RTT TECHNOLOGY TOPIC
July 2010

The RF Performance of LTE user devices

On the 28th June 2010, the Obama administration issued a **memorandum** stating an intention to auction a further 500 MHz of spectrum. Some but not all of this will line up with rest of the world band plans.

This suggests an already complex set of global and often incompatible band plans will only become more complex over time making it progressively harder to realize technically and commercially efficient RF front ends in user equipment. The commercial inefficiency is a product of the sub scale volume implicit in nationally specific spectral allocation. Even apparently large markets like the US are small in global terms.

In last month's technology topic, **RF Multi Band Power Amplifiers**, we discussed the challenges of achieving RF transmission efficiency for LTE user devices in the US 700 MHz and European 800 MHz bands.

The recent press comment about **the inconsistent RF performance of the antenna embedded in the ceramic case of the new iPhone** suggests that important RF design details still get overlooked or compromised to meet aesthetic rather than functional objectives.

Antenna performance is of course just one factor determining the RF efficiency of a mobile phone. The RF power budget has been considered in recent years as less important than the power drain from base band and application processor functions and displays. The display on its own can account for 40% of the power drain. In dense networks, phones transmitting voice or text are often transmitting at a fraction of their potential peak power output.

However this is less true with data duty cycles and particularly not the case in the 700 or 800 MHz bands in larger cells in rural areas. Additionally in LTE if voice is supported, the protocol overheads in the IP stream will increase the amount of power needed per information bit transmitted.

For many data exchanges, packets received on the downlink will be acknowledged on the uplink creating an increased load on the transmit chain. Always on applications like push e mail, location based services and social networking create signalling load. This absorbs further power.

The higher order modulations used to increase peak data speeds improve bandwidth efficiency but require more linearity so are not inherently power efficient.

Over time RF transmission efficiency will therefore have an increasing impact on user duty cycles (voice and data) and data throughput rates. This in turn effects the user experience and by implication operator profitability. Poor antenna design and the additional losses inherent in supporting additional bands compound the problem.

This month we broaden the analysis to look at the fundamental RF innovations at material level that have driven the industry forward for the past thirty years and some of the RF efficiency challenges and opportunities that exist looking forward in multi band mobile broadband user devices.

Alternatives such as higher capacity batteries offer only a partial answer – substantial RF device efficiency gains are needed in order to avoid heat dissipation issues.

Similarly algorithmic innovation can deliver efficiency gains at system level but these gains are inherently constrained by physical RF hardware limitations.

RF hardware innovation opportunities exist and some are identified below but the commercial incentives needed to translate these opportunities into market reality are not always clear. A failure to resolve this potentially compromises present and future spectral and network investment.

RF Power amplifiers – materials and process innovation

In last month's technology topic we highlighted that transmission efficiency is compromised by the difficulty of matching the power amplifier to the antenna or multiple antennas and to the switch path or multiple switch paths across broad operational bandwidths. However transmission efficiency is also influenced by the material and process used for the amplifier itself.

The provenance of many of today's power amplifiers can be traced back to military applications in the 1980's, partly the result of the Reagan Star Wars programme.

This provided the basis for the commercialisation of processes such as gallium arsenide in the early 1990's which provided gains in power efficiency to off set some of the efficiency loss implicit in working at higher frequencies,1800 MHz and above, and needing to preserve wanted AM components in the modulated waveform.

In some markets, GSM for example, CMOS based amplifiers helped to drive down costs and provided a good trade off between cost and performance but for most other applications GaAs provided a more optimum cost/performance compromise.

This is still true today. WCDMA or LTE is a significantly more onerous design challenge than GSM but CMOS would be an attractive option in terms of power consumption, cost and integration capability if noise could be reduced sufficiently.

Noise can be reduced by increasing voltage. This also helps increase the passive output matching bandwidth of the device. However good high frequency performance requires current to flow rapidly through the construction of the base area of the transistor. In CMOS devices this is achieved by reducing the thickness of the base to microns or sub microns but this reduces the breakdown voltage of the device.

The two design objectives, higher voltage for lower noise and a thinner base for higher electron mobility are therefore directly opposed. At least two vendors are actively pursuing the use of CMOS for LTE user devices but whether a cost performance cross over point has been reached is still open to debate.

