# RF Switches Guide Signals In Smart Phones

The myriad of different bands, modes, radios, and functionality found in a modern smart phone calls for the increased use of simple, high-performance RF switches as well as integrated switch modules.

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Smart phones represent the leading edge of RF personal communications, as well as one of the most challenging of RF product designs. These third-generation (3G) cellular multimode, multiband devices can operate in three or four bands based on EDGE/GSM (2.5G) standards and as many as three to four bands of the 3G WCDMA/ HSPA standards. Evolving versions of smart phones will support additional bands using WCDMA and 3GPP Long Term Evolution (LTE) standards requiring as many as 10 or 11 frequency bands of operation. One of the key components in enabling so many frequency bands and operating modes within one small device is the RF switch, which is used in various forms throughout a smart phone's front-end circuits.

A typical smart phone (***Fig. 1***) features many antenna elements and multiple radio streams to ensure high data rate wireless communications, whether through cellular or mobile connectivity networks and peripheral devices. Multiple RF components are necessary to amplify, filter, and switch the required RF signals. The RF switch content is highlighted in blue.
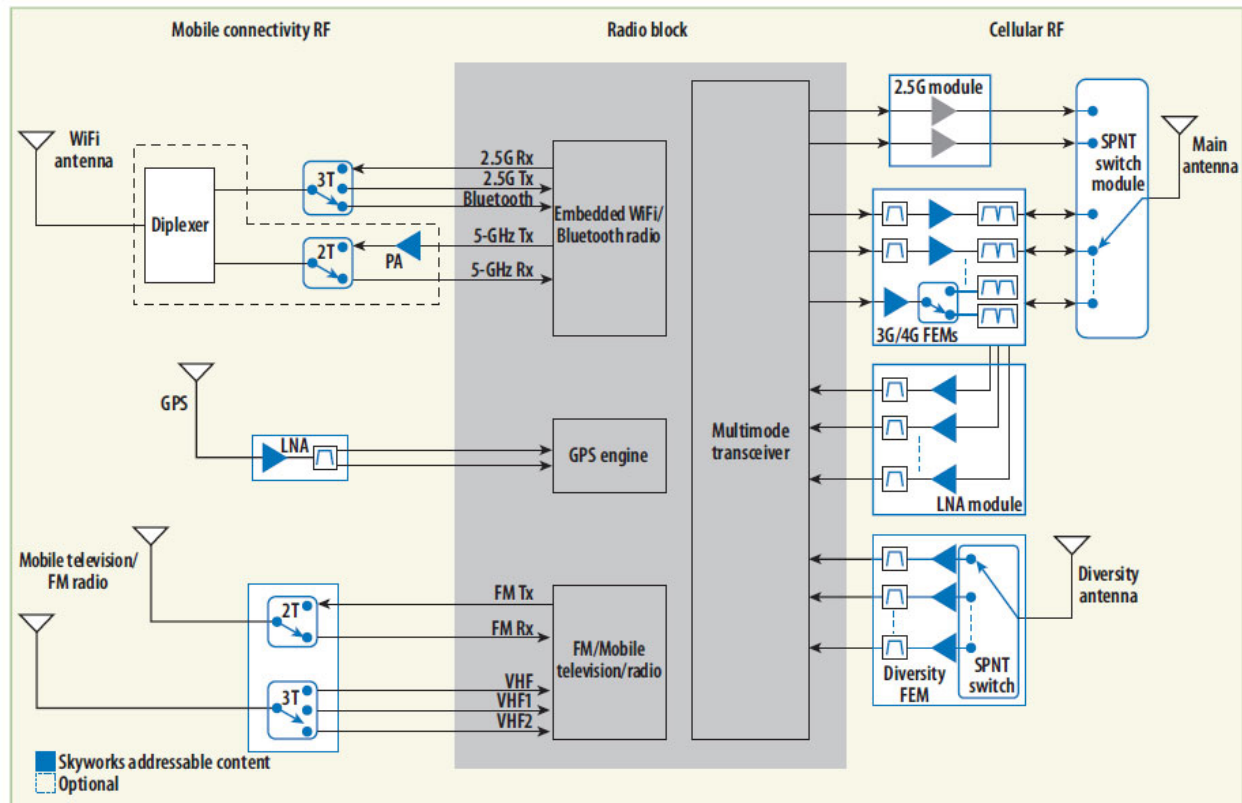
1. This block diagram shows a typical smart phone architecture, with embedded Bluetooth, GPS, and FM radio functionality in addition to the multiband cellular telephone.

