EEEN3006J

Wireless Systems

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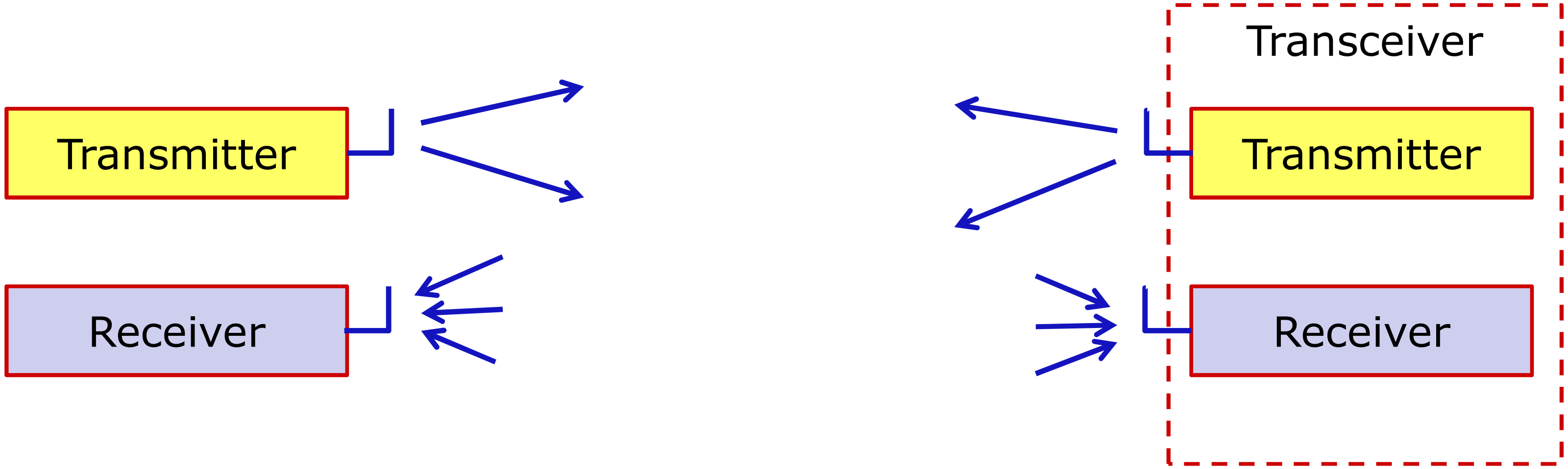
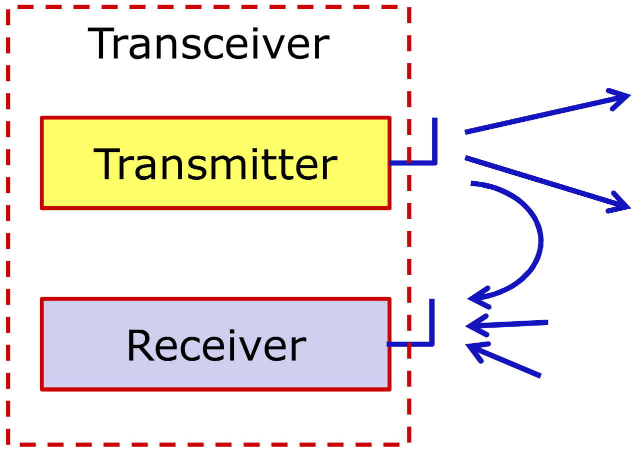
Transceiver ?



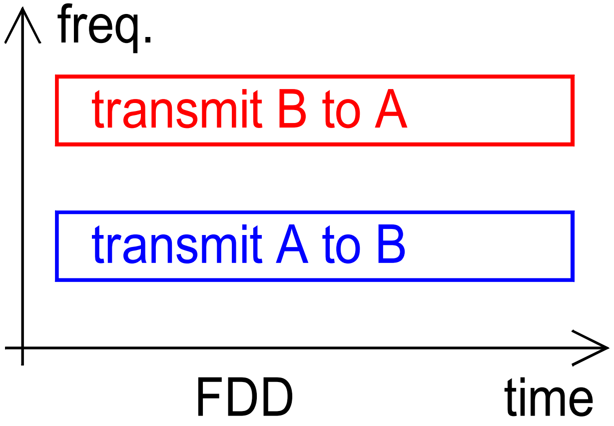
- Combined transmitter and receiver
  - most systems want 2-way communication
  - can share some blocks between tx and rx
- Problems
  - transmitter is major source of interference to receiver
  - transmit signal power >>> receive power
  - other unwanted interactions...

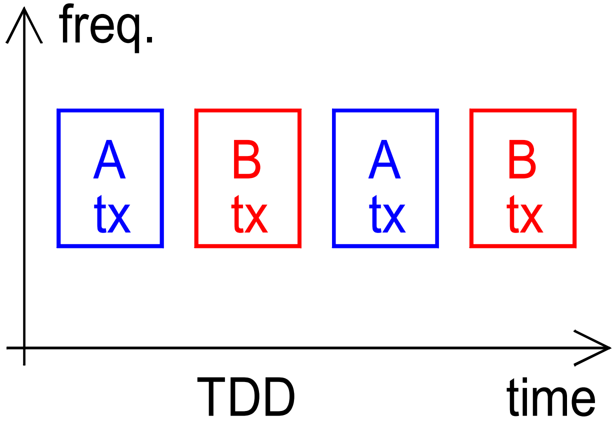
Transmitter Interference



- Cannot keep transmit signal out of receiver
  - even small fraction of tx signal overloads rx...
  - antenna often shared
- Transmit power could be mW to W
  - short-range device: +10 dBm = 10 mW
  - 3G phone: +24 dBm = 250 mW max (class 3)
- Receive power often < 1 pW
  - 3G phone: sensitivity -117 dBm = 2 fW
    - minimum power, in 3.84 MHz bandwidth, for BER 10^{-3}
    - 141 dB below max transmit power...

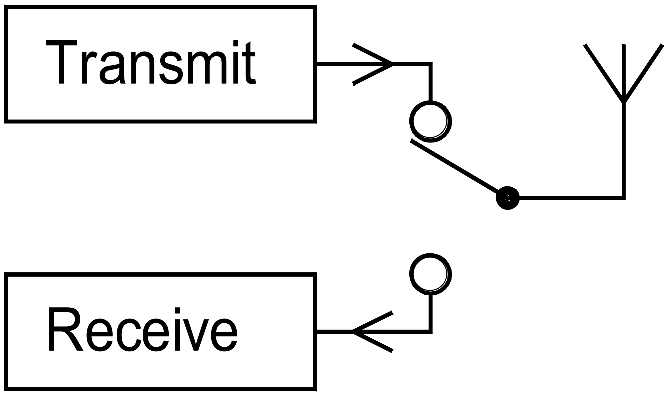
Solutions

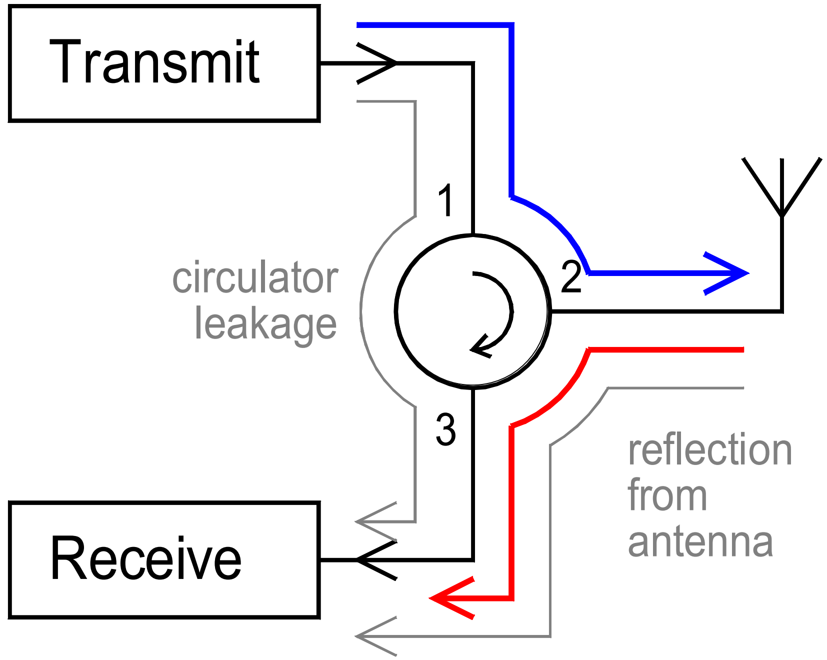




- Transmit and receive at different times
  - simplex or half-duplex system
    - one way at a time, e.g. push-to-talk system. (“Over“)
  - time-division duplex (TDD)
    - gives full duplex service to user, in digital system
    - transmit at twice bit rate for half of time
- Transmit and receive on different frequencies
  - frequency-division duplex (FDD)
  - easy to arrange if only two transceivers
    - e.g. mobile phone and base station
  - not for peer-to-peer network