Gallium arsenide in comparison allows electrons to move faster and can therefore generally deliver a better compromise between efficiency, noise and stability, a function of input impedance. However the material has a lower thermal conductivity than CMOS and is more brittle. This means that it can only be manufactured in smaller wafers which increases cost. The material is less common than silicon, the world's most common chemical element, and demands careful and potentially costly environmental management.

But as at today, gallium arsenide remains dominant in 3G user devices for the immediately foreseeable future and is still the preferred choice for tier 1 PA vendors.

Gallium nitride, already used in base station amplifiers is another alternative with electron mobility equivalent to GaAs but with higher power density allowing smaller devices to handle more power. Gallium nitride power amplifiers will be used for **example** **in the next generation of unmanned aerial vehicles.** However gallium nitride devices exhibit memory effects which have to be understood and managed. Agilent have a useful **application note** on how to use X parameters to model these effects.

Silicon germanium is another option, inherently low noise but with significantly lower leakage current than GaAs and even silicon. However an additional thin base deposition of germanium is required which adds cost.

There is therefore still considerable scope for process innovation but just because something is technically feasible and able to deliver value in terms of the user experience through longer duty cycles and faster data throughput does not mean that innovation or change makes commercial sense.

For example Tier 1 PA vendors all have sunk significant investment in gallium arsenide processes which they would like to fully recover.

RF switch - materials and process innovation

The same argument applies to the RF switch where GaAs FET devices have delivered performance gain based on significant process investments. Applications include band switching and TDD switching in GSM and potentially LTE TDD user equipment.

RF MEMS have also been proposed as TDD switches though doubts about mechanical reliability over millions of duty cycles have so far prevented their adoption. A MEMS based switch is a broadband device with low insertion loss, good isolation and good linearity and is physically small. Being electrostatically activated it needs a high voltage which is inconvenient but means the devices draw low current so are power efficient. Solving mechanical durability problems in these very small devices is however complex and involves implementation risks that are generally not commensurate with the short term returns needed from venture capital investment.

For band switching, other processes have started to be introduced. For example silicon can be combined with a sapphire substrate to achieve low loss and low capacitance and is **used effectively in many present WCDMA multi band switch paths.**

Silicon on sapphire is widely used in military and space communication and is one of several silicon on insulator (SOI) combinations that offer performance advantage with only marginal cost premiums in the front end RF BOM.

RF Capacitors and voltage tuneable devices

Silicon nitride, obtained by a direct reaction between silicon and nitride at high temperatures is used as an efficient dialectic in chip and integrated capacitors but capacitors are also starting to be fabricated as RF MEMS – using micro machining to build structures in CMOS to create tuneable devices for adaptive matching, essentially lots of capacitors (eighty or so) built on one die. Polymer based MEMS switches with lower actuation voltages are another potential option.

Voltage tuneable devices are also being built out of composite thin film barium strontium titanate doped ceramic materials.

Adaptive matching techniques are presently being focussed on off setting losses from mismatches on the TX path caused by changes in load condition caused, for example, by hand capacitive effects.

Longer term these techniques could be more aggressively applied to improving performance over extended operational bandwidths in multi band phones.

RF Filter innovation

SAW filters, rather like GaAs power amplifiers and switches have now been in use for at least thirty years. SAW filters were originally used in military applications then in the IF stages of colour TV’s then in mobile phones.

SAW filters are a form of MEMS device using 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 (intermediate frequency) stages of mobile phone designs.

In a SAW device, the surface acoustic wave propagates as the name suggests over the surface of the device.

An alternative is a device known as a Bulk Acoustic Resonator where a thin film of piezo electric material is sandwiched between two metal electrodes. Hence they are often known as Thin Film Bulk Acoustic Resonator or T-FBAR devices. 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.

The piezoelectric film is made of aluminium nitride deposited at a thickness of a few tens of microns, the thinner the film the higher the resonant frequency.

BAR filters are smaller than microwave ceramic filters and have a lower height profile and relatively sharp roll off characteristics. They are also more temperature resilient than SAW devices and can therefore live more happily in densely populated heat sources such as transceivers and power amplifiers.

