High-frequency solutions: how to manage burgeoning data traffic on a finite RF spectrum

Background: Congestion on the airwaves

It's widely reported that the world's limited natural resources are being depleted at an unsustainable rate – and huge efforts are underway globally to develop new sustainable solutions. But one finite commodity that's rarely talked about – but which is increasingly central to the way we live today – is the radio frequency (RF) spectrum.

The functioning of almost every part of society and industry relies on signals transmitted by radio waves at microwave (MW) and millimetre wave (mmWave) frequencies. Demand for wireless broadband access is growing exponentially, with the number of 5G subscriptions due to surpass 1 billion by the end of 2022. By the end of 2027, 5G subscriptions are forecast to reach 4.4 billion. In 2022, the monthly average usage per smartphone is expected to exceed 15GB. *(Source: Ericsson Mobility Report, June 2022)*.

Entire industries rely on fast and reliable mobile broadband access – and new industries will open up and expand when high-speed and low latency access becomes widely available. Remote surgical procedures could be carried out by surgeons anywhere in the world, but only if high-speed signals with extremely low latency (lag) can be guaranteed. Faster data transfers could allow high-frequency city traders to secure deals nanoseconds faster than the competition. Transport applications, such as driverless cars, need rapid uninterrupted data connections along every route. Key to these and many more applications are rapid transfers of large volumes of data at high speed, across multiple devices.

The limiting factor in all of these possibilities is the availability of RF spectrum for mobile applications. Very few people are aware that the capacity of the RF spectrum is finite, and existing licensed bands are becoming highly congested.

Solutions: How to make space for more data

There are a number of possible solutions to the problem of congested RF bands.

1. The first is to make better use of the existing licensed frequency bands. The use of dual polarisation can increase capacity through spectrum re-use. In the microwave bands, the use of very high-order modulation techniques can also be used, but there is a limit and a law of diminishing returns. Additional techniques like MIMO extend capacity further, as can more effective filtering to help separate existing frequency bands, in conjunction with software that can encode signals to improve channel separation.

However, at the lower frequencies, we are already operating in very narrow bands, which don't provide the very high data rates required for some of the more challenging applications. Fundamentally, the existing licensed bands alone will not provide sufficient bandwidth to cope with growing demand.

2. It is possible to use frequencies outside the currently licensed channels. However, in this unlicensed environment, different users are likely to be competing for the same wireless bandwidth, which is why the licensed bands are so tightly regulated. In addition,

the licensed bands occupy the frequencies with the lowest environmental absorption, making them the most effective and reliable frequencies for RF communications.

3. Ultimately, backhaul data traffic will need to move into the higher frequency bands that haven't yet been widely exploited (above 86GHz). In these higher mmWave bands, there are wide open areas of uninterrupted bandwidth available. E-band frequencies (71-86GHz) have already been licensed in most countries, offering much higher capacity than lower frequency bands due to the much wider spectrum channels. As E-band itself becomes congested, it's inevitable that licensing and technology will need to move into even higher frequency bands, such as W-band (92-114GHz) and D-band (130-174GHz) where atmospheric absorption remains reasonably low and opens up significant new capacity.

What's the current situation?

The currently licensed microwave bands and the lower mmWave bands are rapidly becoming saturated, increasing the likelihood of signal failure or unreliability, especially in crowded environments. As well as being narrower, bands at the lower end of the spectrum include restricted bandwidths that are reserved for specific uses, such as the military or weather satellites. Traffic on the traditional frequency bands comes from many devices and applications besides mobile phones, including emergency services radios, Satcom and aircraft radar systems.

The problem of congested airwaves is even impacting space communications. The recent arrival of new mega-constellations of low earth orbit (LEO) satellites, all trying to use the same bandwidth, means that signals have already had to move up the frequency spectrum from Ku to Ka band. For feeder links there is now a push to move into Q, V and even E-band.

Congestion in the RF spectrum is becoming a significant problem in the defence sector. If these critical communications are disrupted by interference or jamming, lives could be at risk. Filtronic is working with the defence sector to address these issues through advanced filtering techniques and by moving into frequencies that are less congested. A good example would be a shift to E-band, benefits include signals at these frequencies being highly directional, less likely to face interference and harder to jam. Power is also difficult to achieve at these frequencies reducing the opportunity for long-range jammers – meaning they are less likely to be intercepted or blocked in critical situations.

Challenges of mmWave communications

Moving up to the higher frequency bands may be a necessity, but it brings with it some major challenges.