Shared Antenna

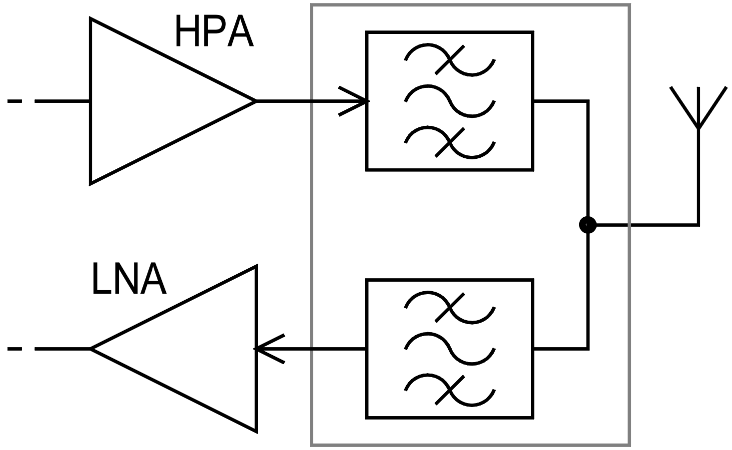


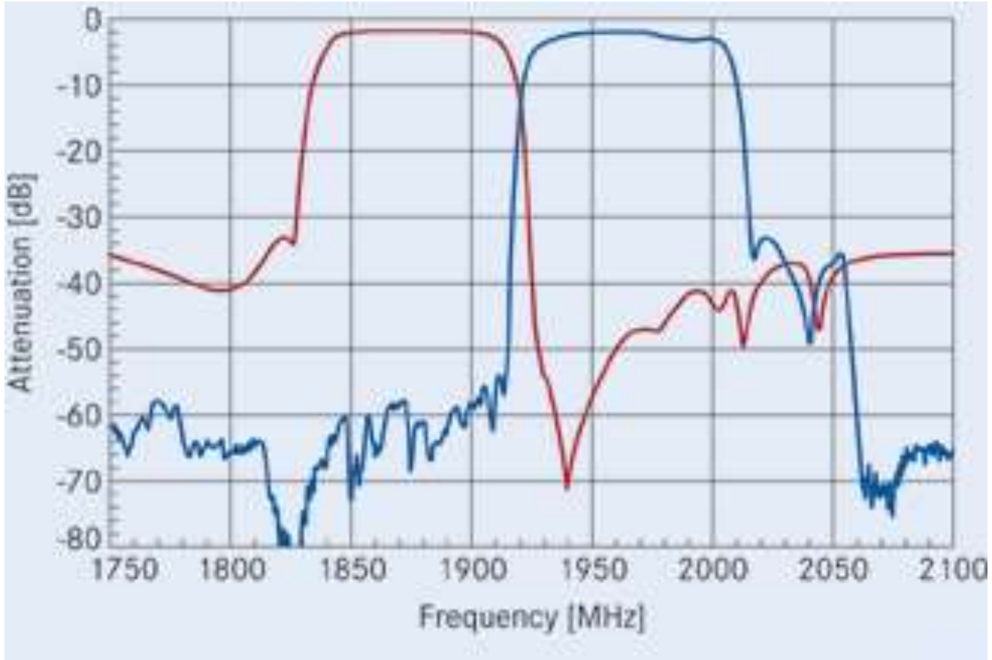


- Switch for time division duplex
  - transmit/receive switch – simple solution
- Circulator: 3-port network
  - input port 1 -> output port 2
  - input port 2 -> output 3; etc.
  - insertion loss 0.3 – 1.3 dB
  - but isolation only 16 – 23 dB

www.dpvrf.com

Duplexer

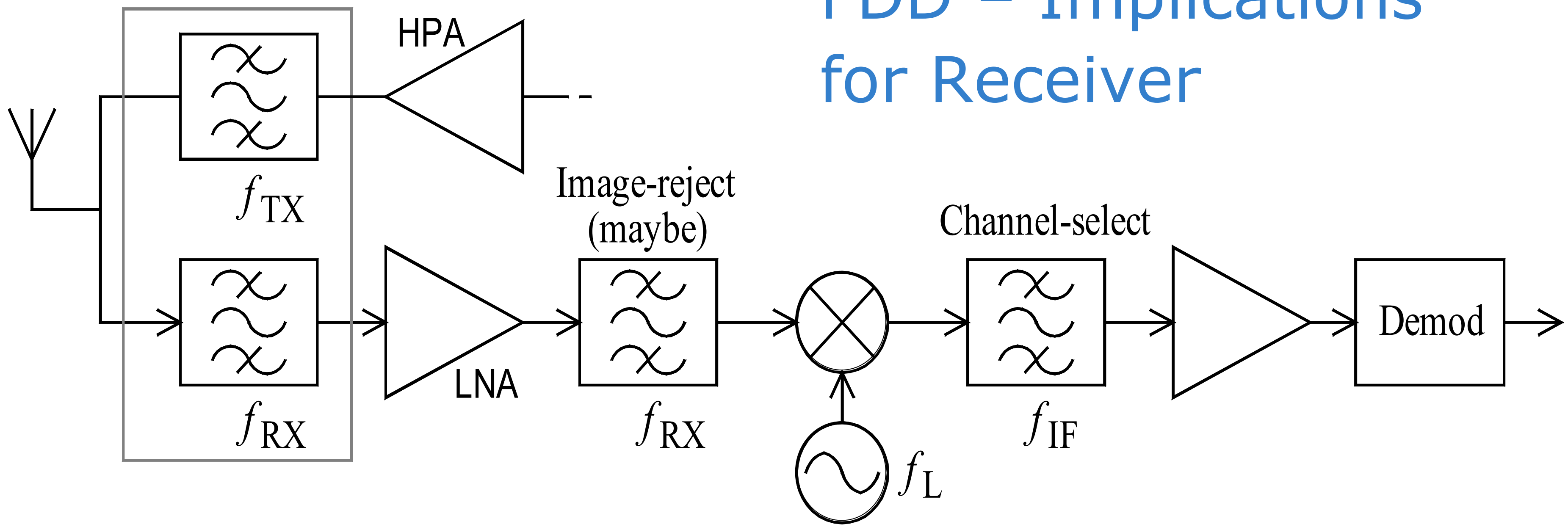




www.epcos.com

- Pair of filters – for FDD transceiver
  - can get 60 – 80 dB isolation, if good freq. gap
- Transmit path – pass transmit signals
  - attenuate any output in receive band
  - can also act as final filter in transmitter
- Receive path – pass receive signals
  - attenuate signals in transmit band
  - can also act as band select filter for receiver

FDD – Implications for Receiver



- Example: transmit 1 W (20 V p-p into 50 Ω)
  - assume 60 dB attenuation in duplexer
  - still have 1 μW at receiver (>> receive signal)
  - need LNA 1 dB gain compression point > 1 μW
  - more attenuation in image-rejection filter ?
  - if not, consider mixer non-linearity
  - tx signal blocked by channel-select filter ?

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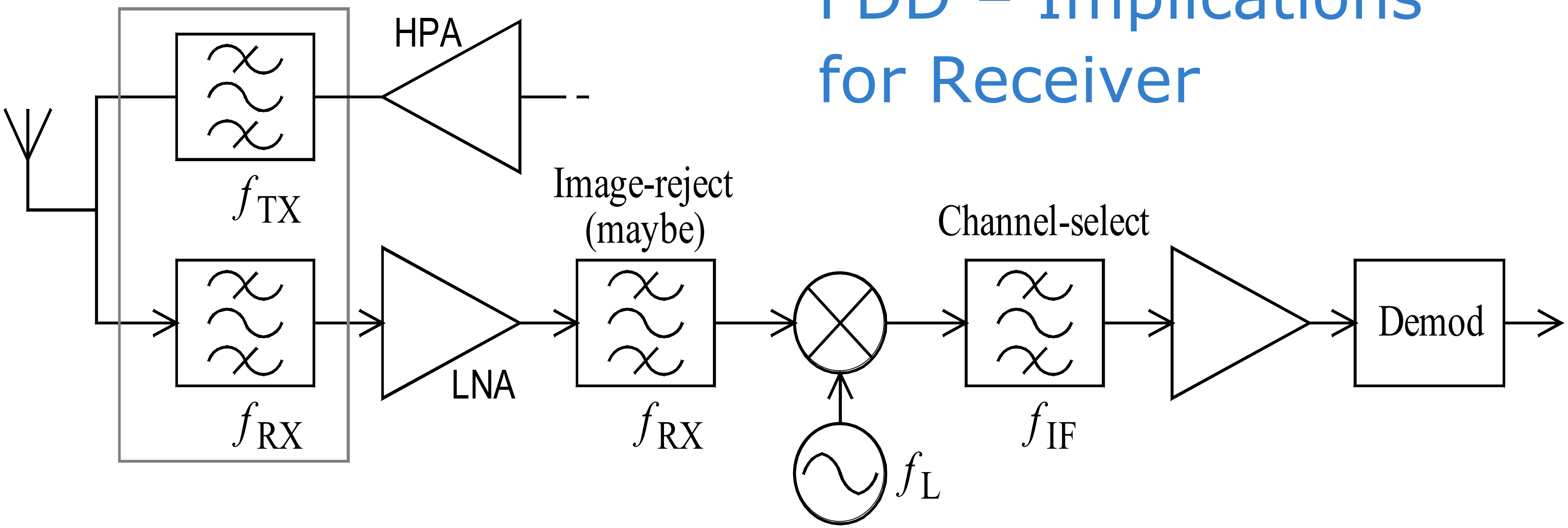

