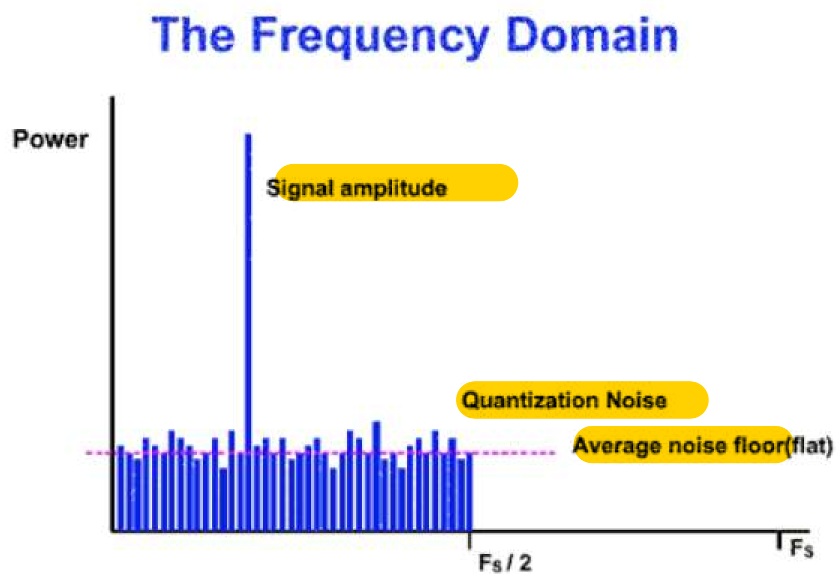
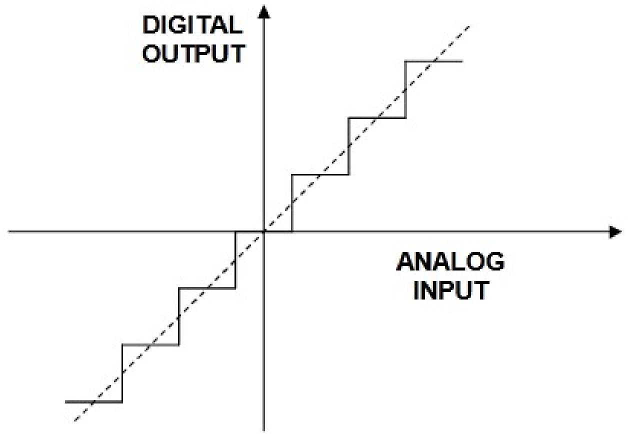
Digital IF Receivers

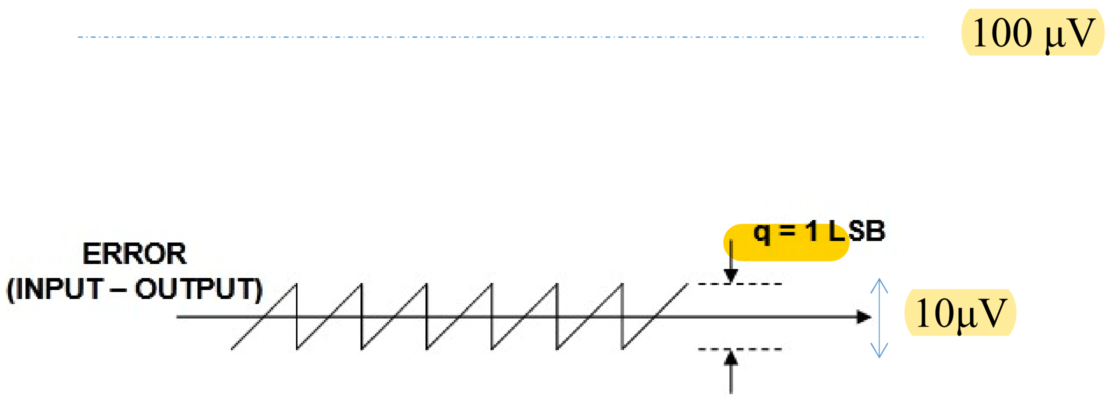
Required A/D converter performance :

· Requires sampling at least at the Nyquist rate $1/T_s = 2 \times f_{IF}$:

· The signal level is typically as small as $\approx 100\ \mu$V(-80 dBV) and the quantization and thermal noise of the ADC must be smaller than $10\ \mu$V(-100 dBV).