Firstly, the atmospheric absorption is higher, therefore the signal is attenuated more if the same power level is used, meaning the distance over which signals can be transmitted in the terrestrial environment is shorter than at lower frequencies. This can be overcome by increasing power or infrastructure, but there is an additional cost.

Sub-systems for higher frequency bandwidths are more difficult to manufacture. That's because tolerances are much tighter, and the smaller size of geometries means that machining, part placement and wire bond formation become more intricate and challenging.

The commercial availability of suitable semiconductors is another issue at very high frequencies. However, the technology required is beginning to emerge. Transmit and receive functions at this level must incorporate tightly packed semiconductor components, and there have been huge advances in the packaging techniques required to build these units.

At Filtronic, we have been pushing the boundaries of RF technologies for ten years, and have developed a suite of products that solve many of the problems at 71-86GHz (E-band). We're now engaged in the novel solutions required to overcome the challenges at higher frequencies.

How do we get to the next level?
To successfully move up into higher frequency bands a number of factors need to combine.

Firstly, licensing authorities need to release the required bandwidth. The higher mmWave frequency bands are well understood, and the licensing bodies associated with the telecoms industry are well organised globally. E-band is now licensed in most countries, but it has taken ten years since it was first made available to achieve widespread adoption. Now there is an urgent need to start moving into W-band and, eventually, D-band. To make this happen, major industrial nations need to come together to set standards and define how these frequency bands will be used.

At the higher frequencies, standard silicon semiconductor devices are unsuitable for transmit, receive and amplification functions. New compound semiconductor processes need to be developed so that devices can be created for the higher bands. Due to the greater losses associated with higher frequency communications, the fundamental problem is achieving sufficient power to transmit signals over a reasonable distance – typically 3 to 5km for links at E-band or W-band. Different semiconductor compounds offer different capabilities for delivering high power, high frequency, or both.

At Filtronic, we have exploited gallium arsenide (GaAS) as our compound semiconductor material of choice for many years, which offers scope for further development into the higher frequency bands. More recently we have seen gallium nitride GaN processes emerging that will support frequencies up to E-band with far higher power densities offering significant benefits in higher mmWave bands. We are also actively engaged with semiconductor manufacturers to overcome the challenges of moving into higher frequencies. We can only design new chipsets once the necessary semiconductor processes are available to deliver the power required. What's more, these semiconductor processes need to be commercially viable, to meet the volume requirements of the telecoms and other industries.

The process of designing RF devices for higher frequencies takes at least two years, once suitable semiconductor processes are commercially available. It involves working through multiple runs of MMICs to ultimately create robust and effective devices.

Keeping pace with change
The pace of growth in this market is relentless. Before long, 6G will be here. But true 6G performance capability will only be possible if there are very efficient, uncongested RF communications networks in place.

Developing technology for mmWave communications is not for the faint-hearted. The costs are high, and the challenges become greater the higher up the frequency spectrum you go. Moving from E-band to W-band does not pose major obstacles in terms of technology, but progressing into D-band will demand some fundamental changes to transmit, receive and amplification technologies. D-band opens up significantly higher data rates but requires a complete change to the architecture of devices and the way they are manufactured.

At Filtronic, we are well advanced in this endeavour. Semiconductor processes for W-band are now becoming commercially available with sufficient power to enable us to develop initial chipsets for transmit and receive functions. At D-band, we eagerly await the development of suitable semiconductor processes. Meanwhile, we are working actively to solve some of the fundamental challenges associated with interconnects and packaging for D-band products. Our aim in both cases is to ensure that the technology is available by the time licences are granted. We expect to have products ready for the release of W-band licences and are on course to meet the needs of D-band in the years ahead. Once these challenges are resolved we will be in a position to manufacture these devices at scale, as we have been doing with E-band for over 10 years.

Innovation through collaboration

Filtronic is at the centre of efforts to optimise the available RF spectrum and enable whole industries to access higher frequency bandwidths as demand grows and applications proliferate.

The telecoms industry is in the spotlight, but the problem of frequency saturation affects many other industries that rely on RF communications, including defence, aerospace, critical communications, transport and many more. Whatever your starting point on the RF spectrum, the growing demand for high-speed, reliable data with low latency means the direction of travel will always be upwards into higher frequencies.

Just as in other areas where limited resources are becoming depleted, the solution lies in bringing together technology specialists, innovators and people with the will to make change. When the pressure is on and there is a strong enough commercial and societal need for change, there is always a way to resolve even the greatest challenges.

If you are impacted by the need for more efficient and reliable data communications, or if you're involved in any aspect of RF technology development, come and talk to Filtronic. The more we work together to maximise the capabilities of the RF spectrum, the brighter our prospects of meeting global demand for data, long into the future.