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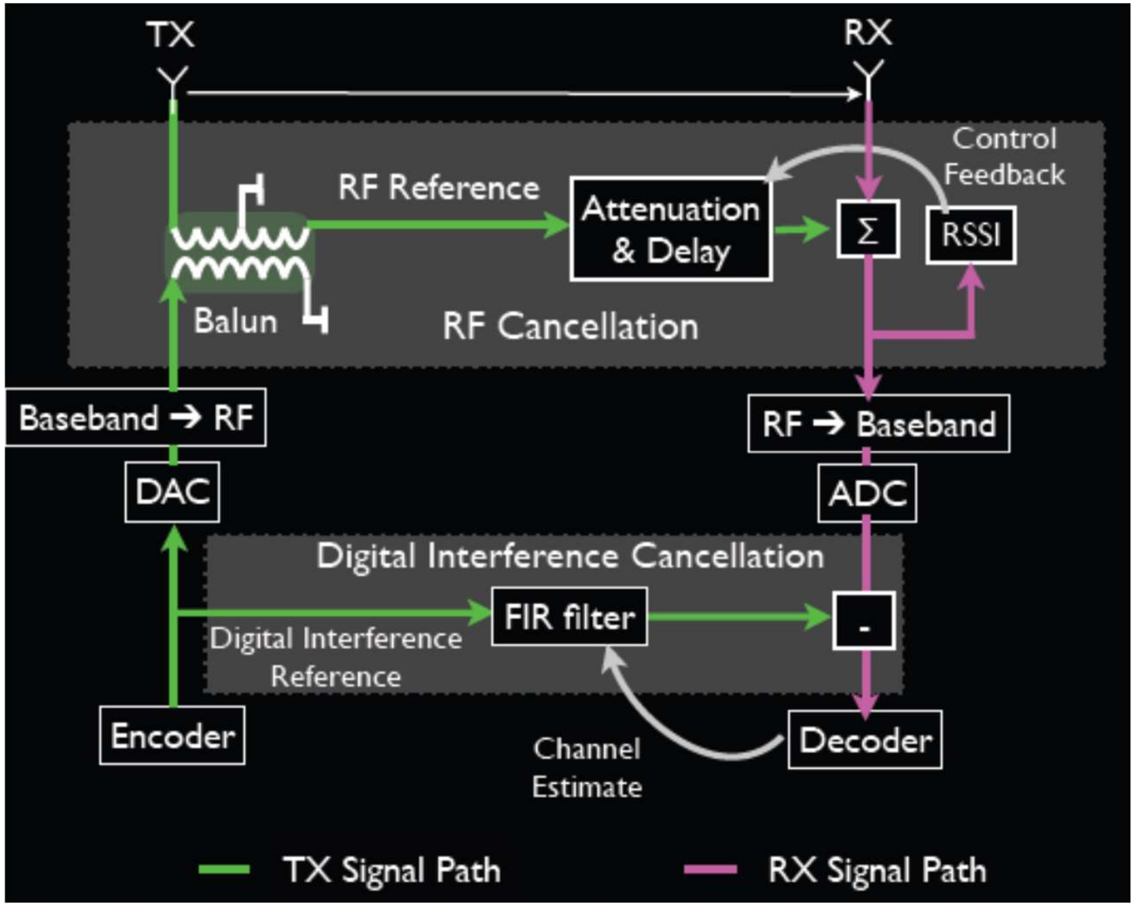
Options

Single Channel Full Duplex

Transmit and receive on same frequency, at same time ?



Jain et al.
Stanford University

- Research topic…
  - idea: transmit signal is known, so generate copy of unwanted receive signal, subtract it…
  - first use circulator or similar to minimise problem
  - then analogue (RF) processing – get unwanted signal down to level where ADC has enough dynamic range
  - then digital signal processing

Other Interference

- Leakage from any oscillators in tx or rx
  - fundamental and possibly harmonics
  - possible unintended mixing: sum, difference...
- Non-linear power amplifier in transmitter
  - need to consider harmonics of tx signal
  - may leak into receiver circuits...
- Non-linear mixer in receiver
  - many use diodes or transistors as switches
    - effectively multiply by square-wave at LO frequency
    - so all odd harmonics...
  - any imbalance or DC offset: inputs leak through
  - vulnerable to interference at many frequencies
    - e.g. $3f_{LO} \pm f_{IF}$ $5f_{LO} \pm f_{IF}$ f_{IF}

Multiple Transceivers ?

- Example
  - 3G network transceiver, FDD:
    - TX 1920 – 1980 MHz   RX 2100 – 2170 MHz
  - GSM transceiver, FDD in at least 2 bands:
    - TX 880 – 915 MHz   RX 925 – 960 MHz
    - TX 1710 – 1785 MHz   RX 1805 – 1880 MHz
  - WiFi transceiver: 2400 – 2483 MHz
  - Bluetooth transceiver: 2400 – 2483 MHz
  - GPS receiver: 1559 – 1610 MHz
  - Broadcast FM receiver: 88 – 108 MHz

Multiple Transceivers ?

WiFi receiver IF 300 MHz, LO below rx freq?

GSM receiver IF 420 MHz, LO below rx freq?

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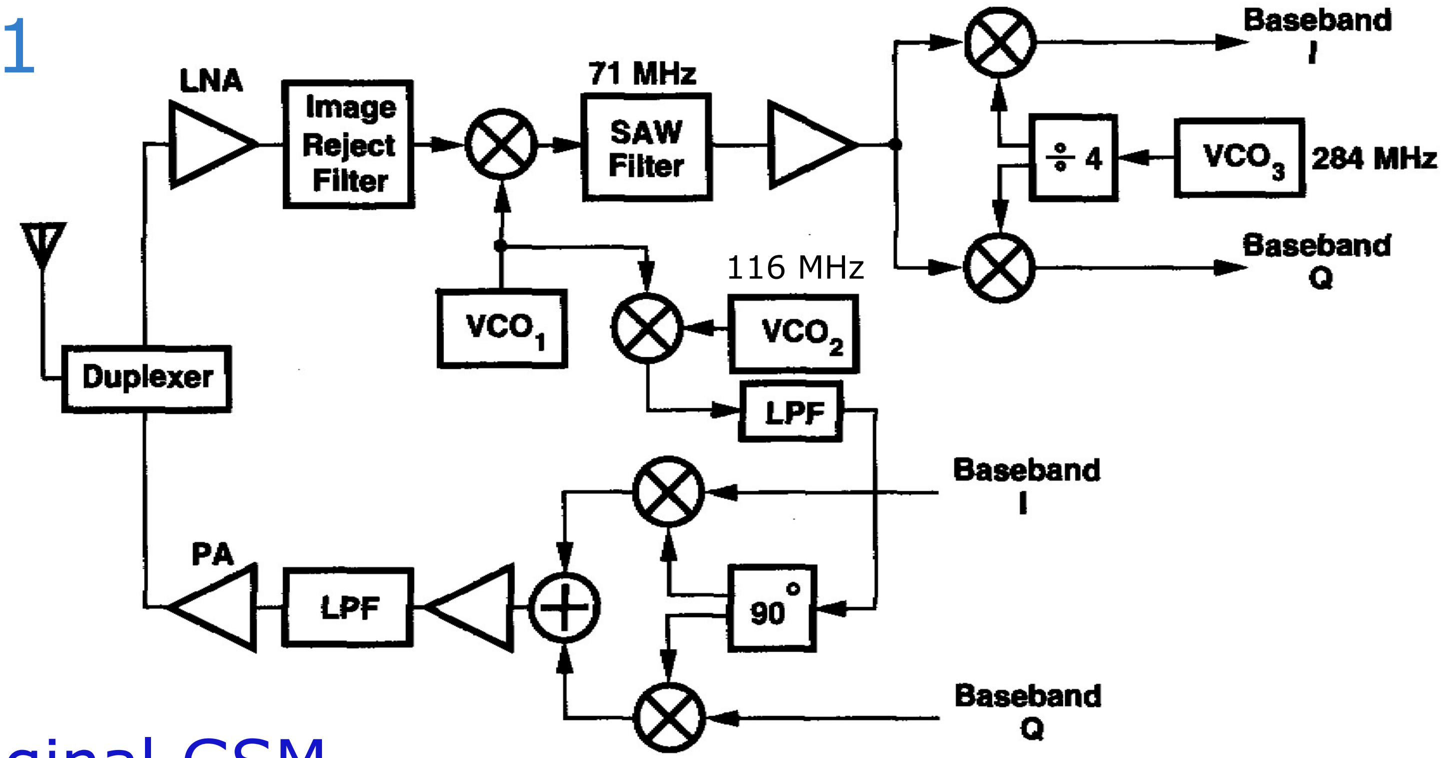
- Frequency planning critical design step...