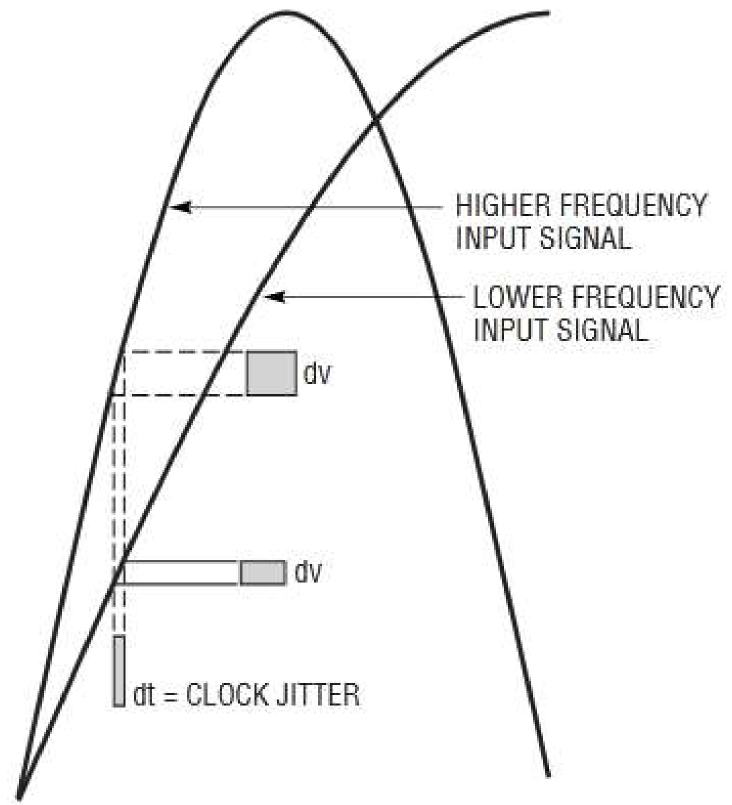






· ADC is affected by the clock jitter :
the higher the IF frequency sampled the higher the signal slew rate and the error voltage.

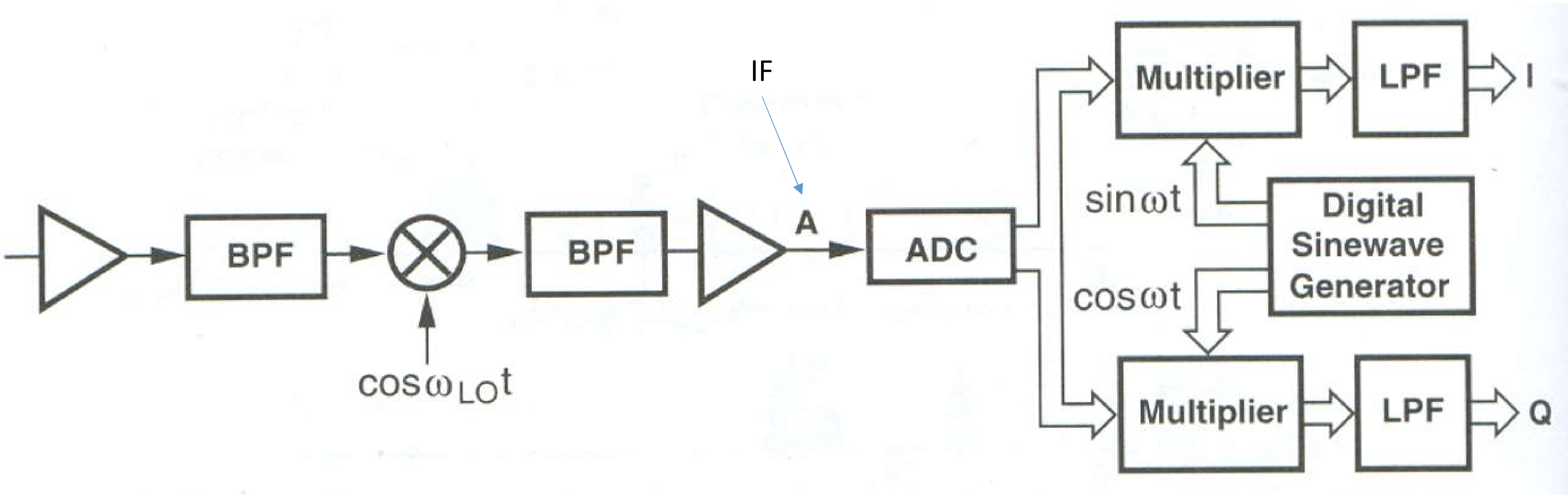
· 14 bits ADC from 50 to 200 MHz are now available : software radio



- ADC dynamic range should be large enough to accommodate variations in the signal level due to path loss and multipath fading.

$$\text{ADC} \quad \mathrm{DR} = 20\log_{10}\left(\frac{\left(2^{N}-1\right)LSB}{LSB}\right) \approx 6.02\times N(dB)$$

- BW of ADC should be sufficient to the IF BW. e.g. Say an ADC has Analog i/p bw of 500 MHz (this is the analog 3 dB BW) with sample rate 100 Msps. This means that it can sample frequencies till 50 MHz.



