RTT TECHNOLOGY TOPIC
October 2015

Satellites, spacecraft and the competition for EMC spectrum

In this month's technology topic we develop the narrative of the two previous topics (5G Astronomy August 2015 and Pictures from Pluto - the radio story (September 2015) and explore the potential for translating space sector technologies into 4G and 5G terrestrial mobile broadband networks.

We show how space communication systems have evolved over the past sixty years and their likely future evolution.

We study how space and satellite systems are integrating RF and shorter wavelength (infrared, optical, ultra violet, x ray and gamma ray) measurement technologies and how communication components and systems are evolving to manage these systems in space.

We examine the impact of space communications and observation technology on 5G network and user device functionality and how and why the competition for spectrum in the centimetre and millimetre bands may frustrate the realisation of the potential technical and commercial benefits to be gained from translating space sector technologies to the terrestrial mobile broadband market.

Read on

Cold War Space Communication

In 1957 the 'Mark 1' telescope now known as the Lovell Telescope was completed at Jodrell Bank just outside Manchester. With a diameter of 76.2 metres it was the largest steerable dish radio telescope in the world. Part of the gun turret mechanisms from the battleships HMS Revenge and Royal Sovereign were used in the telescope's motor system.

The telescope was finished just in time to track the launch of the world's first satellite, the Russian Sputnik 1[1] at midnight on 12 October 1957.

There are only two main windows in the electromagnetic spectrum that are open to space. One is the optical spectrum and is the reason we can see stars in space, the second is the radio spectrum with an optimum RF window (with some exceptions) from 30 MHz to 30 GHz though lower and higher frequencies (longer and shorter wavelengths) are useable.

Below 30 MHz, the ionosphere between 100 and 500 kilometres absorbs and reflects radio waves (which is how long wave signals propagate around the world). Above 30 GHz, the lower atmosphere or troposphere below 10 kilometres absorbs radio signals due to oxygen (at 60 GHz) and water vapour. Even between 20 and 30 GHz, there are absorption bands that must be avoided including the first water vapour resonance peak at 23 GHz (used for weather radar).

The oxygen peak at 60 GHz produces an attenuation loss of about 15 dB per kilometre with a lower peak at just over 100 GHz producing attenuation of about 2 dB per kilometre. Water vapour losses peak just below 200 GHz with a loss of almost 40 dB per kilometre.

Sputnik carried two radio beacons at 20.005 MHz and 40.01 MHz. The Soviets continued to use frequencies around 20 MHz and 15 MHz for subsequent missions. The first satellite launched by

[1] http://history.nasa.gov/sputnik/

the USA (Explorer 1) carried beacons on 108.00 and 108.03 MHz just above the terrestrial FM broadcast band (from 88 to 108 MHz) and just inside the civil aviation band from 108 to 136 MHz.

This frequency had been specified by an international committee for the International Geophysical Year (IGY - 1957/8) as the one to be used for all scientific satellites launched in pursuit of IGY objectives. The Soviets had chosen to ignore this recommendation and use lower frequencies.

Sputnik was the first of many space probes that the Lovell telescope could and would track including the US Pioneer 5 between 11 March and 12 June in 1960.[2] The telescope was used to send commands to the probe including the instruction that separated the probe from its carrier rocket.

The 43 kilogram probe set off towards Venus to explore inter planetary space and to test how far radio communications with a small (baseball sized) object could be extended.[3] The solar powered miniature spacecraft set a new record of 22.5 million miles before carrier wave contact was lost.

Pioneer 5 had two radio transmitters operating at 378 MHz, a low power 5 watt transmitter used when close to Earth and a 150 watt transmitter which was turned on by a command from the Lovell telescope when the probe was 8 million miles away. The signals from the probe were analysed to determine the Astronomical Unit (the average distance from the earth to the sun) used to express distances in the solar system. The cosmic ray flux density and flow of charged particles now known as the solar wind were measured to a distance of 17.7 million miles until telemetry encoding was lost. Data was collected that provided insight into magnetic fields in space. This set of instruments became the standard measurement kit for the next ten years of deep space exploration including four Pioneer spacecraft launched between 1965 and 1968.

The Lovell telescope tracked the USSR unmanned Moon lander Lunar 9 in February 1966 and Lunar 15 in 1969. A new 15 metre dish was constructed at Jodrell Bank in 1964 which was used to track the journey of Neil Armstrong and Buzz Aldrin to the Moon in Apollo 11 and their arrival on 20 July.

