RF Front End Components and Limitations

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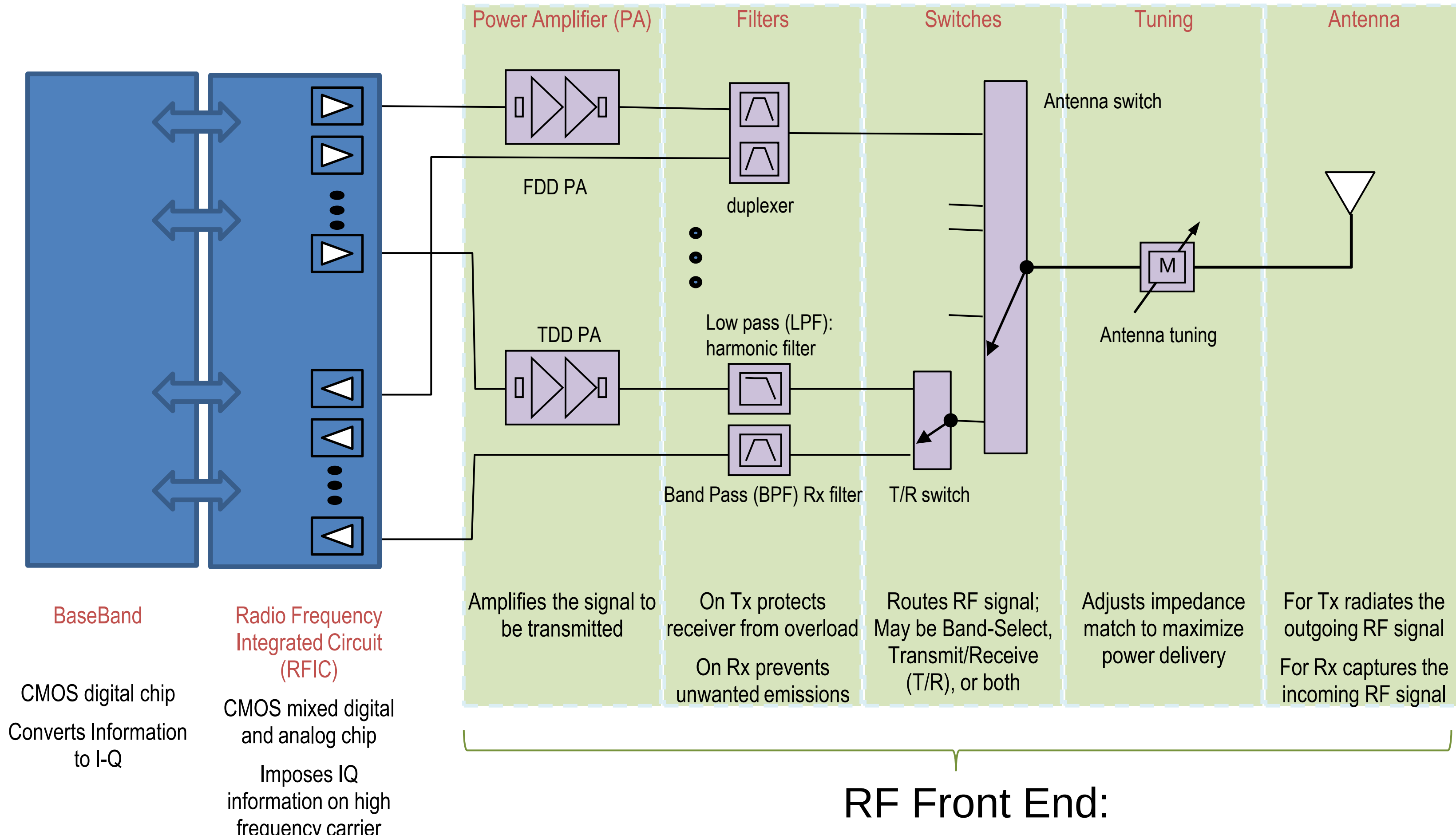
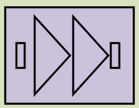
Simplified Block Diagram of the RF Front End