Modern smart phones are complex devices that blend computing and communications technologies within a handheld package that must provide a wide range of consumer and business-related functions through an intuitive operating interface. The close proximity of electromagnetic (EM) field-generating computer circuitry to radio circuits that must receive other EM signals is just one example of the design challenges posed by a smart phone handheld device. The complexity of a smart phone carries over to the RF analog/ mixed signal world of these multiradio transmitters.

One look at the radio blocks inside this new breed of phone reveals the complexity inherent with multiple radios operating and coexisting within a small physical volume. The complex signal routing and RF switching requirements present significant challenges in smart phone designs. The RF switch configurations in smart phones range from relatively simple, single-pole, double-throw (SPDT) configurations through more complex single-pole, ten-throw (SP10T) configurations and sometimes even higher throw counts. The driver for all these switches is the plethora of communication radios and the multiple frequencies and antennas in the smart phone.

Multiple RF switch components are used in cellular communications systems, as can be seen from a review of a block diagram (*Fig. 2*). These switch components include the primary antenna transmit/receive (T/R) switch, which is used to connect the main device antenna to the primary cellular transmit and receive functions in time-division-duplex

(TDD) transceivers, such as those used for GSM-based service for all bands. In addition, a band-mode switch is used predominantly to route wideband CDMA signals from the output of the power amplifier to the frequency selective band duplexer. Also, diversity switches are used to connect a secondary or diversity cellular antenna. Diversity antennas are quite common in data card applications and are growing in popularity for smart phone use, especially for data-centric systems such as LTE.
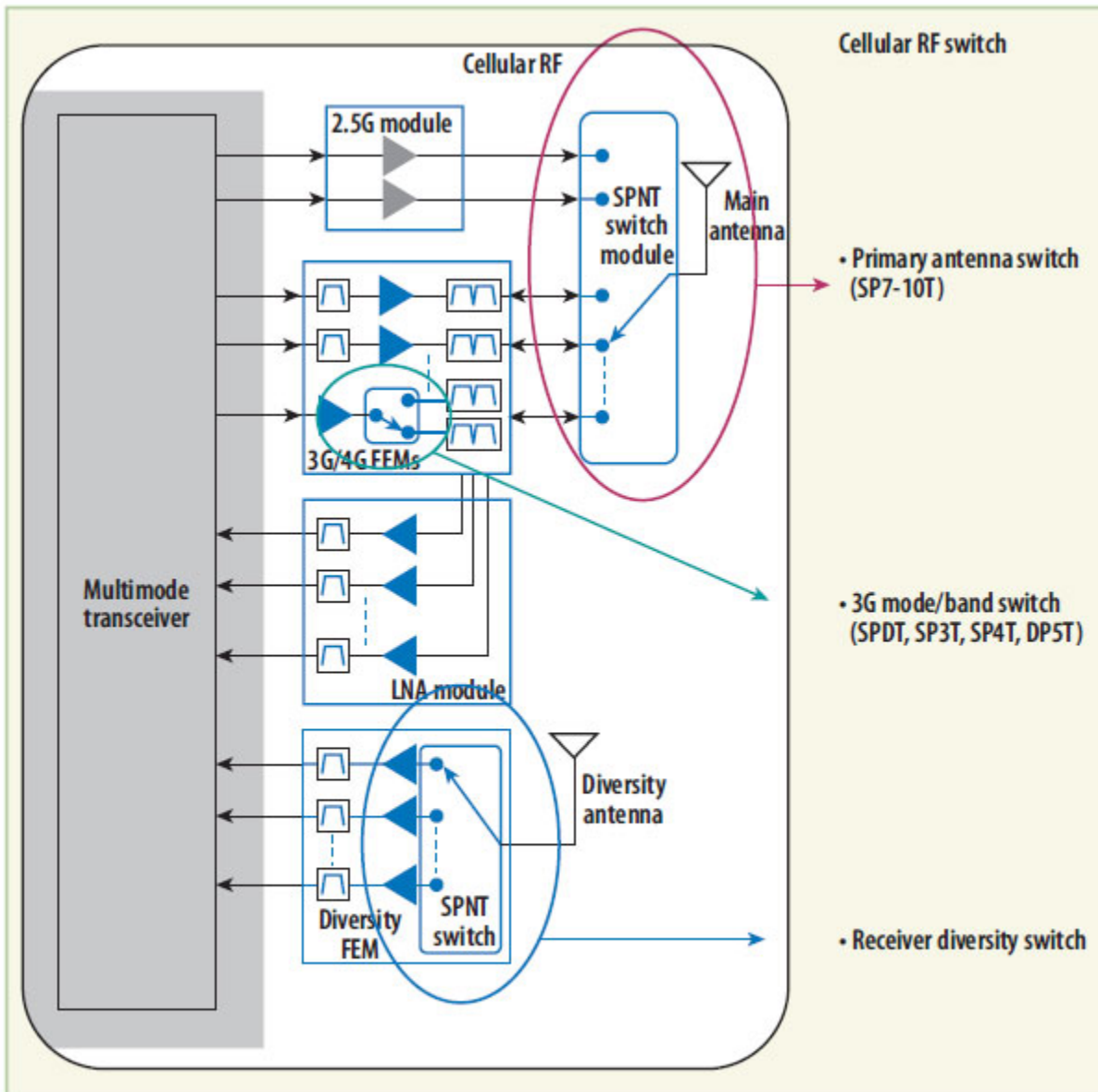
2. A number of RF switches are required in a cellular handset, for antenna switching, band switching, and diversity switching.