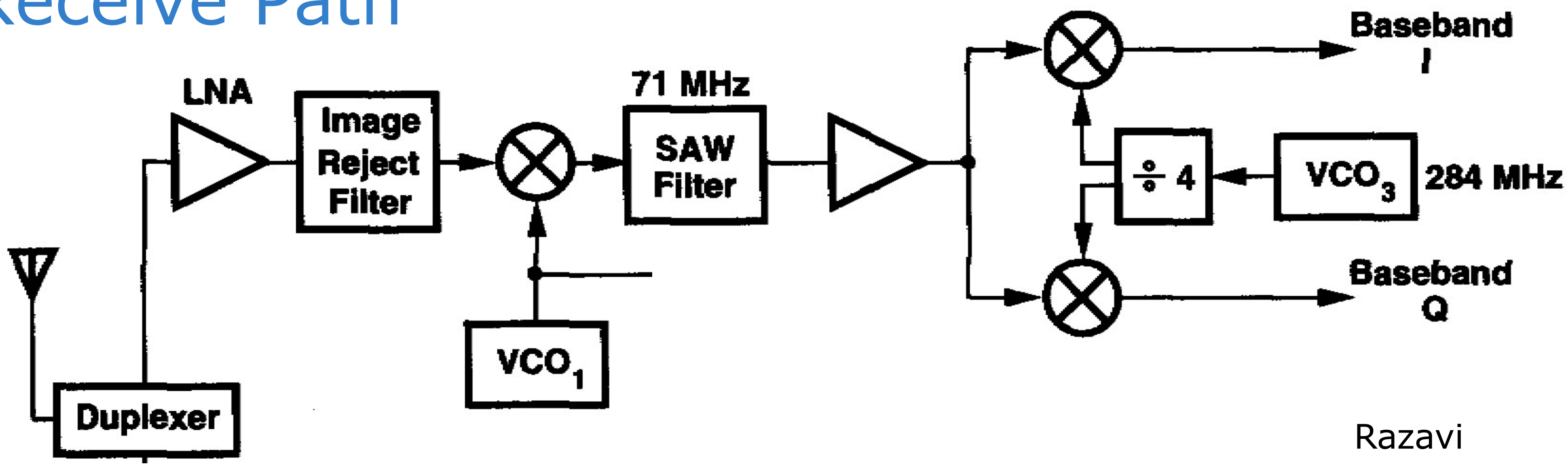
Example 1



Razavi

- Original GSM
  - FDD: up 890 – 915 MHz, down 935 – 960 MHz
    - allocated frequencies always 45 MHz apart
    - band edges only 20 MHz apart – need good duplexer
  - 270 kbit/s in 200 kHz bandwidth
  - 8 users share channel, divided into 8 time slots
    - timing arranged so handset need not transmit and receive at same time, but base station must…

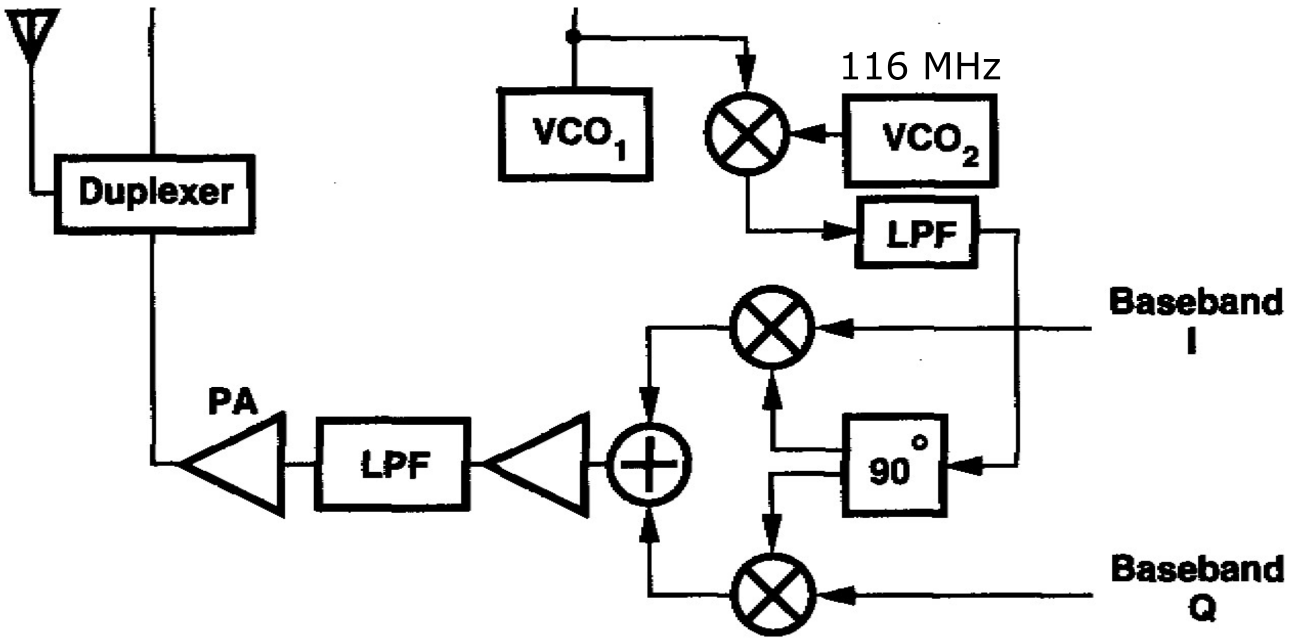
Receive Path



Razavi

- Duplexer – gives some band selection
  - then good image rejection filter, after LNA…
- Shift to intermediate frequency 71 MHz
  - LO adjustable 1006 – 1031 MHz (above rx freq.)
  - 200 kHz channel selection: 0.28% fractional BW
  - adjustable gain amplifier – AGC
- Quadrature shift to baseband
  - fixed oscillator at $4f_{IF}$ – divider gives 90° shift

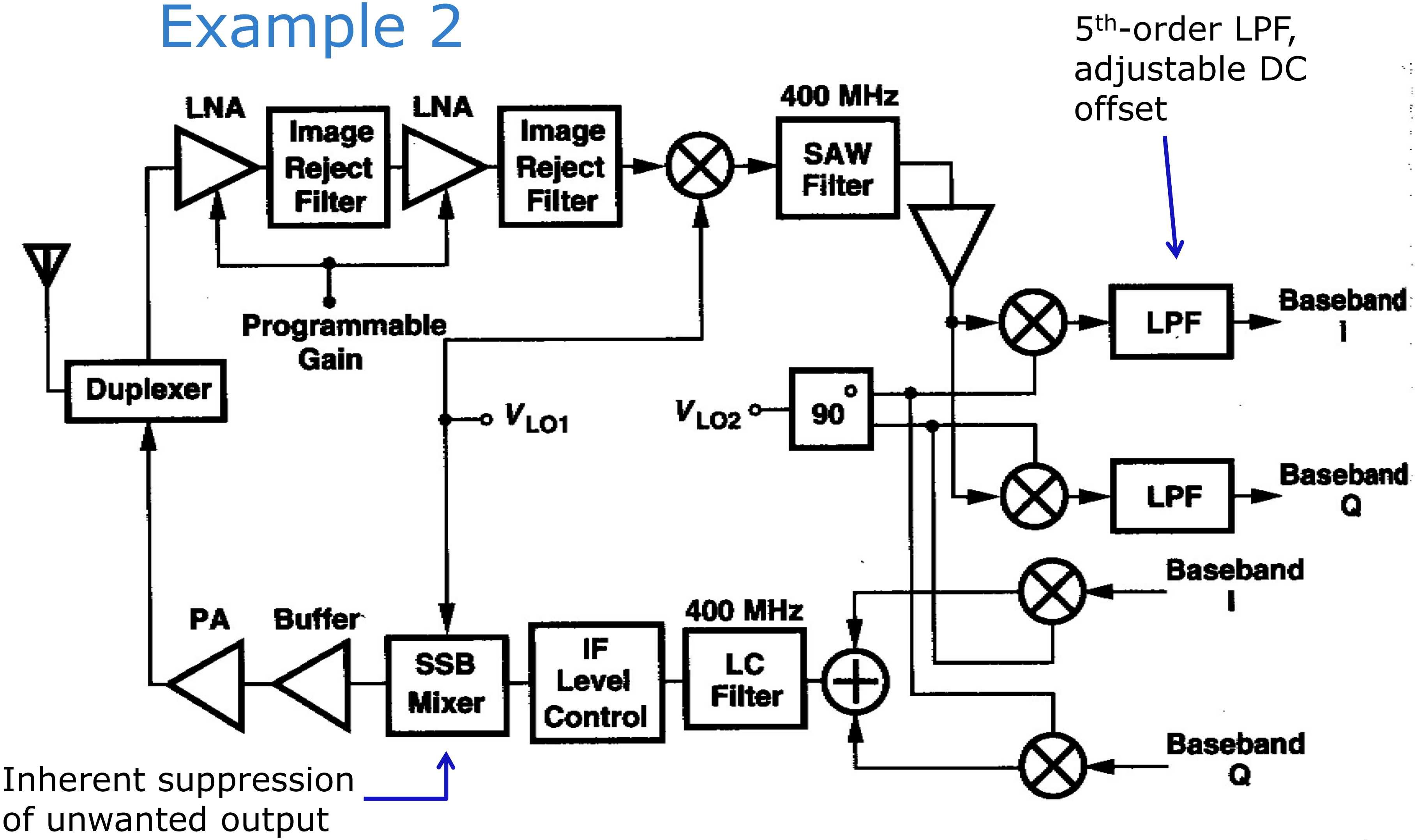
Transmit Path



Razavi

- Direct modulation at tx frequency
  - but no oscillator at tx freq. – generate from VCO
    - mix with fixed 116 MHz oscillator, LPF selects diff.
    - VCO 1006 – 1031 MHz, –116 MHz = 890 – 915 MHz
- Adjustable gain pre-amplifier – power control
- Duplexer gives harmonic suppression
  - ensures meet spec. on unwanted emissions