RF Front End:
Analog devices operating at high frequencies

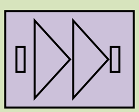
Power Amplifier

Power Amplifier (PA)



FDD PA

TDD PA



GaAs or other specialty semiconductor

Amplifies the signal to be transmitted

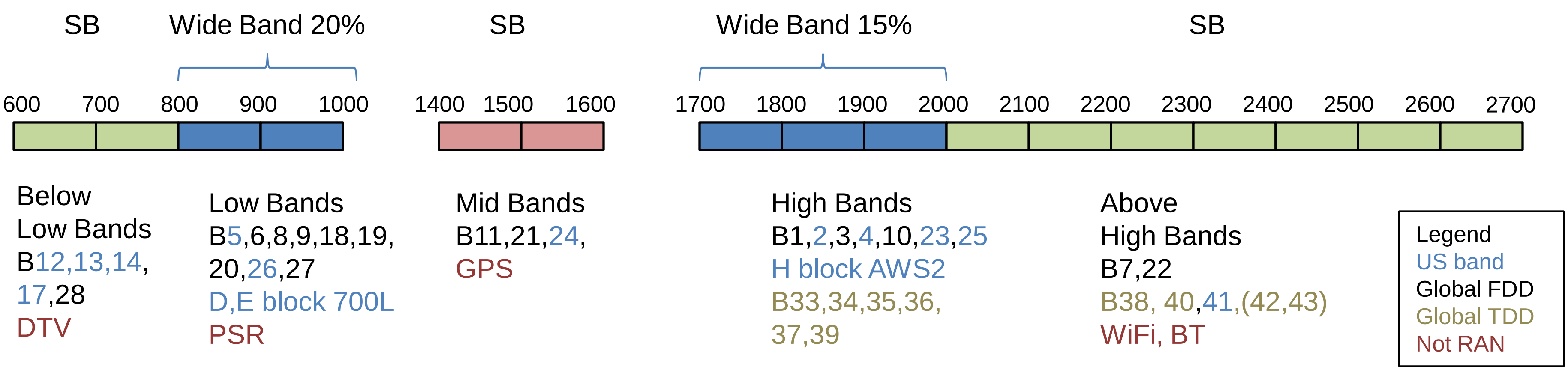
Key Specifications:
Output Power and Gain across a Bandwidth

Design:
•Device sized for power, using enough stages (typ 2 or 3) to provide gain .
•Tuned for Bandwidth (BW), Efficiency (PAE) and Linearity (Intercept Point, spectral regrowth (ACPR), Harmonics, Error Vector Magnitude (EVM).
•Adjusted by bias (Linear, Average Power Tracking, Envelope Tracking)
•Supporting needed modulations: Peak-to-Average Ratio (PAR)

Limitations / Tradeoffs:
•Single Band (up to 5% BW) has best efficiency [45% nom.]
•Wide Band sacrifices efficiency: 15%BW costs ~3 points PAE; 30%BW costs another 3 points PAE, wider possible at higher cost.
•Supporting wide PAR range [i.e. many modulations] costs efficiency. [few points]
•Suppressing ACLR (or harmonics, etc) costs efficiency [few points]
•Multi-Band Multi-Mode (MBMM) PA may have efficiencies in the 30% range
•Adding smart bias (APT, ET), Digital PreDistortion (DPD) or other techniques recover performance at the cost of complexity

The PA is very flexible, but you will pay in battery (or $) if you ask it to do too much.

Covering More Spectrum with Fewer PAs



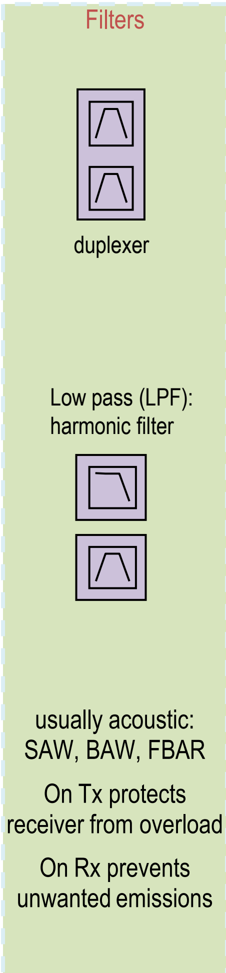
A Power Amplifier Module (PAM) has multiple internal components. These may include active semiconductor, bias circuitry, matching circuitry, and coupler.

