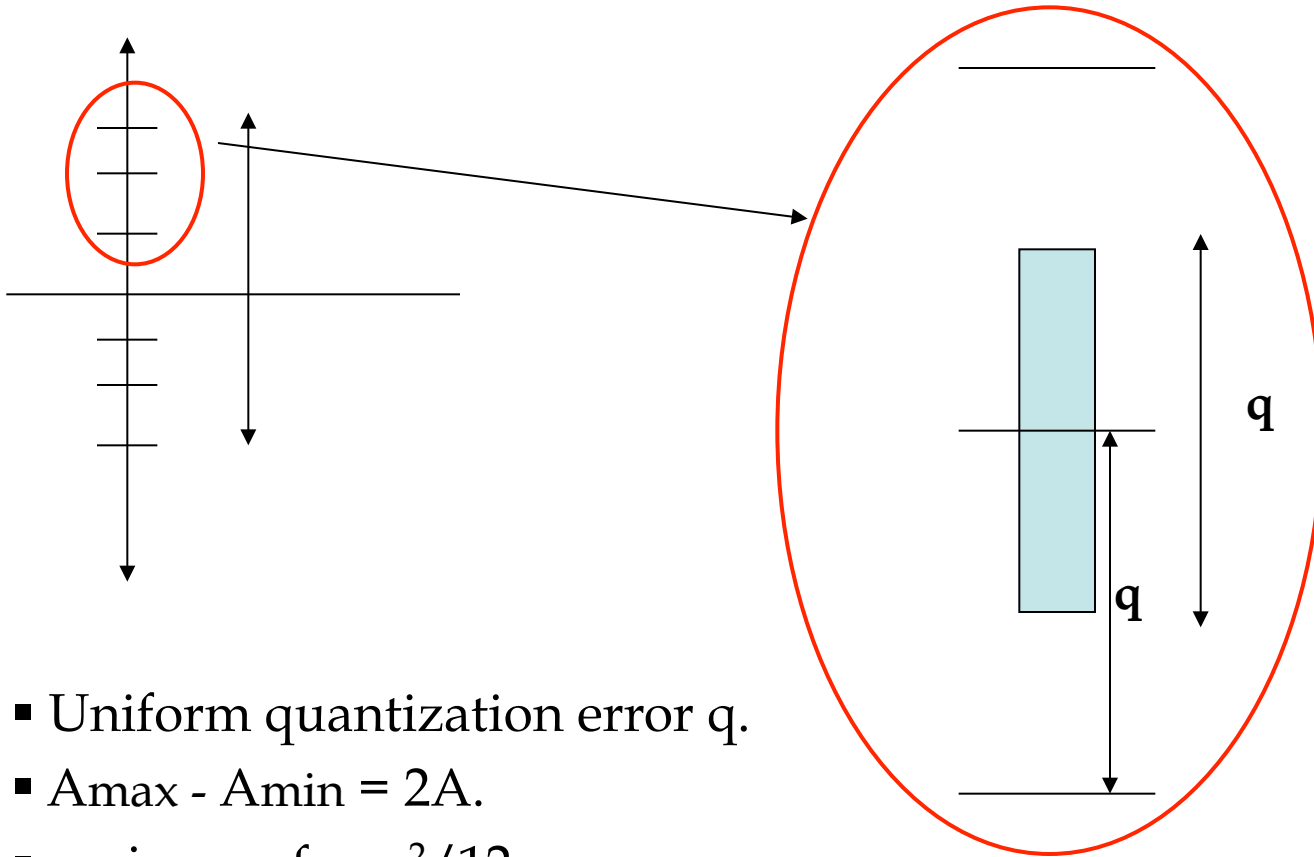


- ADC must have small non-linearity  
(in case the first BPF cannot suppress adjacent in frequency interferers).
- ADC must have high dynamic range  
(to accommodate path loss and fading – AGC at LNA is highly desired).
- ADC must be fast and consume reasonable amount of power!





# Dynamic Range of an ADC



- Uniform quantization error  $q$ .
- $A_{\max} - A_{\min} = 2A$ .
- variance of  $q$ :  $q^2/12$
- $q = 2A/(2^n - 1) \approx 2A/2^n \Rightarrow A = q 2^{(n-1)}$
- $S/N = (A^2/2) / (q^2/12) = 3 \cdot 2^{(2n-1)} = 1.5 \cdot 2^{2n} \Rightarrow 6n + 1.76$  [dB]

More than 14 bits of dynamic range is hard to achieve in practice, even if power dissipation and cost are not an issue.

# Questions?

