RTT TECHNOLOGY TOPIC
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Multi Band Power amplifiers

This month's technology topic leads on from last month's topic on multi band switching and looks at the particular challenges of implementing efficient broad band amplifiers capable of supporting LTE signal waveforms at frequencies anywhere between 698 and 2600 MHz.

RF amplifier power consumption

In the 1980's and 1990's handset RF power consumption was a dominant design consideration. The introduction of large displays and high performance application processors in the late 1990's meant that the power consumption design challenge broadened but certainly did not go away.

Always on connectivity and a need to support higher peak and average data rates means that the need for RF transmit efficiency has increased rather than decreased over time. This has coincided with a transition to the use of higher order modulated waveforms which trade an increase in bandwidth efficiency for a decrease in transmission efficiency.

LTE theoretically has a similar TX linearity requirement to HSPA Plus though in practice needs a dB or so of extra headroom to maintain signal integrity. Essentially LTE handset RF power amplifiers are likely to be more sensitive to distortion caused by linearity constraints. Distortion can be avoided by backing off the amplifier but this will reduce its efficiency.

Linearization techniques such as envelope tracking and or pre distortion mitigate these effects but do not eliminate them entirely.

The underlying efficiency of the RF transmit path therefore remains as a key performance metric.

It is easier to realise gain from active devices at lower frequencies. It should therefore be easier to deliver better RF power transmit efficiency at 700 or 800 MHz compared to 2 or 2.6 GHz

However the operational bandwidth at 700 MHz and 800 MHz as a ratio to the centre frequency is substantially wider than other bands. While it is possible to build relative wide band power amplifiers it is harder to match and linearize devices as operational bandwidth increases.

For example in the US, AT and T are deploying LTE into the lower band A immediately adjacent to terrestrial broadcast at 698 MHz, into lower band B at 704 to 710 MHz and lower band C spectrum, 710 - 716 MHz.

Verizon own nationwide upper C block with a two by eleven MHz paired allocation of 746 to 757 and 776 to 787 MHz.

As the lower band is standard duplex (mobile TX in the lower duplex) and the upper band is reverse duplex (mobile TX in the upper duplex) and if the brief is to produce a handset that works over both bands then there either has to be a separate RF PA for each band or the PA has to be capable of working across 90 MHz at a centre frequency of 743 MHz.

A similar deployment could be expected in other parts of Region 2 (US, Canada, Americas)

But really what is needed to achieve economies of scale is to have one RF PA that can also work efficiently in the European DSO band (Region 1 and most parts of Region 3) at 831 to 862 MHz (assuming this band is also worked as reverse duplex), the US 850 MHz band at 824 to 849 MHz and the 900 MHz band at 880 to 915 MHz.

That implies one RF PA and an associated matching network that goes from 698 to 915 MHz, an operational bandwidth of 217 MHz at a centre frequency of 806 MHz, a 27% bandwidth ratio.

If you compare this with a single PA to cover the 1800MHz bands in Europe, the US PCS 1900 band and Band 1 then 'the stretch' goes from 1710 to 1980 MHz or 270 MHz but this is against a centre frequency of 1845 MHz, a 14.63% bandwidth ratio.

Similarly a single RF PA to cover Band 40 in China at 2300 MHz and Band 38 at 2570 to 2620 MHz implies an operational bandwidth of 320 MHz but this is 'only' a ratio of 13% of the centre frequency of 2460 MHz.

As previously stated, wider operational bandwidths result in a poor power match from the PA to the antenna which will absorb power and cause problems with reflected energy back into the front end of the device. A non optimum antenna design, for example a size constrained antenna, will compound this problem.

Adaptive matching techniques, for example using digital capacitors, mitigate these effects but do not eliminate them entirely.

Power amplifiers are not simple devices but a collection of devices and functions that have to deliver an acceptable trade off between power efficiency, linearity (to preserve the shape of the modulated waveform), output power control and stability over a wide range of operational conditions including temperature, voltage and impedance loading. Techniques such as harmonic shorting can help reduce unwanted signal energy but shorting networks tend to interact with terminating networks and therefore require careful implementation.

The devices have to be capable of delivering a substantial amount of reverse isolation to protect the transmitter back end stages. This is particularly true when strong unwanted signals are close to the transmit frequencies – an example is the US lower 700 MHz band which is configured as a standard duplex with transmit on the low side of the duplex, immediately adjacent to broadcast TV signals. Some devices are more robust than others in these conditions.

The factors that determine how well a power amplifier works in terms of efficiency, linearity and cost therefore depend on the semiconductor material used, for example silicon, gallium arsenide or silicon germanium, the transistor construction and packaging technique including bond wire inductances, the number of components used in and around the power amplifiers and the knowledge and skill of the RF PA design team.

It is possible to make some parameters less onerous. For example one of the problems with some power amplifiers is that they exhibit poor power added efficiency when run at low output levels.