Single Band PAs are the most common building block. Typical size is 3x3 mm, with smaller footprints likely in the next generation. BW is <5%

Dual Band PAs are another option for denser layouts. They offer a size savings over SB PAs as they can share some functionality. Typical size is 3x5 mm

Multi-Band Multi-Mode PAs offer the most size savings, but typically only make sense when the Wide Band PA is replacing 3 or more SB PAs. These PAs may also include GSM capability. Typical size is 6x8 mm. BW can be 15-20% or higher.

Filters



Acoustic used for high performance filtering due to size and Quality factor (Q).
L-C filtering may be used for harmonic filtering or other less demanding applications

Key Specifications:
Insertion Loss (IL) in Pass Band (usually <2.5 dB), Rejection in Stop Band (practical limit ~70 dB) or Isolation (ISO) between bands (up to 70 dB).

Design:
Designed for BW, Insertion Loss (IL), and Linearity (Intercept Point, Harmonics).
Temperature Motion and Manufacturing Variation accounted for with extra BW

Limitations / Tradeoffs:
•BW of filter set by materials which establish acoustic coupling (kT^2) –native BW is to ½ kT^2 (so BW ranges from 1% to 5% for acoustic filters). 2x this possible with higher IL and less broadband rejection.
•Steepness of filter enabled by Q which varies by technology.
  Surface Wave Acoustic filters (SAWs) have Qs in the 700-900 range.
  Solidly Mounted Bulk Acoustic Wave filters (SMR BAWs) have Qs of 1k-2k.
  Film Bulk Acoustic Resonator filters (FBARs) have Qs of 2k-4k.
  L-C based filters (including filters based on variable Cs) have Qs in the 30-80 range.
•IL Specification a measure of filter corner "squareness" - so IL level critical
•Steepest filters go 2dB-30dB in 2 MHz at 800 MHz (scales with Freq and Q)
•Temperature motion depends on materials. Native SAW in LiTaO3 is about -39 ppm/C, FBAR ~ -33ppm/C, SMR BAW ~ -24 ppm/C. All can be compensated for less motion, at the cost of reduced BW and/or Q.
•Performance requirements are set both by band plan and neighbors

Miniature (acoustic) filtering is constrained in BW and steepness

Filter Requirements Differ Widely

Most filters support only a single band of operation.

Present generation duplexers are typically 2.0x1.6 mm; previous generation was 2x2.5 mm. Filters may be 1.4x1.1mm or smaller.

FDD systems require a dedicated duplexer per band. Duplexers become more difficult as duplex gap shrinks, bandwidth grows beyond ½ kT^2, or if there are nearby neighbors that might impact performance.

Easy

B1
B4
B5
B6
B9
B10
B11
B14
B18
B19
B21

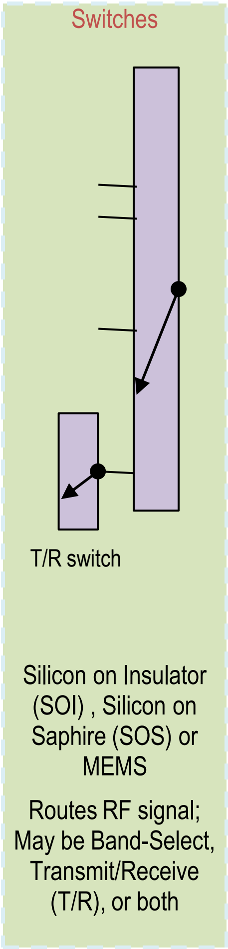
Hard

B2-narrow gap
B3-narrow gap, broad BW
B7-Tx power handling (high frequency), WiFi coexistence
B8-narrow gap, wide BW
B17-TV51 and E block – 6 MHz GB
B20-narrow gap

Extremely difficult

B12-TV51 and E block-no GB
B13-2 MHz to PHS, H2 @ GPS
B23-5 MHz to B25
B24-GPS interference
B25-very narrow gap
B26-very wide band, narrow gap
B28-very wide band, narrow gap