Example 2

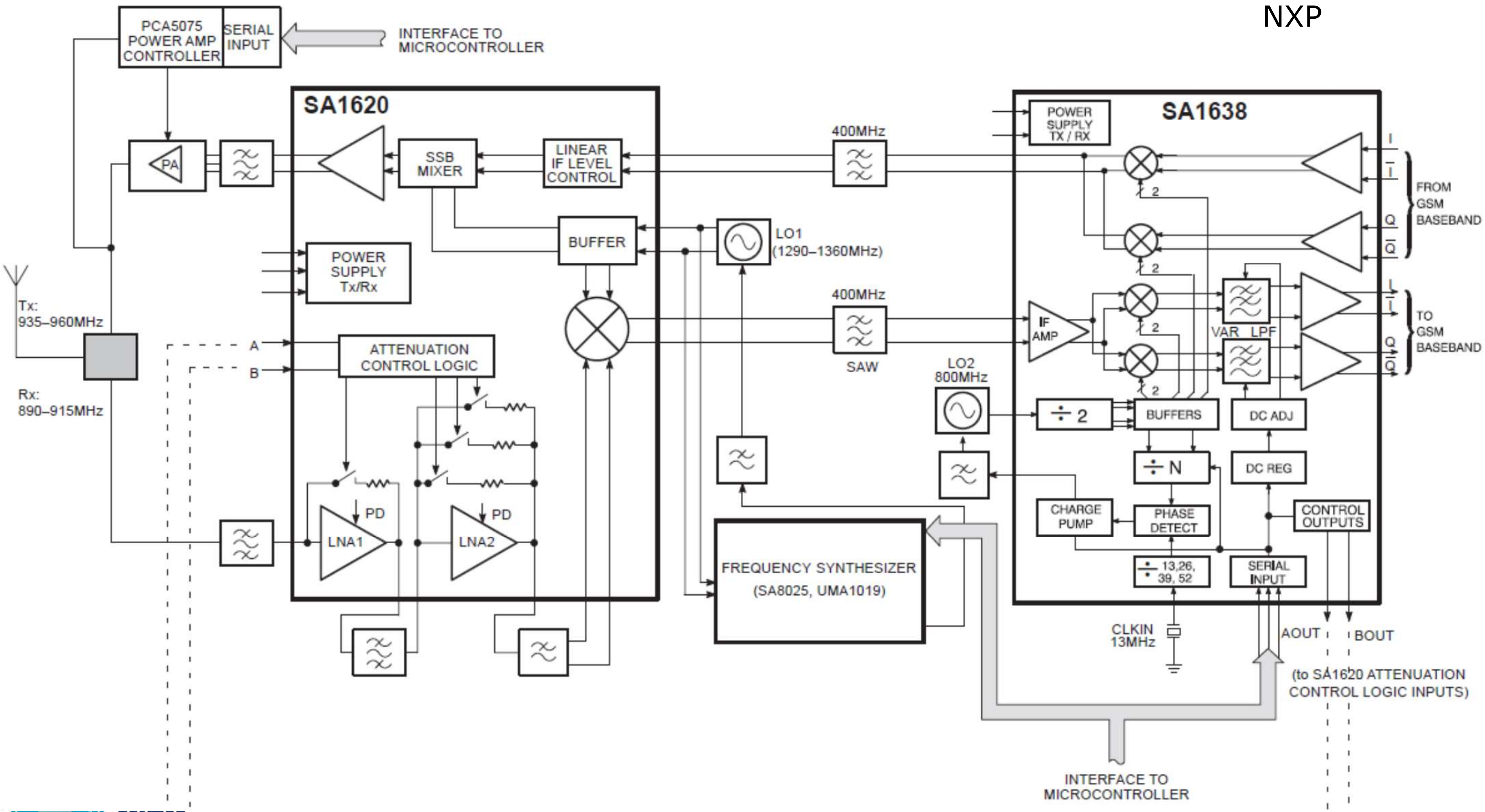


Razavi

- Also GSM, but different approach
  - what is happening here?