Satellites in the VHF Band

Today the VHF satellite band is mainly between 137 and 138 MHz and is used by meteorological satellites transmitting data and low resolution images and for low data rate satellite downlinks with a matching uplink at 148 to 150 MHz.[4] Russian manned spacecraft have historically used 121.5 MHz FM for voice communication and 143.625 MHz and 166 MHz.

144 to 146 MHz is used for amateur satellites mainly in the upper half of the band between 145 and 146 MHz. 149.95 to 150.05 MHz is used by satellites providing positioning, timing and frequency services for ionospheric research. Before GPS, this band was used by large constellations of US and Russian satellites to provide positioning for ships using the Doppler Effect. Many of these satellites also transmitted a signal at 400 MHz.

The 240 to 270 MHz band is used for military satellite communication and lies within the 225-380 MHz pass band for military aviation.

Post war VLF terrestrial positioning systems

VHF positioning systems were the last of an era of post second war navigation systems which included very long wave systems which could be and continue to be used by submarines to get a positioning fix and to communicate without surfacing. These systems are affected by complex very

[2] http://nssdc.gsfc.nasa.gov/nmc/spacecraftDisplay.do?id=1960-001A
[3] http://epizodsspace.airbase.ru/bibl/spaceflight/2005-5/pio5.html
[4] http://www.orbcomm.com/networks/satellite

long wave propagation effects determined by the varying height of the ionosphere over 24 hours and location and seasonal fluctuations and electromagnetic storms.

Long wave systems included the Decca Navigator System operated between 1946 and 2001 and using five low frequency bands, 70.087–70.583, 84.105–85.900, 112.140–114.533 KHz.

Loran A, B and C was a similar land based location system extending about 1000 kilometres to sea. Most signals were transmitted on 1950 or 1850 kHz, though 1900 and 1750 with a 100 KHz option to provide better sea and land coverage.

DECCA and Loran had significant limitations. BOAC pilots flying across the Atlantic in the first generation of passenger jets in the 1950's would do a star and or sun sextant fix mid-way across to get an additional location fix. We take today's L band positioning systems very much for granted.

But we digress- back to satellite frequency allocations and the UHF band.

Satellites in the UHF Band

The 399.9-403 MHz band includes timing and frequency standards, navigation and positioning. The band has also been used for two way radio. Radiocomm 2000 handsets are now a collector's item[5]

432-438 MHz is an amateur satellite and earth resources satellite band.

460 to 470 MHz supports meteorological and environmental satellites including uplink frequencies for remote environmental sensors. It overlaps with the downlink of Band 31 LTE[6] being deployed in Brazil for rural broadband and the focus for some vendor interest groups developing LTE sparse network service propositions.[7]

LTE Band 31

Band	Name	Uplink		Downlink		Bandwidth	Duplex spacing	Guard band	Area
	MHz					MHz			
31	450	452.5	457.5	462.5	467.5	5+5	10	5	CALA

The Russian International Space Station (ISS) uses 628-632 MHz.

Satellites in L Band

This includes GNSS and MSS satellites for example Iridium and Inmarsat [8] 1.67 to 1.71 GHz is one of the primary bands for high resolution meteorological satellite downlinks of data and imagery.

Terrestrial broadcasting has bandwidth allocated at 1.4 GHz.

Satellites in S Band

2.025 to 2.3 GHz includes the Unified S Band (USB) which has been used by many spacecraft,

[5] http://www.mobilophiles.com/pages/Le_MATRACOM_2000_Un_Matra_Nokia_Radiomobiles_ER_2402-8362360.html
[6] https://itunews.itu.int/en/4618-LTE-450MHz-technology-for-broadband-services-in-rural-and-remote-areas-BR-Case-study-of-Brazil.note.aspx
[7] http://450alliance.org/
[8] http://www.rttonline.com/tt/TT2007_007.pdf

notably for the Apollo Lunar missions. These provided an early (1965) example of multiplexed imaging, data and voice.

A USB antenna could transmit and receive simultaneously. Voice, telemetry and television were all received together with slow-scan television frequency modulated on the carrier. Telemetry was phase modulated on the subcarriers. The system also allowed for accurate ranging to determine the distance of the spacecraft from Earth.[9] Today the band is used for military space links, military meteorology and earth resource sensing.

The 2.52 to 2.67 GHz band overlaps with LTE Band 7, 2500-2570 MHz, 2620-2690 MHz and LTE TDD band 38 (2570-2620 MHz) and 41 (2496-2690). Space use is now limited to fixed point to point communication and broadcast links in parts of Asia and the Middle East.