IF
A
BPF
BPF
ADC
$\cos\omega_{LO}t$
Multiplier
LPF
I
$\sin\omega t$
Digital Sinewave Generator
$\cos\omega t$
Multiplier
LPF
Q

Sampling IF

- If the sampling is at a rate $f_s = 1/T_s$ slightly smaller than f_{IF} the signal is downconverted to $f_{IF} - f_s$.
- This relaxes the sampling rate by a factor 2 since the Nyquist rate if $2 \times f_{IF}$.
- Requires high-speed and high linearity sampling and hold circuits.
- Works only if $f_{IF} – f_s$ is greater than Δf.

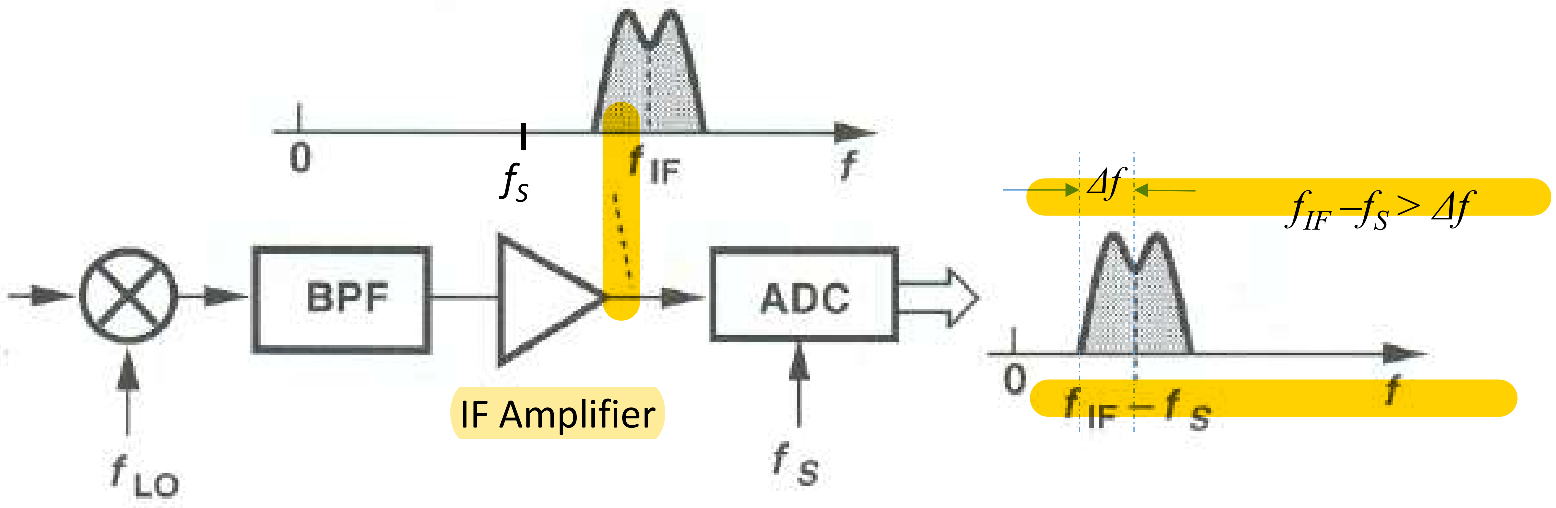


Figure 5.32 Sampling IF architecture.