The main function of the primary antenna switch is to connect overthe- air RF radio communications to the main transmit and receive functional blocks in the communications modem. Current implementations of this antenna switch range

anywhere from the single-pole, seven-throw (SP7T) through single-pole, ten-throw (SP10T) configurations, depending upon the number of RF bands supported by the smart phone.

The primary antenna switch is tasked to maintain the signal linearity and to provide isolation between transmit and receive chains, with the lowest insertion loss possible. The transition to wireless data communications as opposed to previous generations of voice only use, have stimulated a movement to the use of higher-order modulation schemes such as orthogonal-frequency- division-multiplexing (OFDM) modulation and the closely related orthogonal-frequency-division-multiple- access (OFDMA) modulation. These complex modulation schemes yield waveforms that vary widely in amplitude, resulting in high peak-toaverage- power-ratio (PAPR) signals that demand increased dynamicrange from the components that process them and require excellent linearity from the RF switch in order to minimize distortion in the RF signal path.

To maintain linearity in the face of increasingly higher power level signals, most antenna switches feature increasingly sophisticated design topologies to meet these tougher linearity requirements. For example, often there are integrated charge pumps in the antenna switch module, which are used to boost the battery voltage to control the field-effect transistors (FETs) comprising the switch. This is often a reasonable tradeoff, since it mitigates the need for larger FETs, improves switch insertion loss and isolation, and enhances the robustness of the switch's compression point, as defined by the output-power point at which gain is compressed by 0.1 dB ($P_{0.1dB)}$ or by 1 dB (P_{1dB}).

Depending on the approach to system partitioning, the switches may include GSM transmit harmonic frequency filtering. This configuration is commonly referred to as an antenna switch module (ASM). Some variations include a surface-acousticwave (SAW) filter for a complete switch/receive filter in a miniature module package. Whether an ASM or a switch without a GSM filter, or a complete T/R switch and SAW module, the primary path switches always include main switching and control logic functions in a compact module.

High-throw-count switches for smart phone applications are typically fabricated with GaAs pseudomorphic- high-electron-mobility-transistor (pHEMT) processes, although products are also being developed using standard silicon CMOS and silicon- on-insulator (SOI) technologies. Each of the approaches provides benefits and limitations, and the choice usually depends on the end user's requirements.

Several high-throw-count switches developed recently by [Skyworks Solutions](#) include devices with as many as ten throws for multiband operation. For example, the model SKY13362-389- LF single-pole, ten-throw (SP10T) switch supports as many as five 3G cellular communications bands. Controlled by four CMOS/TTL-compatible control voltages, the switch features an integrated CMOS decoder and a GSM transmit filter, and operates from 0.4 to 2.2 GHz running on a single +2.5 to +3.0 VDC supply. It exhibits insertion loss of typically 0.5 dB from the antenna port to the transceiver port, 1.1 dB from the antenna port to either of the GSM transmitter ports, and 1.1 dB from the

antenna to the receive port. The isolation is at least 17 dB and as high as 32 dB, depending upon which two ports are selected for the measurement. The switch has 5-μs switching speed and an input third-order intercept point of +61 dBm or better when tested in UMTS mode, and is supplied in a 3.0 x 3.8 mm Quad-Flat-No-lead (QFN) package.