The band is also used for a wide cross section of terrestrial radar applications.[10]

Satellites in C Band

3.4 to 4.2 GHz is used for fixed satellite service (FSS) and TV broadcast satellite downlinks in some countries. The band overlaps LTE FDD Band 22 (3410 to 3490 and 3510-3590 MHz) and LTE TDD Bands 42 (3400-3600) and 43 (3600-3800).

The FSS and TV uplinks are at 5.9 to 6.4 GHz.

Satellites in X Band

8-9 GHz is used for space research, deep space operations and environmental and military communication satellites. Satellites/spacecraft often have S and X band transceivers.

S Band, C Band and X Band Coexistence with weather and aviation radar

S Band, C Band and X band satellites have to coexist with ground and aviation weather radar systems which are implemented in all three bands. The choice of band for weather radar is determined by the size of the raindrop to be measured, the heavier the rain, the bigger the raindrop. Raindrops should correctly be described as hydrometeors.

10 centimetre wavelength (longer wavelength) S Band weather radar has good heavy rain cloud penetration and is best for long range weather radar up to 300 kilometres. 5 centimetre wavelength C band weather radar is good for rain detection up to 200 kilometres. 3 centimetre wavelength X band radar is more sensitive than C band or S band and therefore better at detecting light rain/small rain drops but is limited to a range of 50 kilometres.

Weather radar bands

Band	Wavelength cm	Frequency MHz	Range	Application
S Band	11.7-10.33 (10 cm))	2700-2900	300 kilometres	Heavy rain
C Band	5.7-5.24 (5 cm)	5250-5725	200 kilometres	Light rain
X Band	3.22-3.155 (3 cm)	9300-9500	50 kilometres	Drizzle

[9] https://www.hq.nasa.gov/alsj/alsj-NASA-SP-87.html

[10] http://www.itu.int/md/R07-WP5B-C-0389/en

New meteorological ‘micro rain radar’ (MRR) applications are being developed at 24 GHz. These systems are optimised for measuring hydrometeor drop size distribution. Cloud composition radar measurement systems known as ‘cloud radar’ are being developed at 35 GHz.[11]

Satellites in Ku Band

10.7 to 11.7 GHz supports fixed satellite services. 11.7 to 12.2 GHz supports domestic TV BSS (**B**roadcast **S**atellite **S**ervice) downlinks including DVB S. 14.5 to 14.8 GHz is the uplink feed for the Ku downlink. 17.3 to 18.1 GHz is an alternative BSS uplink.

Satellites in Ka Band

23-27 GHz is increasing in popularity as fixed link, broadcast, environmental and space operations satellites move from lower bands to gain more bandwidth. Water vapour and rain absorption limit the usefulness of this band in the tropics. Automotive radar is also in this band.

The European Space Agency provides a more comprehensive listing of communications frequencies specific to spacecraft.[12]

Wavelength/frequency ranges can however be summarised in terms of the antenna footprint on the spacecraft. The choice of wavelength/frequency is largely determined by the atmospheric weather conditions between the spacecraft and terrestrial radio transceiver.

Frequency range	Wavelength Centimetres	Link direction	Spacecraft Antenna	Used when the weather is
1-2 GHz	30 - 15	Earth to space uplinks	wide beam low gain antenna	Clear or rainy
1-4 GHz	30 - 8	Space to earth downlinks		Rainy
1-6.5 GHz	30 - 5	Space to earth downlinks	wide beam low gain antenna	Clear weather
3-5.9 GHz	30- 5	Space to earth downlinks	High gain antenna	Rainy weather
6-16 GHz	5 -2	Earth to space uplinks	High gain antenna	Rainy weather
11.5-35.5 GHz	3 - 0.84	Earth to space uplinks	High gain antenna	Clear weather
26-40 GHz	1.1-0.74	Space to earth downlinks	High gain antenna	Clear weather

NASA Deep Space Network Bands

The three NASA Deep Space Network Ground Stations use S, X and Ka band for tracking and data/telemetry for all NASA spacecraft outside the Earth’s orbit.

Band	Uplink Frequency (MHz)	Downlink Frequency (MHz)
S	2110 - 2120	2290 - 2300
X	7145 - 7190	8400 -8450
Ka	34200 - 34700	31800 - 32300

[11] www.erodocdb.dk/Docs/doc98/official/pdf/ECCRep166.pdf
[12] ttp://www.esa.int/Our_Activities/Telecommunications_Integrated_Applications/Satellite_frequency_bands

NASA spacecraft in the 1960's used S band then X band in the 1990's and Ka band from 2000 onwards. Most spacecraft have dual frequency transceivers, initially S band and X band and more recently X band and Ka band.