Example 2 – Chipset

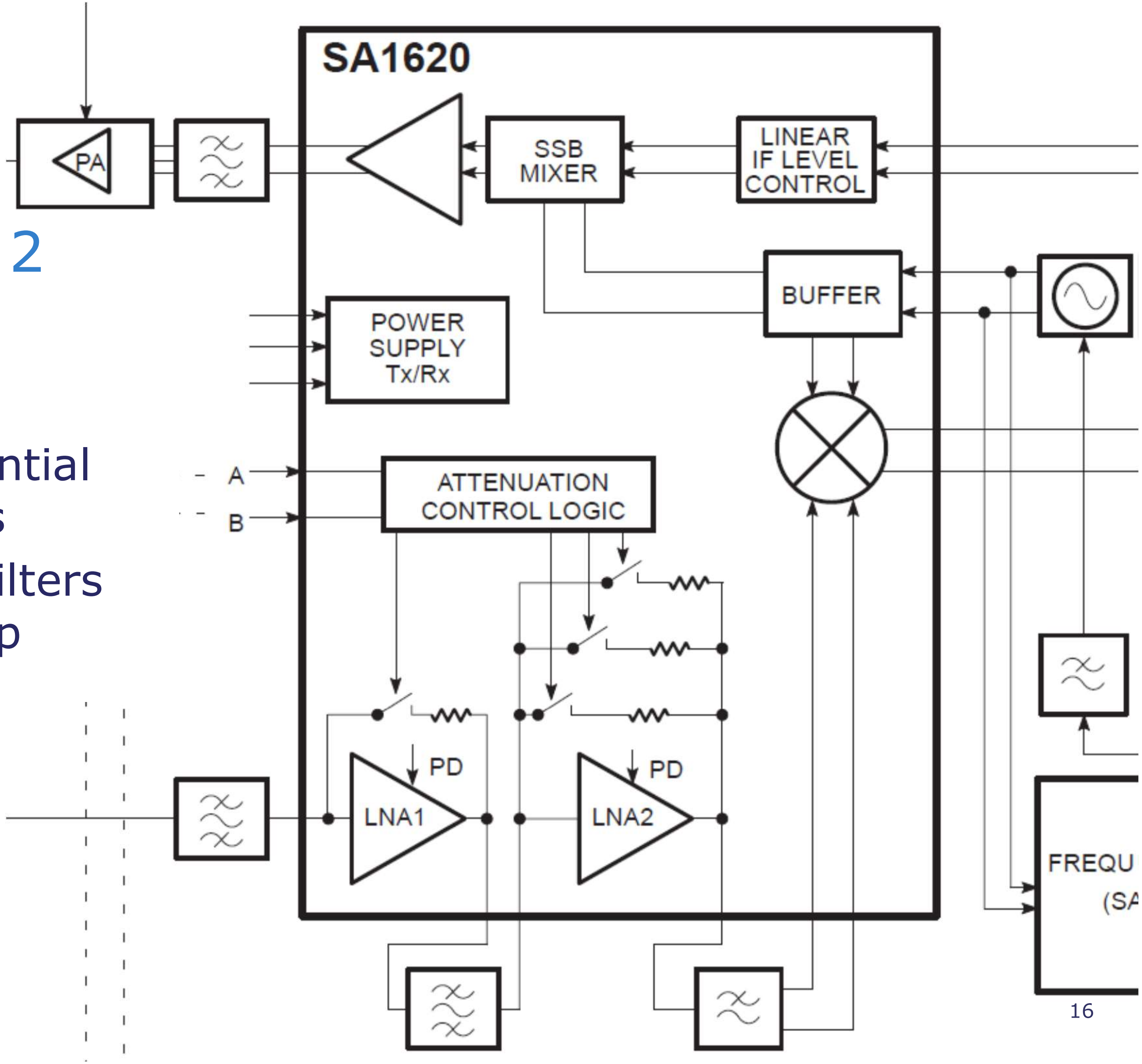
NXP



Example 2

RF side

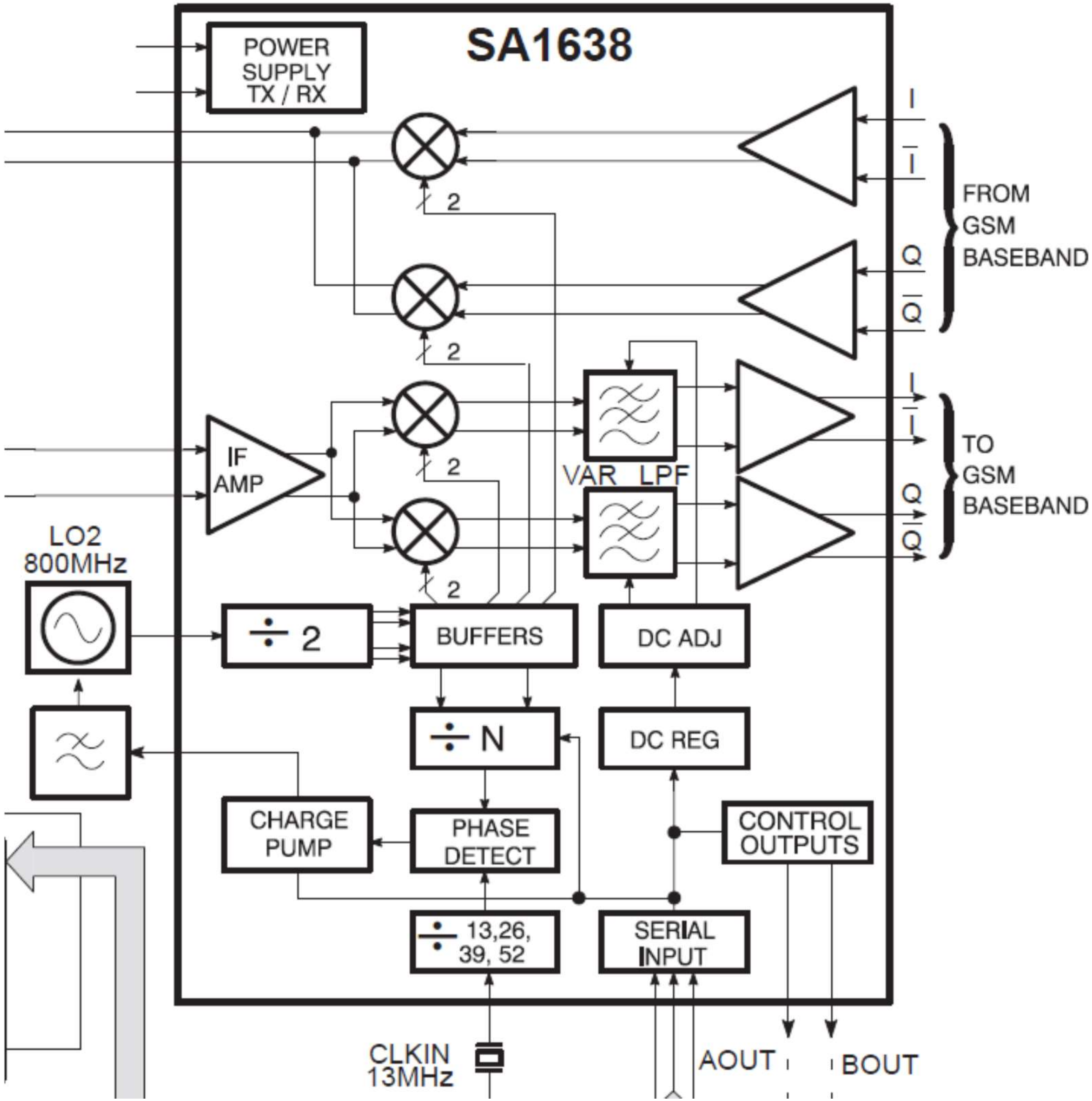
- differential signals
- main filters off-chip



