RTT TECHNOLOGY TOPIC
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RF Device Development

Introducing this month's Hot Topic

Regulatory and standardisation authorities are presently engaged in developing plans to extend existing frequency allocations for GSM and WCDMA.

The successful commercial exploitation of these new allocations will be dependent on the availability of cost competitive and performance competitive handsets.

This in turn is dependent on RF device availability.

We are told in marketing presentations that Software Defined Radio will solve the historic problem of producing handsets that work across multiple frequency bands and multiple radio standards.

In practice, there are a number of frequency specific tasks that presently cannot be implemented as a software function or integrated into common hardware.

The purpose of this Hot Topic is to review present RF processing requirements, to study how these requirements will change over the next three to five years and to match these requirements to present and likely future RF device developments.

A reminder of present spectral allocations

The table below appeared in last month's Hot Topic (on HSDPA) but is also directly relevant to this month's discussion. There are nine band allocations or proposed allocations for cellular spectrum between 800 MHz and 2.6 GHZ. These are specifically bands that are either already designated for UMTS 5 MHz channels or could be used for UMTS and include present GSM band allocations.

This implies the need to produce RF front ends that can switch between GSM and WCDMA. There will likely be additional requirements to support other radio systems including WiFi, Bluetooth and UWB in addition to parallel receive only functions such as DVB and GPS.

Present and potential future cellular spectrum allocations from 800 MHz to 2.6 GHz

Band	3GPP	Allocation	Uplink	Downlink	Region
I	2100	2x60 MHz	1920-1980	2110-2170	Present UMTS
II	1900	2x60 MHz	1850-1910	1930-1990	US PCS
111	1800	2x75 MHz	1710-1785	1805-1880	GSM Europe, Asia, Brazil

IV	1700/2100	2x45 MHz	1710-1755	2110-2155	New US
V	850	2x25 MHz	824-849	869-894	US and Asia
VI	800	2X10 MHz	830-840	875-885	Japan
VII	2600	2x70 MHz	2500-2570	2620-2690	New
VIII	900	2X35 MHz	880-915	925-960	Europe and Asia
IX	1700	2x35 MHZ	1750-1785	1845-1880	Japan

This suggests an increasingly complex range of RF processing requirements.

The industry is capable of meeting these requirements. The development of optimised direct conversion or near zero IF architectures for multi band operation are examples of solutions made available to meet a market need.

However we should not underestimate some of the RF device and design, performance and cost challenges implicit in extending present frequency allocations combined with the need to support multiple radio technologies.

100 years of RF Device Evolution
For the past 100 years radio devices have been required to oscillate, resonate, filter, switch and amplify at RF frequencies, originally long wave, then medium wave and short wave through to the microwave frequencies used today.

The efficiency with which these tasks are performed makes a significant contribution to the overall efficiency of the radio system.

Fleming's thermionic valve in 1904 and Lee de Forest's triode valve in 1907 were major moments in radio device development. These devices, combined with resistors, inductors, diodes and capacitors provided the basis for 80 years of tuned circuit development.

Tuned circuits would not have been realisable had it not been for the discovery of the piezo electic effect by Pierre and Jacques Curie in 1880. The Curie brothers discovered that when pressure was applied to certain crystals, an electrical voltage was generated. Conveniently for the radio industry, this proved to be a bi directional effect. Applying electrical voltage to certain crystals would cause them to vibrate at a specific frequency.

In 1917, Paul Langevin used quartz crystals in a sonar device for submarine detection and from then on quartz became the basis for detecting and creating specific audio and radio frequencies.

In the Second World War, similar research in the US, Japan and the Soviet Union showed that certain classes of ceramics exhibited piezo electric behaviour . Courtesy of two world wars we were provided with a choice of quartz crystals and or ceramic based devices as the basis for providing accurate frequency and time referencing in radio products.

The invention of the transistor in 1947 and the integrated circuit in 1958 used in combination with these devices provided the basis for the power efficient and spectrally efficient radio transceivers which have powered the wireless industry for the past 50 years.

However 50 years on these RF functions are still typically realised as discrete components, existing along side rather than inside present integrated circuits.

Present RF Device Integration Limitations
The reason for this becomes clear when the receive path and transmit paths in a cellular handset are considered in more detail, starting with:

The antenna.
Antennas in hand held devices are either electrical dipoles, small loops, helical, meander antennas or patch antennas. Patch antennas, also known as Planar Internal Antennas are increasingly popular as embedded antennas (hence the description 'internal'). Typically these are used with grounding which shifts the antenna resonance to a lower frequency with a slot added to increase electrical length, a design known as Planar Inverted F Antennas (PIFA).

Antenna size can also be reduced by using dialectrics with a high dialectric constant. Another option is to use fractal based antenna patterns to use whatever space is available reasonably effectively.