Subsampling Receivers

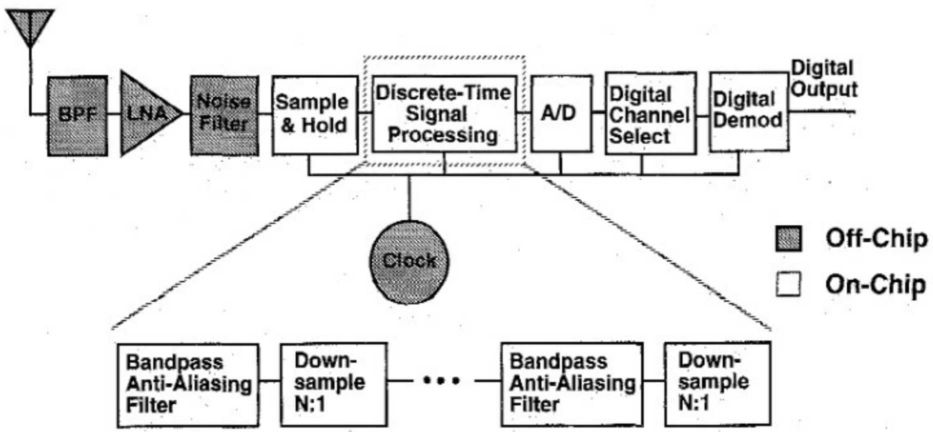
- Signal is sampled at a rate f_s equal or larger than $2 \times \Delta f$.
- Time and frequency representation of sampling:

$$s(t) = \sum_{m=-\infty}^{\infty} \delta(t - mT_s) \Leftrightarrow S(f) = \frac{1}{T_s} \sum_{n=-\infty}^{\infty} \delta\left(f - \frac{n}{T_s}\right)$$

- If the IF signal is $x_{IF}(t)$ the sampled output is in the time and frequency domain:

$$x(t) \times s(t) \Leftrightarrow X(f) * S(f)$$

- This generates multiple replica of the spectrum spaced every $1/T_s$. (see Figure 5.33).
- No aliasing arises since the sampling rate f_s is equal or larger than $2 \times \Delta f$.



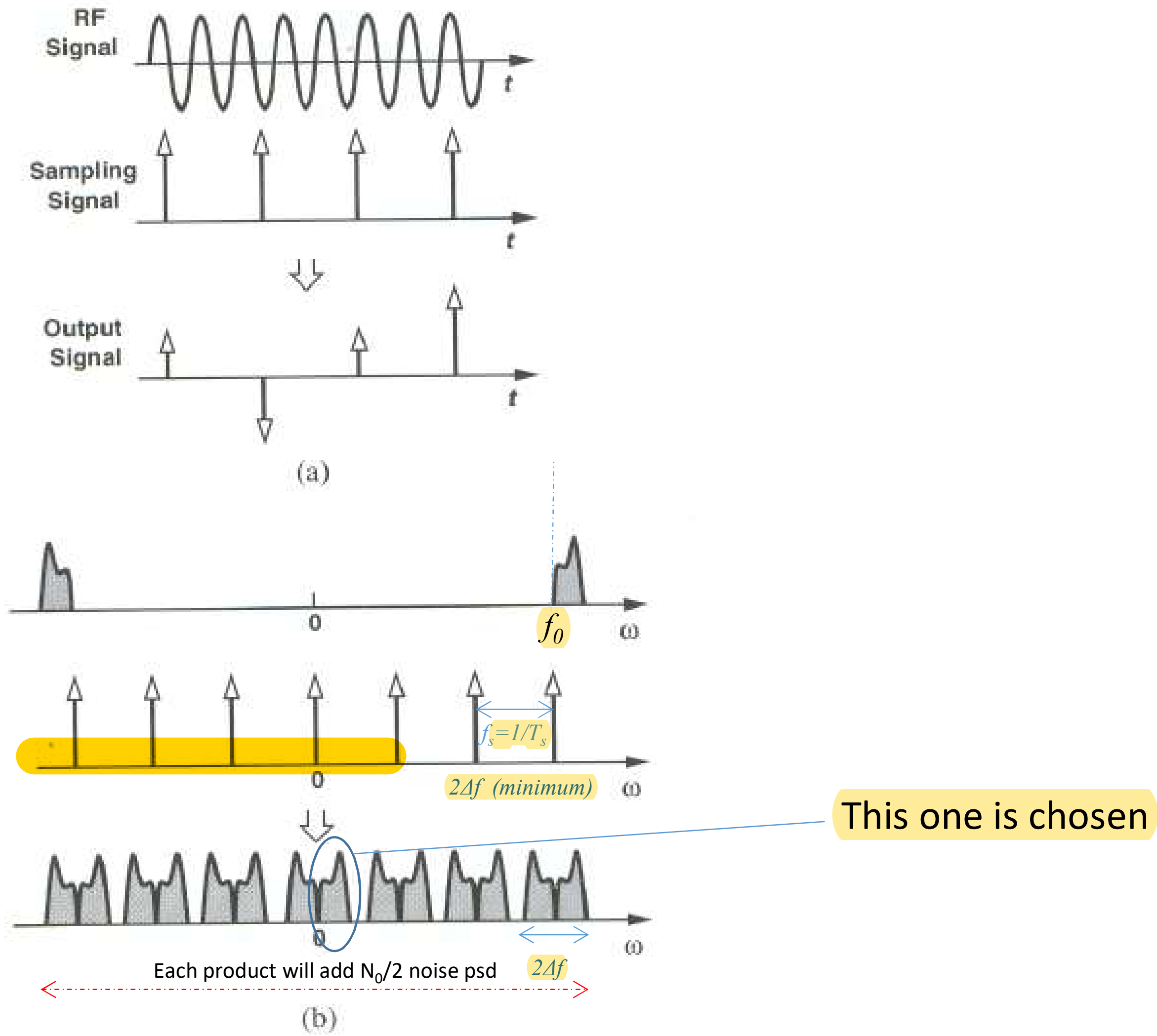
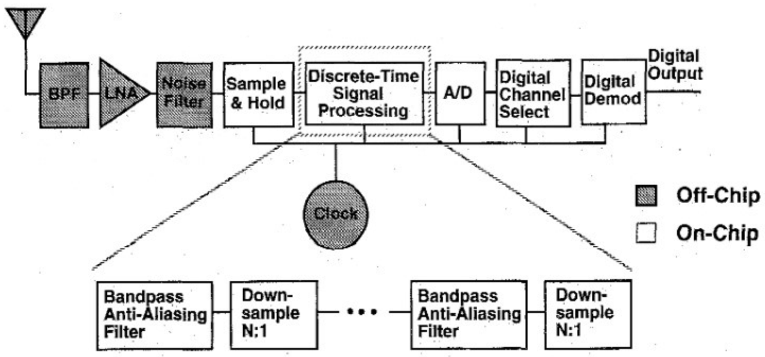