The firm's model SKY14152 front-end module contains an integrated SOI switch and controller, GSM transmit filter, and single-band differential SAW receive filter. The switch is a single-pole, eight-throw (SP8T) component designed for use from 0.4 to 2.17 GHz. It handles at least +27 dBm power at its transmitreceive port, with typical insertion loss of 0.7 dB or better. Isolation between any two ports is at least 30 dB. The module, which is optimized for data card use, is supplied in a 20-pin, 3.2 x 3.2 mm multichip-module (MCM) package.

Products that allow a direct connection to a handset's battery (with the proper supply voltage range) may be useful in some handheld applications. Future designs are also expected to move away from a GPIO-based control interface to an industrystandard programmable interface for high-throw-count antenna switch modules.

With 3G multimode and multiband architectures, there is a greater need for band/mode switching. The highly linear band and/or mode switch is used to switch widebandcode-division-multiple-access (WCDMA) signals from the output of the power amplifier (PA) into the appropriate frequency duplexer before being routed out through the antenna switch module. Requirements for the band or mode switch depend on the PA architecture chosen. In the case of a single-mode architecture, where the GSM transmit path is separate from the linear wideband CDMA path, the band switch is only required to pass WCDMA signals from the output of the power amplifier to the duplexer. In the case of a multimode, multiband-signal-path architecture, where GSM and WCDMA signals are transmitted through the same PA, the mode switch must be designed to handle higher-power saturated GSM modulation signals. Either PA architecture typically has a high band and a low band amplifier chain. In the case of single-mode architectures, the switch is used to select one of several wideband CDMA duplexers.

Typically the band or mode switch is a single-pole, double-throw (SPDT) or single-pole, three-throw (SP3T) configuration depending on the number of wideband CDMA bands supported. However, where space is at a premium, this function can be combined into a double-pole, four-throw (DP4T) switch or double-pole, fivethrow (DP5T) switch for handling as many as five bands. The requirements for the switch will be dictated by the level of RF signals it has to handle. The objective is to have high enough linearity so there is no signal distortion added by the switch.

Band switches are used for both pre-PA and post-PA as bands are added or combined in multiband platforms. The choice of pHEMT or SOI technology is usually determined by the amount of control voltage available. When 2.8 V or more is available, pHEMT technology is a good choice. In cases where the RF subsystem is using lower-voltage logic signals (such as 1.8 V), an SOI approach would be more suitable. Lowthrow-

count GaAs devices typically do not employ charge pump circuitry due to size constraints, in contrast to high-throw-count switches.

Some examples of band/mode switch products from Skyworks Solutions include SOI devices suitable for low logic levels (1.8-V control logic) and GaAs pHEMT devices. The SOI switch devices include the SPDT model SKY13330-397LF, the SP3T model SKY13345-368LF, and the double-pole, four-throw (DP4T) model SKY14155-368LF band switch. The GaAs pHEMT integrated circuits (ICs) include the models SKY13351-378LF, the SKY13320- 374LF, and the SKY13321-360LF SPDT switches, the SKY13309- 370LF and the SKY13317-373LF SP3T switches, and the SKY14151-350LF SP4T switch.

In emerging wireless handset and data card applications, there is often a secondary or diversity receive antenna and an associated receiver signal chain. Diversity receive techniques are used to increase data rates, especially where data throughput is a chief concern. For cost and power consumption considerations, practical diversity techniques are applied in the receive side only in terminal applications and do not include the transmit signal path. Depending on the number of wideband CDMA frequency bands supported, there is a switch required at the diversity antenna. In most instances, this is an application requiring an SP3T, SP4T or a single-pole, five-throw (SP5T) switch. The power-handling requirements for these RF switches are reduced compared to those for the primary path antenna switch since they are not required to withstand large transmitter signals.