Example 2

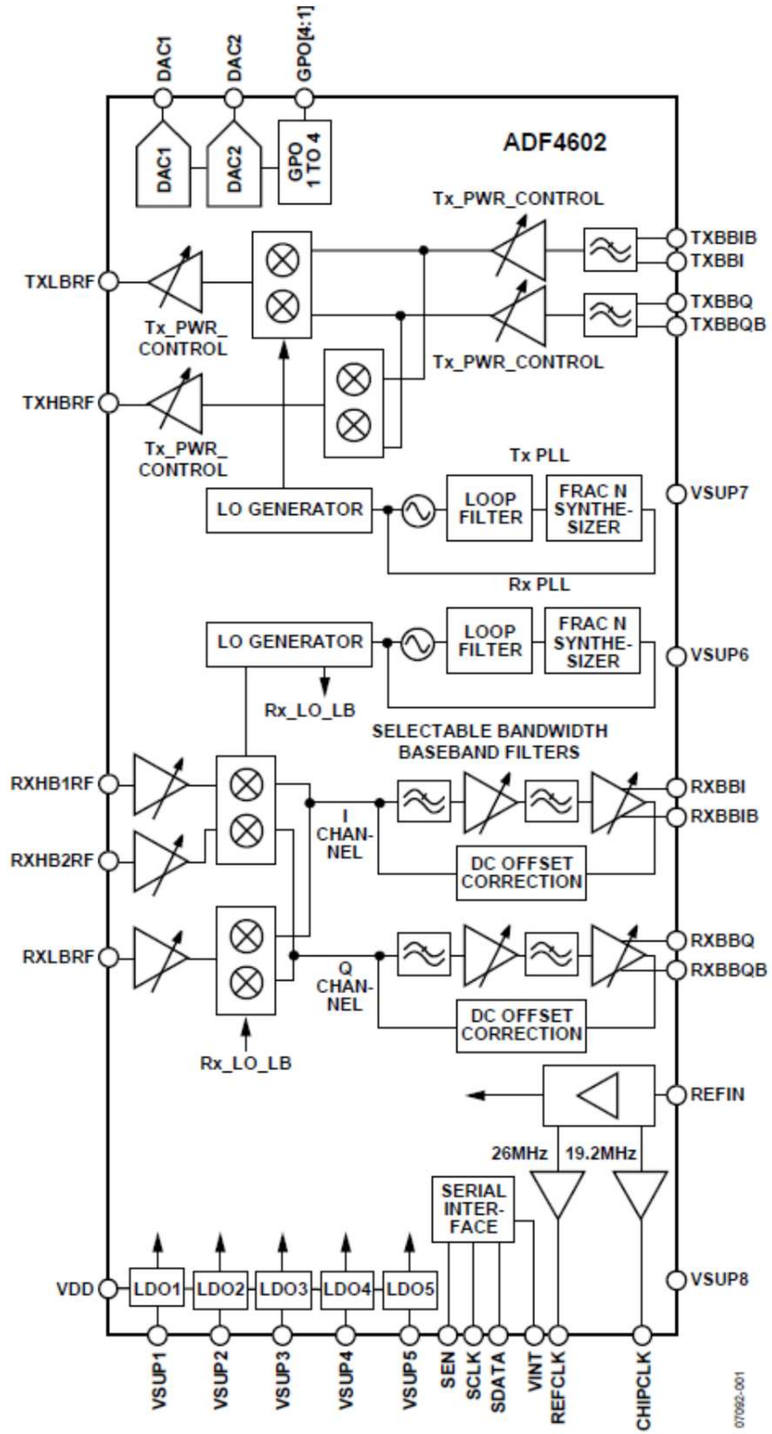
IF side

- includes freq. synthesis

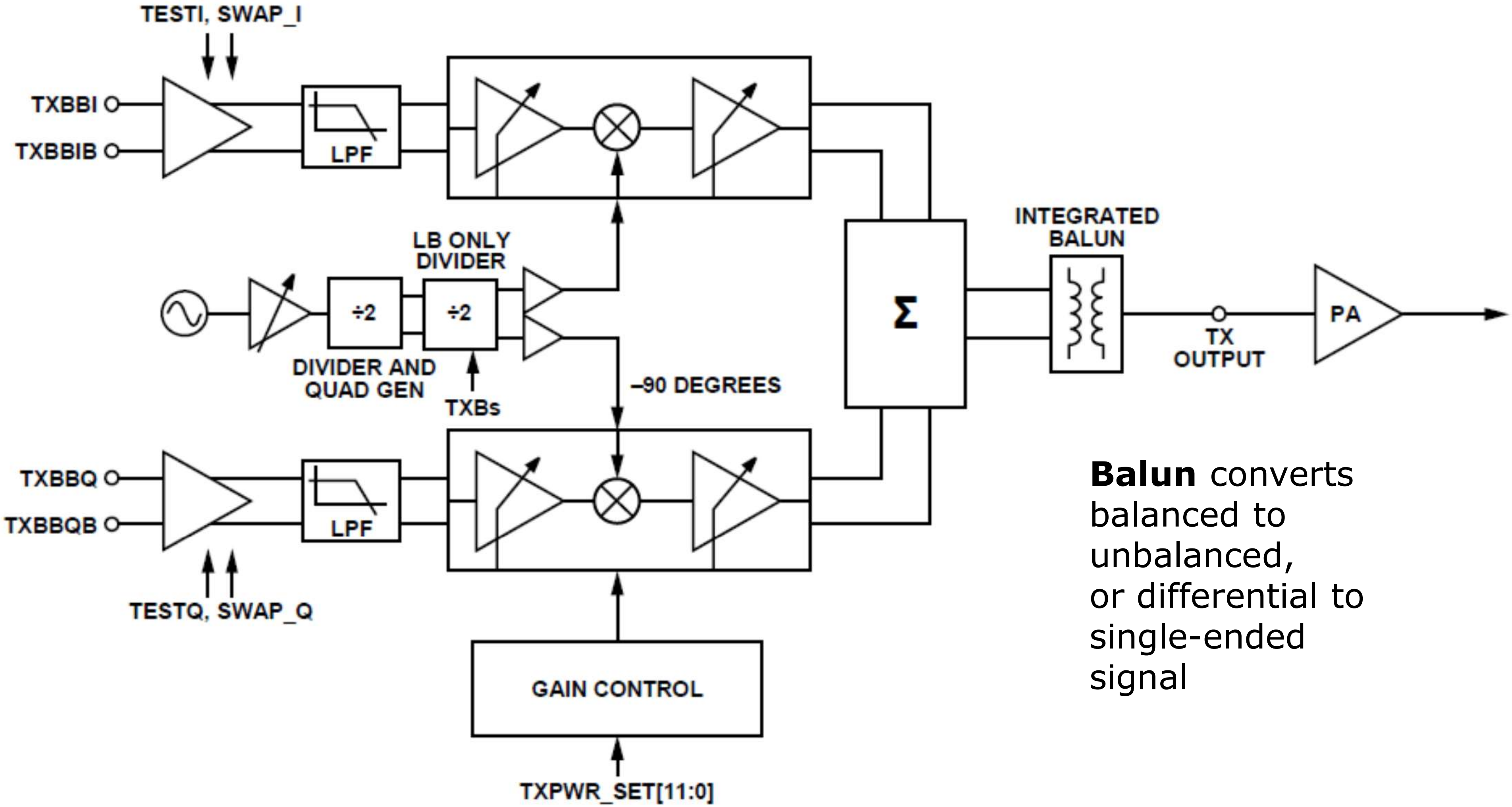


Example 3 – ADF4602

- 3G transceiver chip
  - e.g. low-power base station
  - Analog Devices
- Direct conversion receiver
  - 3 LNAs for different bands
    - covers GSM as well as 3G
  - channel select at baseband
- Direct modulation transmitter
  - 2 outputs for different bands
  - precise modulation ?
    - claim no need for external filters
- Two frequency synthesisers
  - independent tx and rx freq.



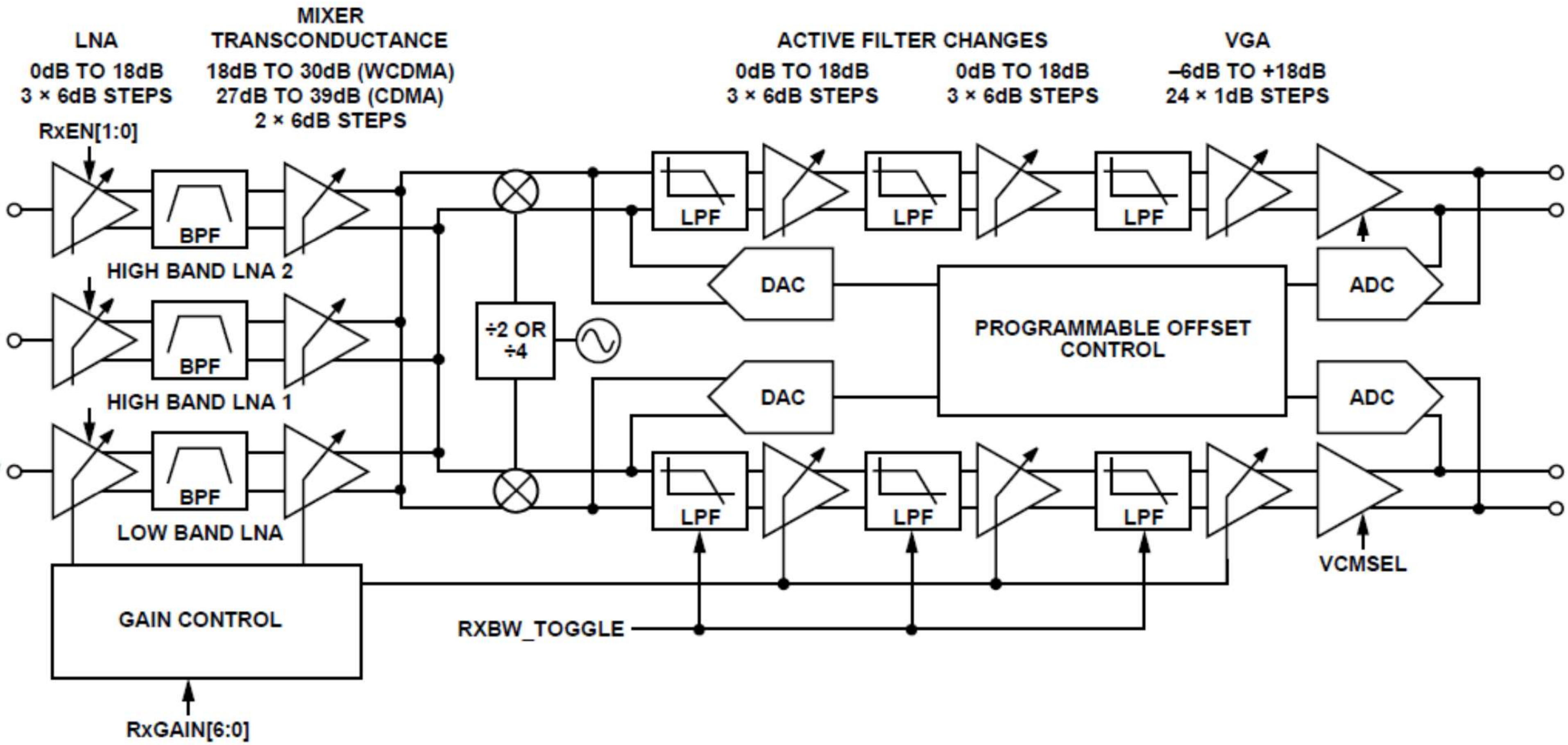
Transmit Path



Balun converts balanced to unbalanced, or differential to single-ended signal

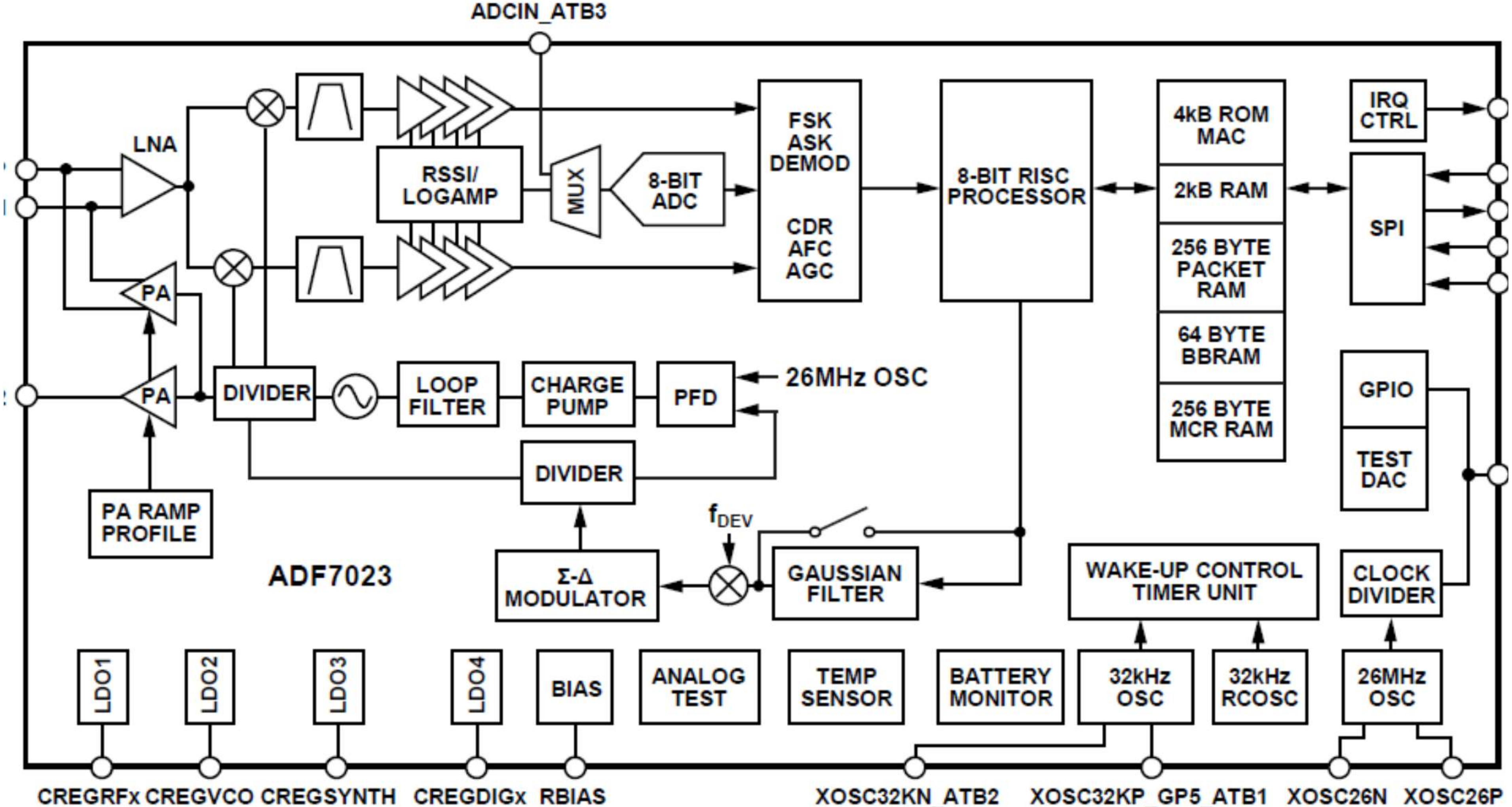
- 80 dB gain control range
- LPFs have 4 MHz corner frequency