Figure 5.33 Subsampling in (a) time and (b) frequency domains.

Problem with Subsampling Receivers

Drawbacks

- The noise in the entire front end bandwidth is folded into the IF bandwidth Δf.
- The noise is multiplied by a factor 2m with $m = f_0/\Delta f$ (the factor 2 is due to the folding from the negative frequency spectra).
- The clock phase noise power is also amplified by m^2 (see reference below).



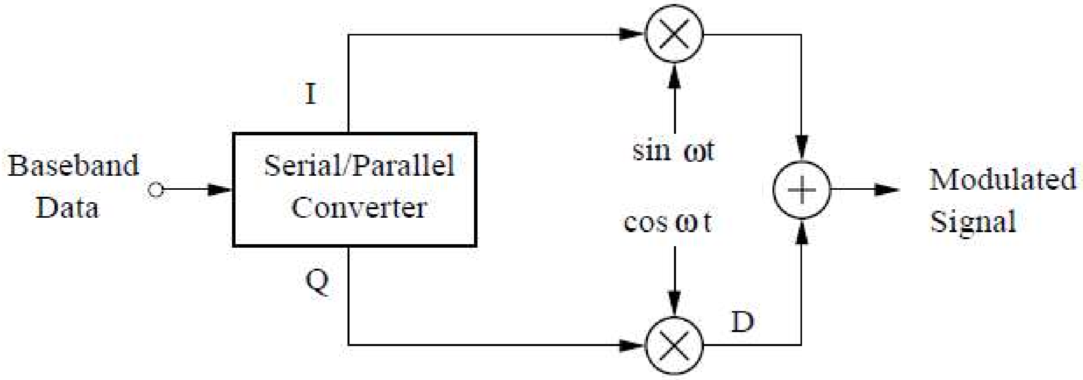
D.H Shen et al., "A 900 MHz RF Front End with Integrated Discrete Time Filters," IEEE Journal of Solid State Circuits, vol 31, pp 1945-1954, Dec 1996

Transmitter Architectures

- Less variety of approaches because noise, interference rejection and band selectivity are more relaxed.
- Types of architectures:
  - Direct conversion: homodyne
  - Two-step conversion: heterodyne
- Signal conditioning. Examples:
  - Baseband pulse shaping, e.g. raised-cosine pulses (Figure 5.37)
  - GMSK baseband generation

Issues

- Mismatch in I and Q paths → gives rise to cross talk.
- PA efficiency → duplexer can cause 2-3 dB loss (corresponding to 370 mW for 1W PA o/p. Since PA efficiency rarely exceeds 50% this can lead to around 700 – 800 mW additional power wastage.



