RTT TECHNOLOGY TOPIC
February 2013

Switches, capacitors and resonators

Our September 2012 technology topic, **'Acoustic Filters'** reviewed the impact of material and manufacturing innovation on acoustic filter performance and the related impact on smart phone performance.

http://www.rttonline.com/tt/TT2012_009.pdf

Acoustic filters are micro electrical mechanical (MEMS) devices based on a piezo electric substrate of quartz, lithium niobate or lithium tantalate. They are a good example of how materials and manufacturing and package innovation can be combined together to meet specific RF performance requirements.

In this month's topic we look at how material and manufacturing innovation is being applied in other areas of the smart phone including high throw switch paths, digital capacitors, reactive components and resonators.

We reference practical components presently available or being sampled from a cross section of vendors.

The switch path

Once upon a time the switch path was simple with two or four or at most five bands needing to be switched. Today it is not uncommon to find an eight or ten throw single pole switch or multiple switches in the front end of a smart phone. An SPT12 (single pole twelve throw) switch will typically support eight UMTS bands and 4 GSM bands, an alternative is to use an SPT10 with eight symmetric TX ports and two symmetric ports optimised for low insertion loss .The devices have to be highly linear with good second order and third order harmonic performance and provide good isolation.

http://www.psemi.com/content/products/product.php?product=PE426171

The devices referenced above are based on silicon on sapphire (SOS), one of a family of silicon on insulator (SOI) options. Silicon on sapphire is not a particularly new combination of materials. Invented fifty years ago at North American Aviation (subsequently Boeing), it was used in professional consumer products in the late 1970's and early 1980's including the HP41 series of calculators, the calculators that flew on space shuttle flights from 1981 onwards.

http://hpinspace.wordpress.com/category/hp-41/

The Voyager 1 spacecraft launched in 1977 has a silicon on sapphire based microprocessor. After 35 years and 12 billion miles Voyager 1 is about to be the first manmade object to leave the solar system having transited through the outermost layer of the heliosphere.

http://www.jpl.nasa.gov/news/news.php?release=2012-177

Silicon on sapphire was used for its low power consumption and radiation resilience for space applications but then outgunned in commercial markets by bulk silicon.

In the 1990's ultra-thin deposition techniques at thicknesses of 100 nm or 100 atoms improved performance and in the past ten years it has become possible to improve yield to the point at which it has become sufficiently price competitive to be reintroduced into consumer devices with cost reduction realised by leveraging standard CMOS production techniques.

Like quartz crystal, sapphire is not dug out of the ground but cultured in a controlled environment. Silicon on sapphire is produced by depositing a thin layer of silicon onto a sapphire wafer at high temperature. As with other silicon on isolator (SOI) substrates, the devices have low parasitic capacitance which is how speed and linearity and isolation are achieved.

http://www.psemi.com/articles/History_SOS_73-0020-02.pdf

Other solutions proposed for switch paths and relays include silicon only MEMS structures using novel mechanical structures. The power handling requirements (+23dBm) and higher voltage requirements are challenging though significant progress is being made.

http://www.delfmems.com/

Digital capacitors

The other consequence of eight band or ten band phones is that it has become necessary to minimize component and circuit duplication. This implies a need to make active components such as RF amplifiers work across wider operational bandwidths to support multiple bands and carrier aggregation. The problem with this is that the devices become progressively less efficient as operational bandwidth increases. The same applies to passive devices, including antennas which not only lose overall efficiency but become more susceptible to hand detuning.

The problem with this is that active devices need to be power matched or noise matched. Similarly changing the electrical length of antennas and compensating for hand effects requires a wide range of capacitance values and the ability to change those values quickly in response to changed loading conditions.

Achieving this by using discrete capacitors and inductors adds cost and takes up real estate. An ideal capacitor only has capacitance but in practice will have some inductance and some resistance. The inductance can generally be absorbed within the required inductance of the resonant circuit but the resistance absorbs energy. An ideal inductor only has inductance but in practice has capacitance and resistance. The capacitance can generally be absorbed within the required capacitance of the resonant circuit but the resistance absorbs energy.

The devices also have to match to acoustic filters which have more ideal characteristics. The mix of discrete and acoustic devices means that impedance will not be constant across the operational bandwidth. The problem with semiconductor variable capacitive diodes is their limited tuning range, low switching speed, relatively low Q, their size and cost and residual resistance. The requirement can therefore be defined as delivering variable capacitance values over a wide tuning range with high Q and low resistance from a small device with minimal cost and insertion loss.

One way of doing this is to build capacitors as microstructures in the range of a few tenths of micrometers using standard silicon micro machining techniques. As a present benchmark it is possible to replicate the function of 32 high precision high Q capacitors in the equivalent board space of two 0402 capacitors with effectively zero insertion loss.
http://www.cavendish-kinetics.com/index.php/applications/antenna-tuning/

Wispry has a similar offering supporting 64 capacitors per die in a slightly different form factor.
http://www.wispry.com/

Resonators

All mobile phone and smart phone transceivers and GPS receivers presently use quartz crystal (XTAL) devices as the source resonator reference for ‘fixed’ oscillator circuits. Crystal Oscillators are used as frequency references for transmit and receive RF (radio frequency) oscillators and directly as clocks and other timing functions.