Scheduling algorithms can be used to ensure that handsets work at the point of maximum operating efficiency – the duty cycle changes rather than the power level - but in practice handsets still need to work over a relatively wide dynamic range to accommodate edge of cell to close to cell operational conditions. Some present solutions have two operating modes for low and high power operation.

One apparently simple way to reduce power consumption is to decrease the voltage used to drive the amplifier, for example from five to three volts.

However a PA transistor running on a three volt rail will have an input impedance well below 50 ohms. Interfacing with a conventional 50 ohm system will require a high ratio matching network which is difficult to scale across multiple bands. A buck boost converter can be used to increase the voltage but this introduces additional cost and complexity.

Multi Band PA Options

So from a performance perspective there are arguments that every band should have a separate power amplifier chosen and configured to deliver optimum power added efficiency for that band.

However in a seven or ten band phone that implies seven or ten amplifiers which will add cost and weight and will occupy additional real estate.

The other extreme would be to have one broad band PA to cover all bands from 700 MHz to 2.6 GHz. This would theoretically produce the lowest cost and smallest solution but it would be extremely hard to design such a device and a matching network that could deliver acceptable performance either in terms of power added efficiency, spurious and unwanted harmonic outputs and linearity (signal integrity).

Another option is to have a single RF PA for all bands below 1 GHz, another for the 1800 MHz band up to and including Band 1 at 2 GHz, and another for Band 40 for China at 2.3 GHz and Band 38 (2.6 GHz LTE). Let’s describe this for sake of simplicity as low band, mid band and high band.

Of the three PA’s the low band one is going to be by far the hardest to implement due to the wider operational bandwidth compounded by the problem of matching to antenna structures which will be far from optimum due to physical size and spacing constraints. Ceramic or other high insulating substrates mitigate these effects but do not eliminate them.

The answer to this is to have separate power amplifiers for the 700 and 800 MHz bands. However a loaded antenna working at anything more than 30 MHz of operational bandwidth at these frequencies will have poor efficiency.

Tuning elements in front of the antenna might help mitigate some of the hand loading and head loading effects but certainly are not going to realize a broadband antenna which is acceptably efficient. Given that these are duplex band allocations there is also a need to separately match the TX and RX paths. Getting both right is nigh impossible and don’t even think about adding MIMO to this mix.

So there is an argument that if you have to have a separate antenna for each band you may as well have a separate power amplifier for each band and separate filters and an extra dedicated switch path (see last month’s technology topic).

However developing RF power amplifiers and filters and switches that are band specific incurs significant direct cost, research and development, and indirect opportunity cost.

The opportunity cost is a function of the gravitational effect in which vendors achieve a better return from developing optimised products for existing bands with known volume rather than new products for new bands with unknown market potential.

In present market conditions RF power amplifier vendors find it hard to justify an R and D project that does not provide early visibility to at least 30 million units per year with growth potential both in terms of volume and value.

Given that you need at least three vendors for a market to be supply efficient and supply secure then this implies minimum visibility to at least 100 million units for any band specific product.

RF power amplifier vendors are also not inherently keen on the idea of replacing seven band specific amplifiers with one broad band amplifier particularly if the per unit realised price remains the same.

Technical and commercial disconnects in the 700 and 800 MHz bands

This highlights a fundamental problem in the way that the 700 and 800 MHz bands have been allocated and auctioned.

The US market is already a sub scale minority market in terms of global economies of scale. Europe is at a similar disadvantage.

Producing narrow band power amplifiers that are specific to either band is not commercially attractive.

Producing wide band amplifiers that extend present 850 and 900 MHz devices with broader band devices that include the 800 and 700 MHz bands is not technically attractive.

As a result it is proving difficult for operators to get RF component vendors to develop and make products for these bands. Operators have spectrum that cost billions of dollars to buy and infrastructure that cost billions of dollars to build …… and either no handsets or handsets that will not work very well.

In the US the LTE 700 MHz service proposition is being pre marketed as ‘4G LTE’ with promised peak downlink speeds of 40 to 50 megabits per second, peak uplink speeds of 5 to 12 Mbps, and average data rates of 5 to 12 Mbps on the downlink and 2 to 5 Mbps on the uplink.

This promise is based on an assumption of a relatively robust and energy efficient link budget but this implies an RF front end in the user’s device that is at least as efficient as any other individual band. This at present seems to be neither technically nor commercially feasible. These multi billion dollar market and business plans are therefore at risk of being invalidated by the technical and commercial constraints of the relatively small and relatively under capitalized RF component industry.

Longer term salvation is possible if India and or China adopt either the US or European band plan. Presently this seems to be a far from certain outcome. The only other possible option would seem to be an acceptance that the RF bill of materials in handset RF front ends will need to substantially increase both in real terms and as a percentage of the overall cost of the phone in order to attract R and D investment.

At the very least it proves that spectrum comes with additional risks that should be more aggressively factored in to bid valuation calculations and underscores the long understood but often overlooked dictum that **handset RF cost economics** remain as **a dominant factor in achieving a return on spectral and network investment.**

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