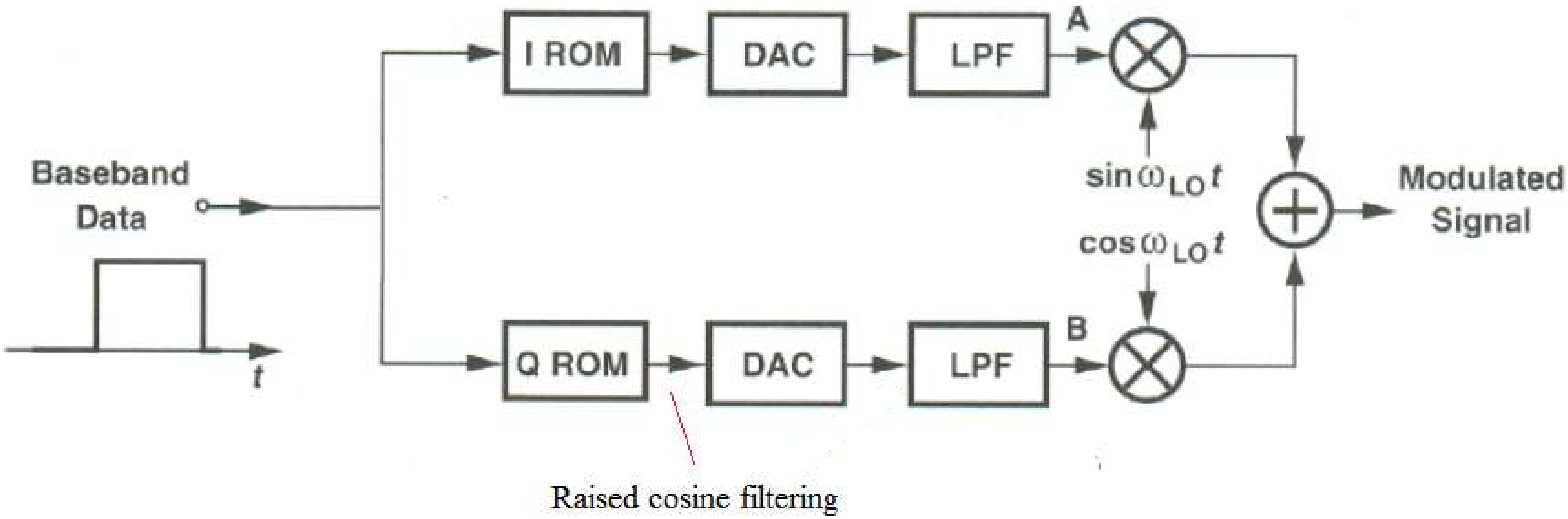

Baseband
Data
t
I ROM
DAC
LPF
A
Q ROM
DAC
LPF
B
sin ωLO t
cos ωLO t
Modulated
Signal
Raised cosine filtering

Fig 5.37

- First level modulation (recall MSK)
- Phase continuity needs to be maintained
- Digital implementation more accurate