Several Skyworks products are designed for diversity applications: the SKY13322-375LF SP4T switch, the SKY14153-368LF SP4T switch, the SKY13345-368LF SP4T switch, and the SKY14151-350LF SP4T switch are the most popular devices for the diversity application. Future products will include an SP5T, the SKY13358- 388LF. For example, the model SKY13322-375LF GaAs FET SP4T switch operates from 0.1 to 6.0 GHz with insertion loss of typically 0.45 dB at 1 GHz and isolation of typically 28 dB at 1 GHz. It has a 1-dB compression point (P1dB) of +30 dBm and is supplied in a 10-pin Micro Leadframe Package Dual (MLPD) measuring 2 x 3 mm. The model SKY14151-350LF SP4T diversity switch operates from 0.1 to 2.5 GHz with 29 dB isolation at 1 GHz and 0.4 dB typical isolation at 1 GHz. The switch has an integrated decoder and uses only two TTL-compatible DC control lines to control four switch ports. It handles +34.5 dBm RF power at 900 MHz and +31.5 dBm at 1.8 GHz. The symmetrical switch is optimized for GSM/WCDMA/EDGE and operates from a single supply of +2.5 to +3.0 VDC. It is supplied in a 3 x 3 mm QFN package.

In addition, 4G standards specify the presence of a second antenna element for multiple-input-multiple-output (MIMO) operation. In its simpler implementation, MIMO will facilitate increased data rates by improving overall received signal strength through the selection of the stronger received signal or through the combination of signals received at the two independent antennas. In its more complex implementation, MIMO will facilitate the simultaneous transmission of two (or more) independent data streams between the base station and the handset. The advent of the fourth-generation cellular

standard LTE will drive additional diversity path configurations as the smart phones expand the data throughput capabilities for portable devices.

On the mobile connectivity side, switches are vital for routing signals and connecting different radios to antennas. The presence of Bluetooth radios, WiFi connectivity, and mobile television receive capabilities in a smart phone all require additional switching functionality. The attach rate (at which additional functions are added to a handset) for mobile connectivity radios within the smart phone category has grown substantially over recent years. Bluetooth and FM radios have greater than 50 percent attach rates, and Global Positioning System (GPS) and WiFi are approaching 20 percent attach rates. The emergence of chipsets that combine several of the common mobile connectivity options together (Bluetooth, WiFi, and FM radio) in a single chip serves to increase their popularity and ubiquity.

Mobile connectivity radio options are typically implemented one of two ways: they can be designed using discrete components and chipsets or they can be delivered by a third-party module manufacturer. Regardless of the implementation details, there are several applications of RF switches on the mobile connectivity side of the smart phone.

In the case of embedded WiFi, a handset manufacturer's frequency band offering will determine RF switch requirements. If operation is confined to the 2.4-GHz band, switch requirements typically will call for an SPDT or an SP3T device depending upon the presence of the Bluetooth signal. The interface to the switches is somewhat dependent on the chipset manufacturer for the WiFi solution. Chipsets providing a 2.8-V regulated voltage output to the switch will typically use a pHEMT device. An increasing number of new WiFi chipsets are optimized for portable applications that use lower level logic voltages in the 1.8-V range. In the instance where only 1.8 V is available, an SOI switch may be the better choice, to avoid the degradation in performance that pHEMT devices might suffer at operating voltages below 2.7 V.

When selecting GaAs pHEMT devices, Skyworks has a large portfolio of products suited to this application. Suggestions include the SKY13323- 378LF SPDT and SKY13351-378LF SDPT (suitable for the 5.8 GHz band) switches, the SKY13317-373LF SP3T switch (suitable for the 5.8 GHz band). If the lower operating voltage is required, the SOI alternatives are the SKY13330-397LF and the SKY13345-368LF.

The SKY13323-378LF SPDT switch is a pHEMT GaAs FET device capable of operating from 0.3 to 3.0 GHz, with 0.35 dB typical insertion loss at 3 dB and 27 dB typical isolation at 3 GHz. It is supplied in a 6-pin 1 x 1 mm MLPD package. The SKY13351-378LF SPDT switch handles 2 to 6 GHz, with insertion loss of 0.35 dB at 2.45 GHz and isolation of 24 dB at 2.45 GHz. It is also supplied in a 1 x 1 mm MLPD housing. It achieves a 40 ns rise/fall time with input IP3 of +32 dBm at 2.45 GHz. The SKY13317-373LF SP3T switch controls signals from 0.1 to 6.0 GHz, with 0.5 dB insertion loss at 2.5 GHz, 0.9 dB insertion loss at 6 GHz. The isolation is 25 dB to 6 GHz. The switch is supplied in a 1.5 x 1.5 mm MLP housing and has a 1-dB compression point of +29 dBm for high linearity applications.