However any antenna, when constrained within a space that is significantly less than a quarter wavelength of its centre frequency will be inherently inefficient.

In addition, transmit frequencies are being generated in immediate proximity to the receive antenna. Typically, locally generated transmit power can be 100 dB higher than the received signal of interest. Achieving acceptable isolation between transmit and receive paths can be particularly challenging.

In present dual band designs, for example an 850/1900 MHz handset in the US, a common antenna will be used for both the receive and transmit operations in both bands which implies some compromise in terms of gain, radiation patterns, matching and isolation.

The two bands are separated by a **diplexer.** The received signal from the antenna is routed through the low-pass filter section of the input diplexer for the 850 MHz band. The 1900 MHz transmit and receive paths pass through the high-pass filter section of the diplexer.

Within each band, the transmit and receive paths are kept apart by the **duplexer**. The duplexer has to prevent transmitter noise in the receive band from desensitizing the receiver, attenuate the power amplifier (PA) output signal to avoid driving the low-noise amplifier (LNA) into compression, attenuate the receiver's spurious responses (first image and others), and attenuate local oscillator feed-through and transmitter output harmonics and other undesired spurious products. The job of frequency selectivity is shared between the duplexer and the image filter.

If GSM is supported in either band, the duplexer can be replaced with a transmit receive switch.

Receivers are either superhet or, more often now, direct conversion. The job of the low noise amplifier in the receive path is to provide gain for the low level RF signal without degrading the signal to noise ratio or introducing non linearities that could result in intermodulation.

The output signal goes through a bandpass filter that is matched to the receive band, for example, 25 MHz or 33 or 39 MHz for some GSM bands. This filter takes out image noise and other spurious responses within the band.

The received RF signals are then routed to the mixer or mixers which will either be at the receive frequency (direct conversion), close to the receive frequency (near zero IF) or at an off set to generate an intermediate frequency (a traditional superhet).

If the design is a superhet, the first IF filter will typically be a narrowband surface acoustic wave (SAW) filter. The second IF filter would probably be a narrowband ceramic filter.

Designers then traditionally have a choice of using discrete or integrated front ends (LNAs, mixers, and LO buffers). Discrete devices mean that gain, noise figures, the third-order input intercept point (IP3), and power consumption can be optimized but at the expense of a higher component count and higher cost. Sharing components across multiple bands also reduces component costs and component count but makes it harder to optimize performance in each band.

The antenna switch module

GSM/WCDMA phones typically end up with a duplexer and a GSM TX/RX switch in the front end of the phone.

In addition, there is a need to band switch and mode switch. In an ideal world you would not introduce these switch paths. They create loss and distortion and dissipate power.

More bands and additional modes therefore add direct costs in terms of component costs and indirect costs in terms of a loss of sensitivity on the receive path and a loss of transmitted power on the transmit path.

Possible new switch technology solutions

One alternative is to use MEMS (micro electrical mechanical system) based switches.

The idea of building micro electrical mechanical switches has been around for twenty years or so but is now becoming practical and has the benefit of sharing available semiconductor fabrication techniques. MEMS components are manufactured using micro machining processes to etch away parts of a silicon wafer or to construct new structural layers that can perform mechanical and electromechanical functions.

A MEMS based switch has low insertion loss, good isolation and linearity and is small and power efficient. In addition it is essentially a broadband device. It is electro statically activated so needs a high voltage which is inconvenient but low current (so practical).

MEMS devices are sensitive to moisture and atmospheric contaminants so therefore have to be hermetically sealed, rather like a quartz crystal. This packaging problem disappears if the device is sealed at the wafer level during manufacture with additional over moulding to provide long term protection.

Integrated MEMS devices are therefore a plausible candidate for band switching and mode switching within the next three to five years. TX/RX switching (for GSM or other TDM systems) would be more ambitious due to the duty cycle requirements but still possible using optimised production techniques.

Possible new filter technology solutions
SAW filters are a form of MEMS device in that they use semiconductor processes to produce combed electrodes that are a metallic deposit on a piezo electric substrate.

SAW devices are used as filters, resonators and oscillators and appear both in the RF and IF stages of present cellular handset designs.

SAW devices are now being joined by a newer generation of devices known as BAW (bulk acoustic wave) devices.

In a SAW device, the surface acoustic wave propagates, as the name suggests, over the surface of the device. In a BAW device, a thin film of piezo electric material is sandwiched between two metal electrodes. When an electric field is created between these electrodes, an acoustic wave is launched into the structure. The vibrating part is either suspended over a substrate and manufactured on top of a sacrificial layer or supported around its perimeter as a stretched membrane, with the substrate etched away.

BAR devices are often referred to as Thin Film Bulk Acoustic Resonators (FBAR). The Piezo electric film is made of aluminium nitride deposited to a thickness of a few tens of microns (hence the thin film description). The thinner the film, the higher the resonant frequency.