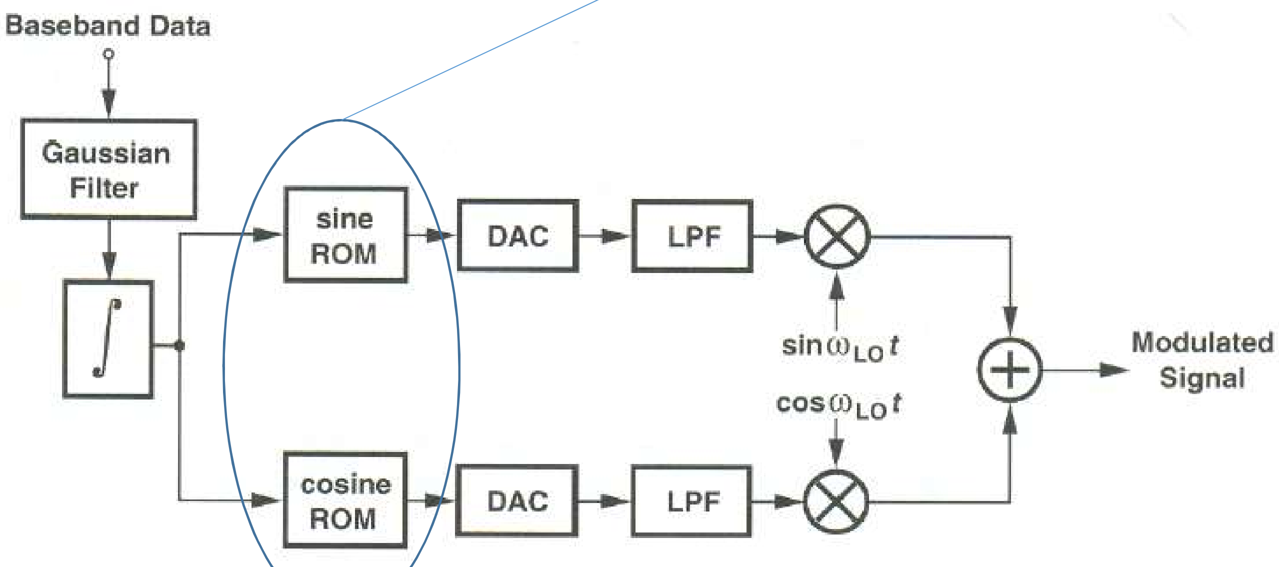


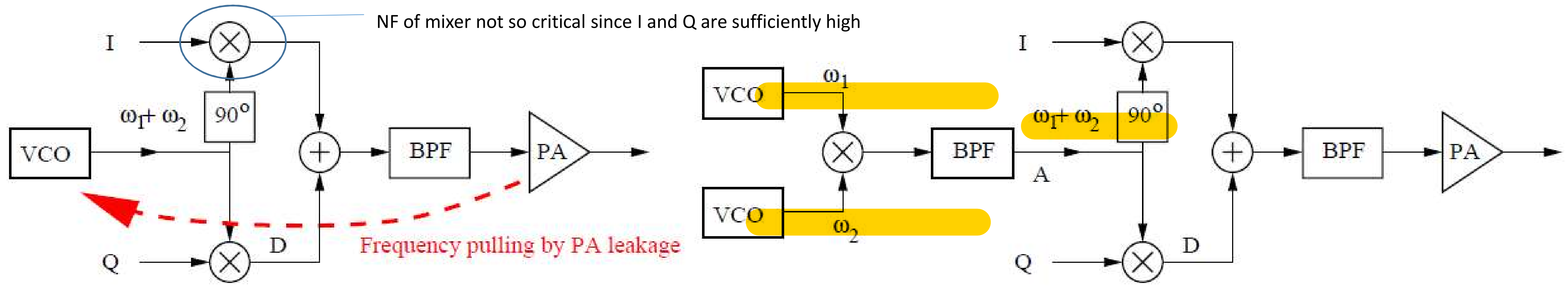
Figure 5.38 Baseband pulse shaping in GMSK systems.

Direct Conversion Transmitter

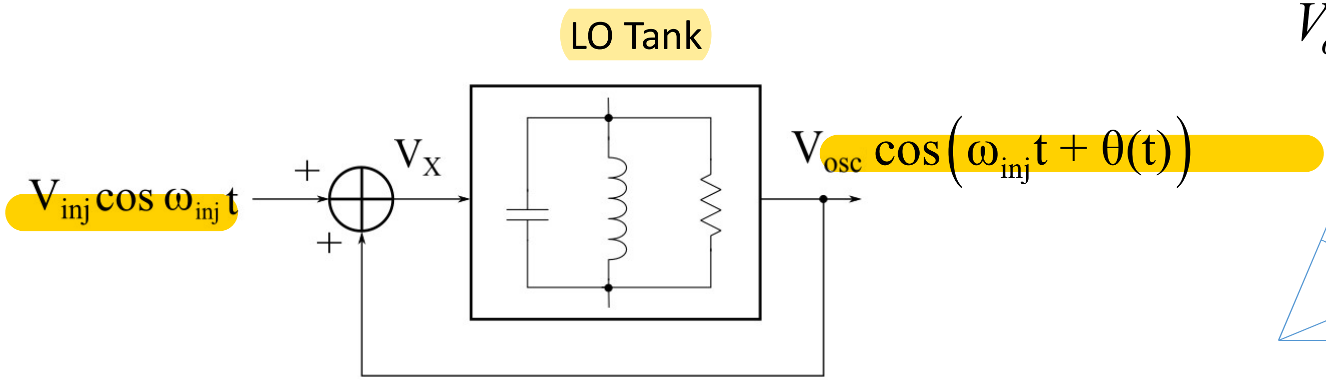
- Modulation and up conversion is performed in one step. Cross talk is more.
- Problem the PA output corrupts the oscillator spectrum by frequency pulling(due to injection locking when frequencies are close).