With the rollout of WiMAX networks, more devices are being designed to operate on WiMAX and cellular networks. WiMAX devices nominally transmit higher output power than a corresponding WiFi network device and require higher linearity switches to avoid signal distortion. Skyworks devices suitable for WiMAX include the SKY13370-374LF, the SKY13299- 321LF and the SKY13348-374LF.

Improvements in battery technology, screen display, processing power/ speed make it possible for the consumer to have a richer experience on today's smart phone mobile platforms. New applications are being devised to take advantage of the new generation devices and streaming video and video highlights are featured prominently. One challenge for broadcast television reception in the handheld device is the physical size of the antenna at very low frequencies. Mobile television and FM radio chipsets typically cover tens of megahertz up through 800 MHz. Because of the traditional relationship of an antenna's physical size to the received signal's wavelength, handsets with FM radio or television receive capabilities rely on some sort of RF tuning in order to make use of a compact embedded antenna for receiving these relatively low frequencies. RF switches can be used to tune the electrical length of the embedded antennas by switching in impedance-tuning and impedance-matching circuits and elements, so handsets with these embedded antenna meet consumers' expectations for good performance in a reasonable device size.

FM radio, one of the highestadopted connectivity radios, has morphed from a receive-only device to include FM transmitter functionality. The explosion of in-car and homebased MP3/FM radio pass-through devices requires FM transmit functionality. Typically, an SPDT switch is used to select FM receive and FM transmit functions. The SKY13322- 375LF (SP4T) and the SKY13309- 370LF (SP3T) were designed to meet the requirements of mobile television applications. The SKY13323-378LF is a good choice for FM transmit and receive applications.

Modern smart phones blend communications and computing capabilities and are complex technological creations that simplify many different applications for consumers and business enterprises alike. The multiple bands and configurations accommodated by modern handsets place a higher premium on high linearity and low signal distortion to provide consumers with error-free high data rate communication on the go. Complex architectures require RF signal routing and are a key driver for the increased presence of multiple, multithrow RF switches.

The primary mobile connectivity applications in smart phones are:

• Embedded WiFi radios, typically requiring a SPDT or SP3T switch. A possible variant is the adoption of WiMAX radios for the connectivity option and will use higher-power versions of SPDT and SP3T switches

• FM and mobile television radios can use SPDT, SP3T, and SP4T switches depending on chipset requirements.
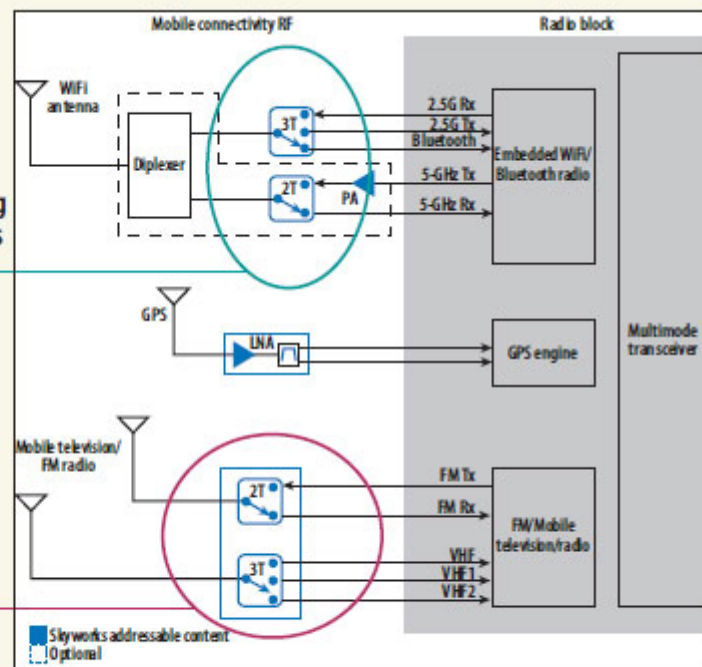
3. This diagram shows some of the mobile connectivity applications for smart phones.