However this does not mean they are temperature insensitive and both BAR and SAW filters drift with temperature and require temperature compensation.

RF oscillator innovation

Similar limitations have to date prevented RF MEMS devices being used to replace quartz crystal based oscillators and other resonant devices at least in mobile phones where short and long term accuracy, stability and phase noise are critical performance metrics.

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 stated above, the frequency of an FBAR resonator is a function of the thickness of the film. Producing ten resonant frequencies requires ten separate deposition procedures which costs pretty much the same as ten separate FBAR filters.

In principle a single layer of silicon could be patterned to create parts that vibrate in directions that are parallel to the plane of the device. The lateral dimensions will determine the frequency.

However because the device is so tiny it is hard to control the resonant frequency and the fragility of the structure would mean it could not handle much power.

At some point in the future these devices have the potential to become building blocks of a new RF front end architecture which could deliver step function improvements both in terms of stability, sensitivity and selectivity.

In particular doing channel selection mechanically would allow a smart and or cognitive radio receiver to monitor multiple channels simultaneously without the power drain of present computational approaches. Case study of present progress is available from **Sand9.**

RF antenna innovation

The need to support additional bands and multiple antennas per band is prompting substantial research into miniaturized adaptive antennas that are combined with adaptive sensing to off set hand capacitance effects. Small ceramic antennas are a candidate for miniaturized diversity applications including hybrid solutions with ceramic elements. The latest iPhone is an innovative example of the use of a ceramic casing as part of the antenna function but as stated above, appears to require more work to produce consistent RF performance.

Getting any of these devices to perform well across a wide range of operating conditions is not for the faint hearted and there can be a significant difference between theoretical performance and the real life result when users get involved.

RF component and process improvements need people to make them work

This of course can be said for all forms of invention and innovation though is particular true of RF innovation where simulation of the real world and the impact if user behaviour is still less than perfect.

Fortuitously this makes experience a valuable prerequisite in the process of RF device design and system implementation and applies equally to all the areas of RF component innovation listed above.

However it cannot have escaped the notice of delegates to the various international microwave symposia that RF engineers rather like the quartz crystal, have something of an ageing problem.

This is a thirty year effect that can be traced back to a probably understandable belief in the global educational system that the world was going digital. This of course was never true – the real world around us remains defiantly analogue and ever more will be so.

The practical result is that we are short of young optimistic energetic motivated sober RF engineers to whom older engineers can pass on their practical knowledge and experience.

This in turn slows down the rate at which promising RF device innovations can be translated into cost and performance efficient RF system solutions.

The people and profitability problem

There are other reasons for this. The gross margins on RF components are lower than other components in the phone but the process and implementation risks are greater, a disincentive to investment.

If there is no incentive to invest there is no pull through effect to encourage young engineers to study and help implement RF engineering innovation – a people and profitability problem.

In the final analysis the problem ends up at the operators door step.

Over the past ten years spectral and network investments have been predicated on delivering significant gains in peak and average data throughput. This has been achieved by delivering significant improvements in bandwidth efficiency. The problem is that there have not been parallel equivalent improvements in power efficiency.

So for example substantial technical research and marketing effort is invested in establishing spectral efficiency benchmarks measured in bits per hertz.

Minimal technical research and marketing effort is invested in establishing power efficiency benchmarks measured in joules per bit which are arguably rather more relevant to future business modelling.

It would be absurd for us to plan a future on the basis of mobile devices which can only be used when connected to a mains supply.

The step function improvement that is needed in power efficiency to avoid this will only be realised as and when or if substantial progress is made in the adoption of new RF components and new front end architectures in mobile user devices.

Summary

A number of potentially important mobile user device RF hardware innovations are technically possible. It can be demonstrated that these innovations could deliver significant improvements in terms of the user experience and by implication could deliver additional operator value.

These innovations will only happen if sufficient returns can be achieved from RF hardware investment. Present market conditions suggest these potential returns are hard to realise. As a consequence it will be harder to achieve a positive return on present spectral and network investment.

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The workshops demonstrate how engineering issues can be practically resolved and how performance gains and cost savings can be achieved.

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Information on the next workshop is available here.

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