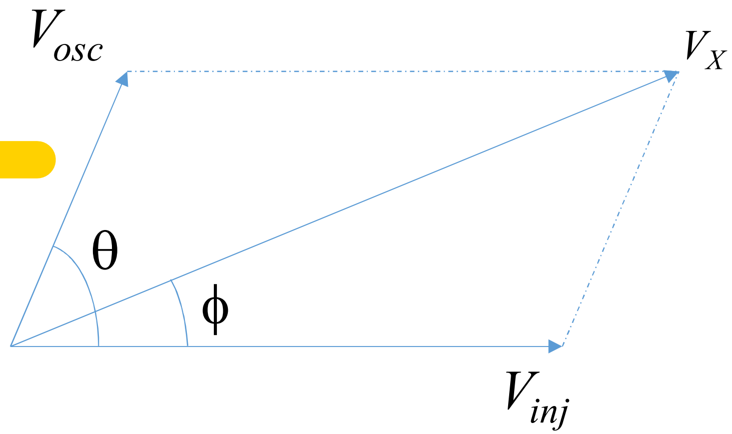
Solution:

- PA o/p frequency must be sufficiently different from the LO frequency.
- This can be achieved by using a mixer to create the carrier ω_c by adding two LO frequencies. $\omega_c = \omega_1 + \omega_2$



Injection Pulling





$\frac{d\theta(t)}{dt}$ is a measure of the injection pulling.

If ϕ is small, ($|V_{inj}| >> |V_{osc}|$), V_X will follow V_{inj} even if $\frac{d\theta}{dt}$ is small.

Conversely if ϕ is near $\frac{\pi}{2}$, ($|V_{inj}| << |V_{osc}|$), V_X will not follow V_{inj} even if $\frac{d\theta}{dt}$ is large.

Two Step Transmitter

See Figure 5.42

- First step: the baseband I and Q undergo quadrature modulation at ω_1.
- The first BPF suppresses the harmonics of the IF.
- Second step: the IF is up converted to the carrier $\omega_2 + \omega_1$.
- The second BPF removes the undesired image frequency. (50 to 60 dB rejection typical).
- A single-sideband mixer (same as image rejection mixer) can also be used.

Channel filter can also be used instead of BPF

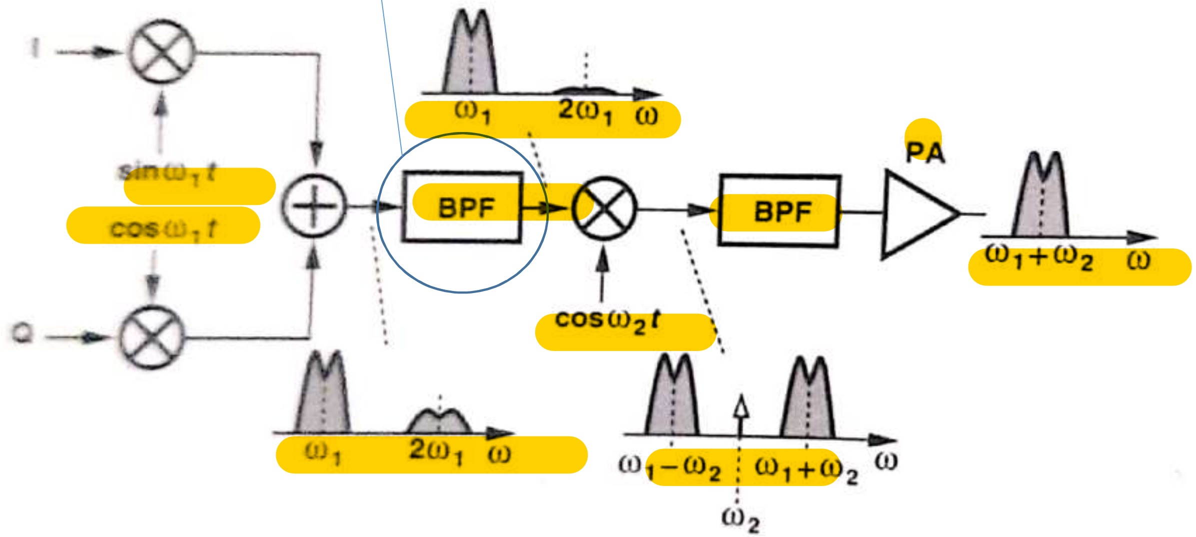


Figure 5.42 Two-step transmitter.

Two Step Transmitter

Advantages

- Cross talk is less since I/Q modulation takes place at lower frequency.
- Channel filter may be used at first IF to limit unwanted signals in adjacent channel.
- Reduces LO pulling by PA since they are at different frequencies.

Disadvantages

- Second BPF needs to be high Q to reject unwanted signals.
- More power consumption, more mixer spurs.