

RF Front Ends for Mobile Devices 2023



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Abstract

This report tracks all the RF components used in 2G/3G/LTE/5G terminals, including smartphones, feature phones, tablets, PCs, hotspots, and IoT devices. Components such as amplifiers, filters, switches, tuners, and LNAs are included. Front End Modules that combine PA/filter/switch/other functions are also included, as well as quadplexers, antennaplexers, and other specialty RF components.

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METHODOLOGY AND DEFINITIONS

Mobile Experts relies on interviews with industry suppliers for most of the data in our forecast. We conduct interviews with almost every supplier of RF components or modules, as well as handset, tablet, and IoT manufacturers.

We compare our interview inputs with information that comes from our research in mobile infrastructure. For key features such as MIMO adoption, CA adoption, 5G investments, and other areas, the infrastructure trends can dominate the overall timing. We check the timing and global scale of new feature adoption to align with handset timing.

Top-Down and Bottom-Up process

Mobile Experts uses a rigorous process to cross-check its forecast estimates. The overall process combines “top down” data and “bottom up” data to create the forecast in two separate ways. The assumptions, pricing estimates, and market shares are adjusted until the top-down numbers match with the bottom-up figures.

In the case of RF Front Ends, our top-down data sources consist of:

- Quarterly OEM reports of handset, tablet, PC, and other modem shipments
- Tear-down analysis of specific handset and tablet models
- Total shipments of the top 20 handset OEMs
- Separate research conducted by Mobile Experts on Cellular IoT device shipments, including interviews with more than 25 mobile operators and key industrial players
- Estimates by industry participants for the market size in each RF product area, as well as the number of devices used in each tier of the market.
- SEC filings and public comments from RF component suppliers, mostly regarding revenue figures.

The bottom-up forecast inputs come from a huge variety of sources:

- Direct interviews with specific RF component vendors. Mobile Experts has interviewed more than 40 different companies in the course of creating this report.
- Direct interviews with mobile device OEMs. Through personal contacts, Mobile Experts is able to ascertain the technical direction for key platforms, and the leading vendors in supply of specific components.
- Pricing analysis. Mobile Experts gathers many conflicting data points regarding pricing in the market and cross-checks with multiple sources wherever possible.
- Shipment reports. Mobile Experts has agreements with more than 20 RF component suppliers, under non-disclosure agreements, to share shipment data in key areas to highlight the usage by frequency band, by air interface standard, or for new

technology introductions. We never reveal the identity of these companies or their specific inputs.

With the current increase in inflation, Mobile Experts has modified the typical annual price reduction of CFEs from 8-10% to 2%. This recognizes that costs in the supply chain are going up and these will be passed along to the smartphone OEMs as can be justified. If the inflationary environment persists for more than 2-3 years, we expect prices to flatten out or slightly increase.

The crucial step in verifying accuracy involved a comparison of the bottom-up shipment/ASP/revenue estimates to the top-down revenue reports from five leading RF component suppliers. The pricing assumptions and market share assumptions were adjusted so that these two methods matched within 5%.

Note that in reporting the market size for a specific technology within front end modules, Mobile Experts made some arbitrary assumptions about the value of each function in the FEM. Our assumptions are based on the estimates of key players at RF FEM suppliers, based on the manufacturing cost of each function within a FEM. The FEM content assumptions are listed in the Excel spreadsheet on the page marked “Assumptions”.

Scope of this report

This market study is intended to thoroughly cover the licensed-band radio components in mobile devices and the introduction of multiple new technologies into the mobile RF Front End. The report is not intended to provide deep technical analysis, but instead aims to provide enough technical information to explain the fundamental advantages or disadvantages of one technology vs. another. The end goal of this project is to provide a vision of the future roadmap for mobile RF front ends, providing RF component suppliers enough information to plan their investments in new products over the next few years.

The market study’s scope is limited to licensed cellular and LTE/5G NR for unlicensed bands, and does not include Wi-Fi, Bluetooth, GPS, FM Radio, NFC, or any other radio modes in the handset. RF components intended for LTE/5G NR signal processing in unlicensed bands are included in this forecast.

Similarly, the scope of this report does not cover Envelope Tracking power supplies or modems. The strategic impact of modem and RFFE co-design is covered in our Expert INSIGHT series of strategic reports.

Definitions

Always, with forecasting of complex technology markets, the definition of each market segment is important for clear understanding. Some of our key definitions for RF Front Ends are listed below.