Switches



Key Specifications:
Routing with minimal IL, high ISO
Number of throws

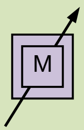
Design:
•Designed for Switching Speed, Linearity (Harmonics, Intermodulation), Lifetime number of throws (T/R vs Band select)
•Common design is series-shunt; higher ISO means adding more stages so increases IL

Limitations / Tradeoffs:
•Typ SOI Single throw IL ~ 0.25 dB @ 1 GHz, 0.4 dB @ 2 GHz; increases .05 to .1 dB per added throw; ~14 throw is present maximum
•Typ Single throw ISO ~25 dB @ 1 GHz, 20 dB @ 2 GHz up to 40 dB with higher loss. Note duplexers provide 60 dB typ ISO, so leakage through switch can effect performance.
•SOS improves loss and isolation but higher cost
•MEMS improves loss or isolation, but needs care with actuation voltage, stiction, longevity, cost – not yet a common solution
•CMOS has inadequate isolation for high power switches but can be used in driver routing.
•Switch control can be integrated with SOI, SOS, or CMOS

The switch has limits in number of throws and often ignored performance impact

Tunable Match

Tuning



Antenna tuning

MEMS, BST or other special technology

Adjusts impedance match to maximize power delivery

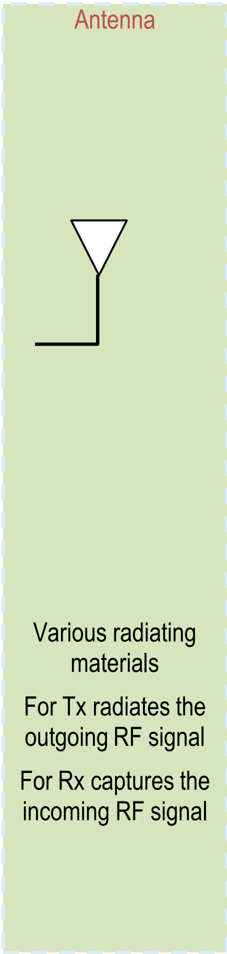
Key Parameters:
Tuning range, Insertion Loss (Q)
Linearity, size, cost, control, response time, reliable number of cycles.

Design:
•Most tuning elements are based on structures with variable capacitors
  MEMS capacitors have variable dielectric spacing
  Switched capacitor banks adjust capacitance in quanta
  Barium Strontium Titanate (BST) has variable dielectric with voltage
•Shunt capacitors (one end grounded) are more common than series elements (both ends floating)

Limitations / Tradeoffs:
•Common Qs are in the 100 range.
•Tuning range is often 3:1 to 5:1 in value.
•Hot tuning occurs under the presence of RF – difficult at present due to stronger actuating forces, and the possibility of entering forbidden operation (SARS, oscillation)
•Cold tuning occurs with the device off – adjustment to pre-determined operating points.

Tuning offers flexibility, but is constrained in performance

Antenna



Key Parameters:
Frequency coverage, Radiation efficiency, volume, radiation pattern
For MIMO, correlation.

Design:
•In general industrial design is king, and the antenna has to be made to fit the available volume. External antennas are viewed as undesirable.
•Classic antennas are dipole-like, so need to be a certain fraction of a wavelength to be good radiators. This makes low frequency antennas (<1 GHz) challenging
•Classic Standards acceptance is conductive (through 50 ohm tap point), not radiated. This makes full integration of the antenna into the RFFE very difficult

Limitations / Tradeoffs:
•Broadband antennas can be >1cm^3 in volume. Narrow band can be <2.5mm^3.
•Range of 800 – 2500 MHz can be covered in two harmonically related sections.
•Tuning, multi-tap, or other advanced techniques (e.g.metamaterials) are needed if a wide range of low frequency bands need to be covered.
•3G systems require diversity – diversity antenna can be inferior to primary
•4G systems require MIMO – MIMO antenna theoretically equivalent to primary
•Most handsets have multiple (4-7) antennas. Antenna-antenna ISO is ~10-20 dB

Volume vs. performance considerations effectively limit the number of antennas