Receive Path



- LPFs 7th-order, BW 1.92 MHz or 100 kHz
- RF gain adjust 30 dB, BB gain adjust 60 dB
- ADCs measure DC at I and Q outputs
  - feedback to DACs - apply offset at baseband input

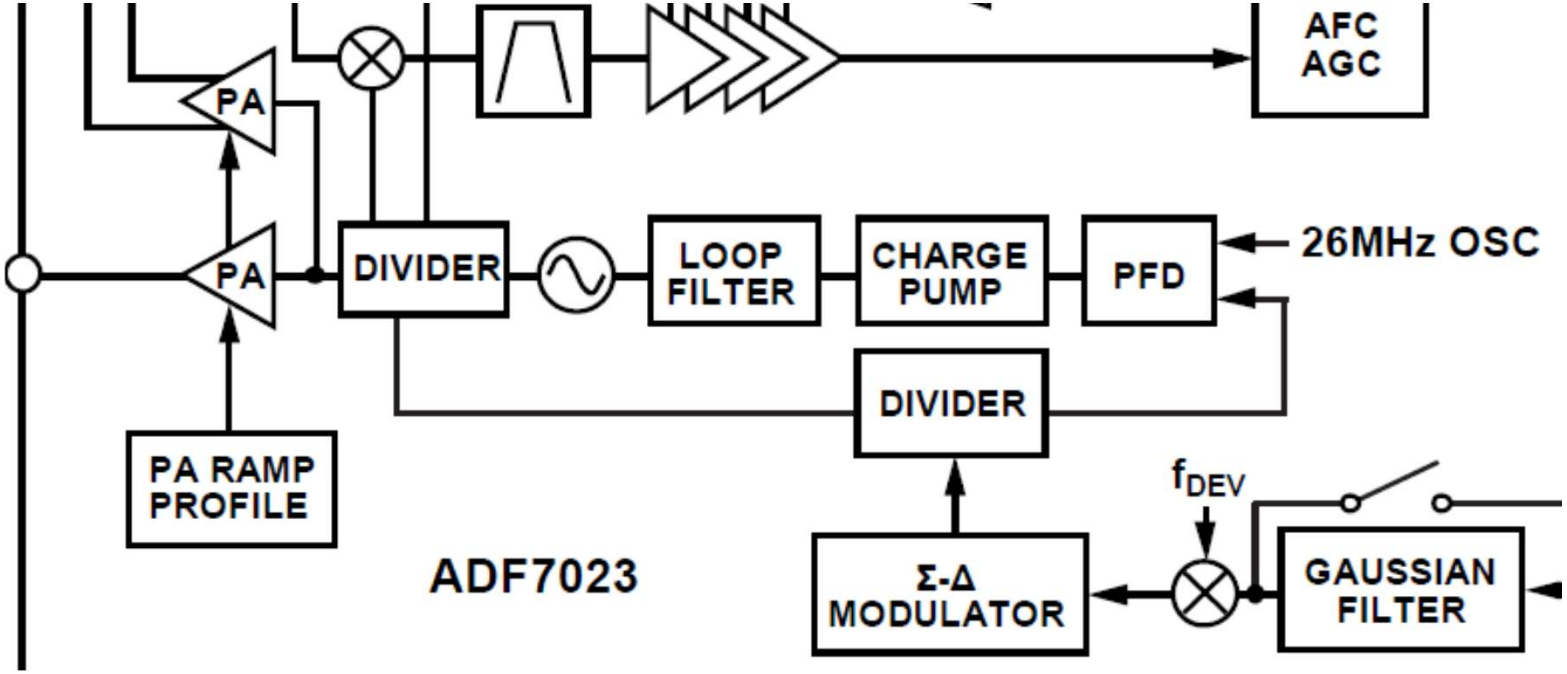
Example 4 – ADF7023



ISM bands, 433 or 868 MHz, low power (max 20 mW)

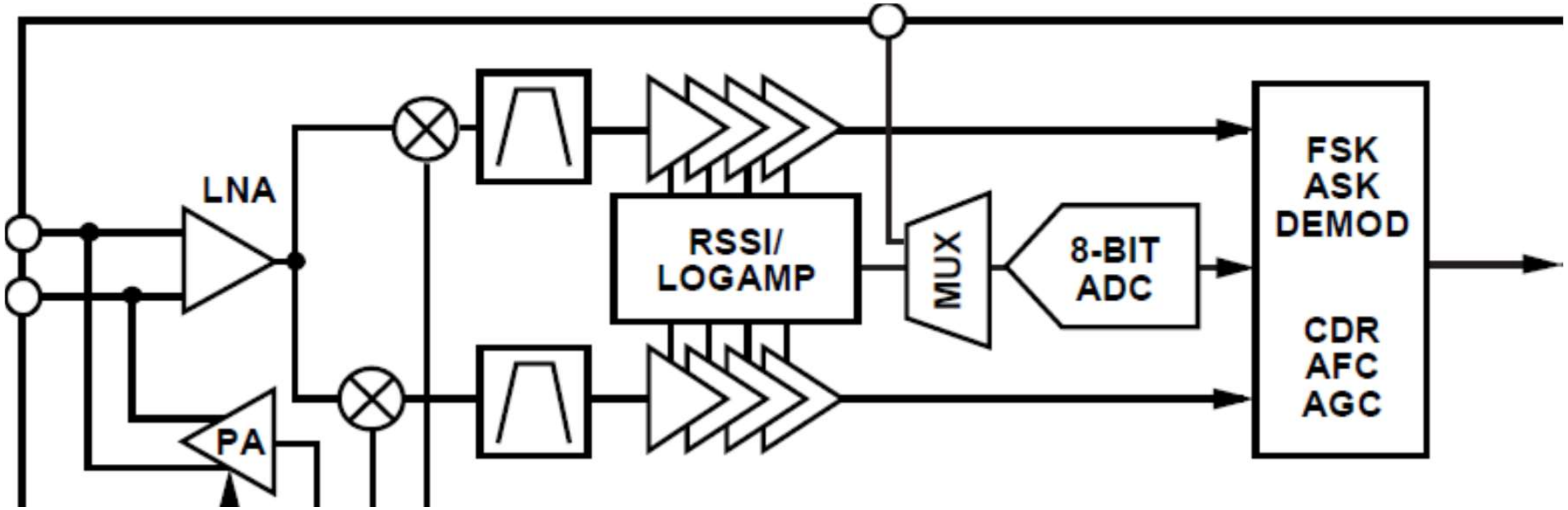
– integrated processor to implement protocol…

Ex. 4



- Transmit path
  - tx power -20 to + 13.5 dBm, -94 dBm when off
  - frequency synthesis with 400 Hz resolution
    - operates at 2x or 4x tx freq. to reduce spurious emissions
  - simple modulation – FSK or OOK, 1 – 300 kbit/s
    - FSK acts directly on frequency synthesis unit
    - OOK acts on power amplifier

Ex. 4



- Receive path
  - low-IF receiver – quadrature shift to IF of 200 kHz
    - IF bandwidth 100, 150, 200, 300 kHz
  - image-rejecting frequency shift, 40-50 dB reduction
    - digital demodulator does the rest
  - sensitivity example: -100 dBm for 300 kbit/s
    - with FSM 75 kHz deviation, BER 10^{-3}
  - max input power +12 dBm
  - log amplifier provides AGC (logarithmic characteristic)
  - RSSI = receive signal strength indicator
    - available to processor in digital form