BAW devices are useful in that they can be used to replace SAW or microwave ceramic filters and duplexers in a single component. BAW filters are smaller than microwave ceramic filters and have a lower height profile. They have better power handling capability than SAW filters and achieve steeper roll off characteristics.

FBAR filters are presently being sampled for integration into GSM front end modules. The benefit apart from the roll off characteristic and height profile is that BAR devices are inherently less temperature sensitive than SAW devices and are therefore more tolerant of modules with densely populated heat sources (transceivers and power amplifiers).

Possible new resonator technology solutions
MEMS are also being suggested as potential replacements for present quartz crystal based sub systems. The potential to use micro electrical mechanical resonators has been the subject of academic discussion for 40 years and the subject of practical

research for almost as long.

The problem with realising a practical resonator in a MEMS device is the large frequency coefficient of silicon, ageing, material fatigue and contamination. A single atomic layer of contaminant will shift the resonant frequency of the device.

As with MEMS switches and filters, the trick is to achieve hermetically robust packaging that is at least as effective as the metal or ceramic enclosures used for quartz crystals but without the size or weight constraint. There are products now available that use standard CMOS foundry processes and plastic moulded packaging.
These devices are not yet sufficiently developed to be used as a replacement for a GSM or CDMA TCXO but they potentially offer significant space and performance benefits. A MEMS resonator is a few tenths of a millimetre across. A quartz crystal is a few millimetres across, one hundred times the surface area.

MEMS resonator performance is a function of device geometry. As CMOS geometries reduce, the electrode gap reduces and the sense signal and signal to noise ratio improves, giving the oscillators a better phase noise and jitter specification. As MEMS resonators get smaller they perform better and get less expensive. As quartz crystals get smaller their performance degrades and they get more expensive.

Parallel developments in ceramic materials
Parallel developments are being made in ceramic materials particularly low temperature co-fired ceramic (LTCC) RF modules. The use of the LTCC process can be used to integrate capacitors, resistors and inductors into a small space and provide a substrate on to which active devices such as RF integrated circuits can be mounted. Issues presently with LTCC materials tend to focus on device characterization.

Implications for future radio systems
It seems inevitable that the regulatory environment will require the industry to produce handsets that are capable of working across ever more numerous multiple bands and that the standards making process will ensure that handsets will also have to support ever more numerous and largely incompatible multiple radio standards.

This potentially increases RF component cost and makes it harder to deliver consistent RF performance across such a wide range of possible RF operational conditions.

This trend also highlights that some of the traditional RF device technologies that have served us faithfully for 50 years or more are non optimum for these extended operational conditions.

From a business perspective, there is evidence of a closer coupling between companies with antenna and shielding expertise and silicon vendors. The recent agreement between Laird and RFMD to co develop more highly integrated RF modules is one example.

Similar agreements are likely between the MEMS community and silicon vendors to meet the perceived 3 to 5 year need for a closer integration of RF MEMS functionality into or at least on to next generation silicon. At that stage, but not before, the software defined radio and/or one chip radio may become a more practical reality.

Summary

To date design efforts aimed at reducing RF component costs in multi band multi mode handsets can be summarised as follows

Active device integration

This includes dual band and multi band receiver integrated front ends with dual or multi band PA's in the same package with the transmitter I&Q modulator, voltage gain-controlled amplifiers, PA drivers, and synthesizers on the same chip.

Putting a receiver-synthesizer and transmitter into a single ASIC remains problematic and RF isolation and shielding remains easier to address with separate RF ASICS. This is particularly true for higher power wide area cellular radio systems.

Passive Device Integration

A large number of passive parts can still be found in multi band transceivers. The problem is solved partly by reducing the packaging size of VCOs, filters, isolators and SAW duplexers and the footprint of standard components like resistors, capacitors, and inductors. 0603 package sizes have reduced to 0402 and to 0201 (0.5 x 0.25 mm) size but this requires significant attention to placement accuracy on the production line with associated production yield/cost and performance risks.

New ceramic materials are becoming available in parallel with other techniques including micro electrical mechanical based devices which will facilitate increased levels of device integration and miniaturisation.

These devices and design techniques reduce rather than eliminate the direct (component related) and indirect (performance related) costs implicit in supporting additional bands and additional radio access technologies.

Nevertheless, vendors with expertise in the product areas listed below will have a potentially valuable role in future cellular handset design.

Relevant Technology/Product areas and example vendors

MEMS based resonators
MEMS based RF switches, tunable filters and multi band diplexers
CMOS silicon on sapphire RF switches
FBAR filters
BAW duplexers
Fractal antennas
PIFA antennas
LTCC based devices and device characterisation

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RTT, the Shosteck Group and The Mobile World are presently working on a number of research and forecasting projects in the cellular, two way radio, satellite and broadcasting industry.

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geoff@rttonline.com

00 44 208 744 3163