A quartz crystal is a high Q device but cannot be integrated with other semiconductors in the phone.

When combined with an oscillator circuit employing temperature compensation, these devices, known as **t**emperature **c**ompensated **c**rystal **o**scillators (**TC**X0) provide the required stability of +-2.5 ppm over a temperature range of -30 to +85 degrees C. Temperature compensation is achieved using components having an equal but opposite thermal characteristic to the crystal.

Within the past twelve months, crystals bonded together with a temperature sensing element have been introduced. The temperature sensing crystal has a crystal and thermistor in a single package separated by a ceramic wall. As the two components are reasonably well thermally coupled and typically operate at the same temperature it is possible to compensate temperature with higher precision compared to circuits which have the crystal unit and thermistor placed apart (poor thermal coupling).

http://global.kyocera.com/news/2011/0602_kdwo.html

It is however potentially feasible to replace the quartz crystal (and temperature sensing crystal) with a silicon based MEMS resonator. This is a resonating silicon plate, capable of running at higher frequencies than a quartz crystal and is given the term MEMS MHz resonator to distinguish the source from less closely specified MEMS devices for less critical lower frequency timing applications.

As the resonator is a multilayer MEMS device it is possible to optimise the coupling of the thermistor and resonator by physically integrating the temperature sensor on the MEMS die as a resistive layer. This allows for closer compensation and provides the opportunity to replace the TCXO (or Temperature Sensing Crystal TSX based oscillator) with a Digitally Compensated **M**echanical **O**scillator (DC**MO**) in GSM/HSPA and LTE handsets. As the resonator is fabricated in silicon it is possible to integrate the whole circuit function. This process of integration further optimises temperature coupling, saves space and reduces design risk (which indirectly saves cost).

MEMS MHz resonators have a number of behavioural characteristics which if correctly applied in a DCMO with optimised compensation could deliver performance gain in LTE front ends. These characteristics can be summarised as improved thermal coupling, (improved stability over temperature), higher frequency operation (less phase noise multiplication), an absence of activity dips (reduced spurious content) and no/less hysteresis (faster more predictable more repeatable response to changing operational conditions).

http://www.sand9.com/products/

Summary

The telecommunications industry has always been dependent on a mix of materials innovation and manufacturing innovation. Examples include the introduction of gallium arsenide for power amplifiers in the 1970s. Over the same period SAW filters and more recently BAW filters (a MEMS device) have yielded radical improvements in front end filter performance. These devices are combined with baseband compensation techniques to meet specific performance requirements. The use of temperature compensated FBAR filters in Band 13 in the US (777 to 787 and 746 to 756 MHz) is one example.

Within the past five years, the introduction of silicon on sapphire has improved switch path isolation and reduced insertion loss improving uplink and downlink performance in multi band handsets. RF MEMS have also been propositioned for the adaptive matching of antennas (digital tuneable capacitors). The use of silicon as a resonator has similar potential as a technology that can improve multi band smart phone performance.

Integrating new components into well-established design and supply chains is however a non-trivial task and component innovation on its own may not provide a complete enough solution. What is needed is a combination of component and circuit innovation.

A colleague recently pointed out that the only recent significant innovation in circuit design was the diplexer and that was 40 years ago. What the industry needs is another Armstrong. Edwin rather than Lance.

Ends

Resources

Peregrine Semiconductor
Ultra CMOS® for high performance switch paths and tuneable components
[www.psemi.com]

Wispry
RF MEMS for antenna impedance tuning and tuneable RF front-ends
www.wispry.com

DelfMEMS
MEMS based technology platform for high performance RF switching
www.delfmems.com

MEMS resonators - a new approach to oscillator design
www.sand9.com

RF MEMS- third generation performance and reliability benchmarks
www.cavendish-kinetics.com

RF Materials, manufacturing and circuit innovation is covered in detail in the RF Innovation Workshop being run at the GSM World Congress in Barcelona on Monday 25 January with technical presentations from the five companies listed above. The event is free to attend and can be booked via this link.

http://ictktnmwc1.eventbrite.co.uk

We are also chairing a Future of Spectrum Usage Workshop on Wednesday 27 January on behalf of Cambridge Wireless with technical presentations from David Barker of Quintel, Paul Egan of Neul and Iris Barcia of Keima. This is also free to attend and can be booked via this link

http://ictktnmwc8.eventbrite.co.uk

Materials and manufacturing innovation are addressed in RTT's fourth book '**Making Telecoms Work- from technical innovation to commercial success'** available from the **RTT book shop.**

About RTT Technology Topics

RTT Technology Topics reflect areas of research that we are presently working on. We aim to introduce new terminology and new ideas to help inform present and future technology, engineering, market and business decisions although as you can tell we sometimes stray into more philosophic territory. There are over 130 technology topics **archived on the RTT web site.** Do pass these Technology Topics and related links on to your colleagues, encourage them to join our **Subscriber List** and respond with comments.

Contact RTT

RTT, the Jane Zweig Group and **The Mobile World** are presently working on a number of research and forecasting projects in the mobile broadband, two way radio, satellite and broadcasting industry. If you would like more information on this work then please contact
geoff@rttonline.com

00 44 208 744 3163