Definitions	Description
Antenna Aperture Tuning	Use of an RF switch or variable capacitor to change the resonant frequency of the antenna.
Antenna-plexer	A passive filter structure that separates GPS, Wi-Fi, and/or Bluetooth from licensed 3GPP signals, located near the antenna.
ASM	Antenna Switch Module, incorporating a multi-throw antenna switch and multiple ports for different bands. Some ASMs include filters but others do not.
Complete Front End (CFE)	Also known as a PAMiD, LPAMiD, or LPAF. An integrated module which contains power amplifier, transmitter and receiver filters, as well as the necessary switches to incorporate all RF functions between the transceiver and the antenna for a specific set of frequency bands. The new PA/LNA/Switch/filter modules for 5G are included in this category.
Diplexer	A filter component which breaks the spectrum into a low band and high band on separate RF paths.
Diversity Module (DRx)	A module with a band selection switch and multiple bandpass filters, typically applied to the diversity or MIMO antenna path. Most also include LNAs
Duplexer	A component which separates transmit and receiver signals, resulting in a single antenna port but two separate filters for Tx and Rx chains.
Envelope Tracking Power Supply:	A voltage supply for an amplifier which ramps supply voltage up and down quickly, following the waveform of the radio signal.
Extractor:	A passive filter structure that separates GPS from licensed 3GPP signals. Some also separate 2.4 GHz signals for Bluetooth or Wi-Fi.
FEM	Front End Module, which may incorporate any combination of amplifiers, switches, tuners, or filters. MMPAs are not counted in the FEM category even if they include switches, for clarity. MMPAs with filters or duplexers integrated are considered Complete Front Ends and are placed in the FEM category.
Filter	A component with only a single input and output, used in the RF chain to select the desired band
Hexaplexer	A filter component which divides the spectrum into six bands, without switches, for simultaneous operation.
Impedance Match Tuning	Use of variable reactance components to modify the interface between two RF components (i.e. filter and antenna)
Inter-stage Tuning	Adjustment of capacitance or inductance values between stages of amplifiers or filters
Low Noise Amplifier (LNA)	An amplifier component used in the receiver chain. Most are integrated with diversity modules or other FEMs but some are used as discrete devices.
MMPA	(also known as MMMB) A multi-mode, multi-band PA component which handles more than one air interface standard and more than one band through a single RF path. MMPAs normally include switches at the output. A quad-band GSM/EDGE PA is not counted as an MMPA even though multiple bands and modes are handled...we require 3G/4G modes to qualify as an MMPA.
Multiplexer	A filter-based module which breaks the band up into multiple paths without using switches.
Passive Filter Bank	A filter-only module with multiple filtering components. This is counted in the Discrete Filter category despite a higher level of integration, because in the marketplace these products can be addressed by filter-only competitors.
Power Amplifier	A single package which may contain multiple die, used only for signal amplification to +20 dBm or more.
Quadplexer	A passive filter structure that separates the signals in four frequency bands, without switches, for simultaneous operation.
Switch	A component which only directs RF signals to different paths, without filtering or amplification. Switches used to change antenna length are counted as "tuners"
Switched Duplexer Bank	Also known as a FEMiD, a Switched Duplexer Bank includes band selection switches and multiple duplexers.
Transfer Switch	A multi-pole, multi-throw switch that is used to "swap" antennas when the main antenna is impaired by the user's grip or other external objects. Most handsets use a DPDT switch today but 4P4T is likely for 4x4 MIMO cases.
Transmit Module	A PA integrated with antenna switching, which does not include ALL of the filters for the relevant bands. A Tx Module which integrates all of the filters would be considered a Complete Front End.

Figure 1: Definitions of product types

Source: Mobile Experts. See the 'Definitions' tab of mexp-rffe-22.xls

Definitions	Description
Multimode:	Capable of simultaneous operation in multiple modes and at multiple bands
Reconfigurable	Capable of one air interface standard at a time, but adaptable to multiple standards
Single-mode:	Capable of only one air interface standard (Note: GSM/EDGE is considered a single mode)
RF Artificial Intelligence	The use of advanced learning algorithms in the modem to adjust large numbers of tuning elements in the RF Front End. This approach is used for digital self-calibration of each handset.
RF Path	Each different mode and frequency band is counted as an individual RFFE path. Because almost every different band requires a different RF filter, the RF signal follows a distinct path through the handset for each mode. Mobile Experts counts RFFE paths as a method to estimate total numbers of filters and other components.
RFFE-Standard	Each air interface standard handled by a terminal is counted as an individual RFFE-Std. Because many handsets handle multiple modes, this is a construct which is used to estimate component shipments. Note that Mobile Experts no longer uses this metric as a tool for estimating market size as of May 2018.
m x n MIMO	MIMO is designated by numbers of transmitters and receivers differently for uplink and downlink. Mobile Experts uses the first number, m, to designate the number of transmitters and n to designate the number of receivers.

Figure 2: Definitions of key terms

Source: Mobile Experts

Definitions	Description
Premium Tier Smartphone	A handheld device a high level operating system that sells for more than \$500. This tier generally includes more than 25 frequency bands, and during 2020 included 5G NR, 4x4 MIMO, CA, TDD, FDD-LTE.
Mid Tier Smartphone	A handheld device a high level operating system that sells for between \$200 and \$500. This tier generally includes 12-20 frequency bands. During 2020, these units saw the beginning of 5G adoption that included some CA or 4x4 MIMO.
Entry Level Smartphone	A handheld device a high level operating system that sells for below \$200. This tier generally includes 3-10 frequency bands with limited features. There will be 5G phones in this segment by 2021.
Feature Phone	A mobile phone without a High Level Operating System.
Tablet	A mobile terminal with the communications module embedded in a panel-style computer. Distinguished from PC applications by the user interface (touchscreen vs keyboard)
PC module	A communications module either embedded in a Personal Computer or provided as a USB dongle. Distinguished from tablets by user interface (keyboard vs touchscreen).
CPE	Customer Premises Equipment for fixed-broadband applications. Some CPE units will use mm-wave and this content is captured on tab 10.
Hotspots	Either plugged in or working by battery, a modem which functions on mobile standards to provide local Wi-Fi access is known as a mobile hotspot.
IoT	A communications module for automated use by local embedded applications... not for direct human use. Internet of Things refers to new battery-optimized formats such as LTE Cat-M, NB-IoT, and EC-GSM.
M2M	A communications module for automated use by local embedded applications... not for direct human use. M2M refers to the legacy standards, GSM, 3GPP53:C58, and LTE Cat-4 and above.

Figure 3: Definitions of terminal types

Source: Mobile Experts