The shorter wavelengths provide better tracking ability but require more pointing accuracy. If spacecraft become power limited due to an accident or malfunction, more ground based receivers are added to the receive array. The most famous example to date has been Apollo 13 which required the combined gain available from the 70 metre DSN antennas and Australian Parkes Observatory radio telescope.

The ITU differentiates deep space band allocations (greater than 2 million kilometres from earth) from near earth applications (less than two million kilometres from earth).

Frequency allocations in MHz				
Band	Deep space >2 Million kilometres		Near space<2 million kilometres	
	Uplink Earth to space	Downlink Space to earth	Uplink Earth to space	Downlink Space to earth
S band	2110-2120	2290-2300	2025-2110	2200-2290
X Band	7145-7190	8400-8450	7190-7235	8450-8500
K Band				25500-27000
Ka Band	34200-34700	31800-32300		

Communicating with the Hubble Telescope

Communication with objects in space is often done indirectly via another satellite. The Hubble telescope provides an example, talking to earth via the five NASA Tracking and Data Relay Satellites (TDRS) in geosynchronous orbit at 35,000 kilometres[13].Hubble is orbiting the earth every 97 minutes at a height of 569 kilometres so is officially a LEO satellite.[14]

The first generation of TDRS relay tracking satellite was launched between 1983 and 1995, the second generation was launched between 2000 and 2002. The third generation was launched between 2013 and 2016 (scheduled). The third generation satellites have S band, Ku band and Ka band transceivers. The S band antenna array has 32 receive antenna elements and 15 transmit antennas. It might seem odd to communicate from the Hubble low earth orbit to a GSO satellite and then back to Earth but the result is a more efficient path link.

RF and baseband components in space

There are two identical S band transceivers on board Hubble, one of which has failed.

Low earth orbit satellites can be repaired in space. MEO satellites, for example GPS at 20,000 kilometres and GSO satellites at 35000 kilometres are far less accessible though there are studies to make servicing these more distant platforms in space technically and commercially feasible.[15]

The reliability of RF systems and their supporting digital processing sub systems is therefore critically important. Part of the problem for space communications hardware is radiation damage. Digital components such as A to D and D to A converters, Digital Signal Processors and CMOS based FPGA's can be particularly vulnerable and can inconveniently and unpredictable latch up when exposed to high levels of radiation.

[13] https://www.nasa.gov/content/tracking-and-data-relay-satellite-tdrs/#.Vb9levnNE9k
[14] http://hubblesite.org/the_telescope/nuts_.and._bolts/spacecraft_systems/

[15] http://www.space.com/27128-darpa-robotic-satellite-repair-droids.html

It is possible though expensive to produce radiation hardened DSP and FPGA chips which are resilient to high ionising dosages, the cumulative effect of ionizing radiation on components on longer space missions described as Total Ionisation Dosage and single event effects, a random failure due to a charged particle arriving in the wrong place at the wrong time described as a Single Event Upset (SEU). The TID and SEU rates differ by orders of magnitude depending on orbit trajectory, the sun's solar cycle and shield efficiency. The TID is relatively easy to calculate. SEU by its nature is more unpredictable.

The present approach is to build in hardware redundancy and manage failure through software resets. Given that we are due for another massive electromagnetic storm (on a 150 year rather than 11 year Sun cycle[16]), it might be useful and potentially profitable to translate this space sector experience into terrestrial component and sub system design.

Space observation- the EMC spectrum – relevance to 5G technology and business modelling

The Hubble Telescope is an instrument of wondrous capability which after a dodgy start has produced astonishing images of the known and previously unknown Universe.[17] It is astonishing to realize that Hubble is now 25 years old and being replaced by a more capable optical telescope, the James Webb Telescope named after the Apollo mission administrator and scheduled for launch in 2018[18].

Unlike Hubble in a low earth orbit, it will do this from a million miles from Earth from Lagrange Point 2 (see our August Technology Topics on the significance of the Planck measurements from Lagrange Point 1). The orbit has the advantage that the telescope is not rushing around the earth but hanging at a stable point in space. The disadvantage is that there is no repair option if something doesn't work after launch or fails in space.

In addition to optical observations from the 6.5 metre mirror almost three times the size of the Hubble mirror, the James Webb telescope will be looking at the Universe at infra-red frequencies. The infrared measurements will provide the basis for studying the universe from 200 million years after it was born (13.7 billion years ago) when the first stars and galaxies were beginning to coalesce. It will also study the planets around other stars and the planets in our host solar system.

This is part of a trend to extend space based optical telescopes either side of the visible wavelength bands including measurements below infra-red in the Terahertz band between 300 GHz and 3 THz, 0.999 millimetres to .099 millimetre wavelength, also described as the sub millimetre band.

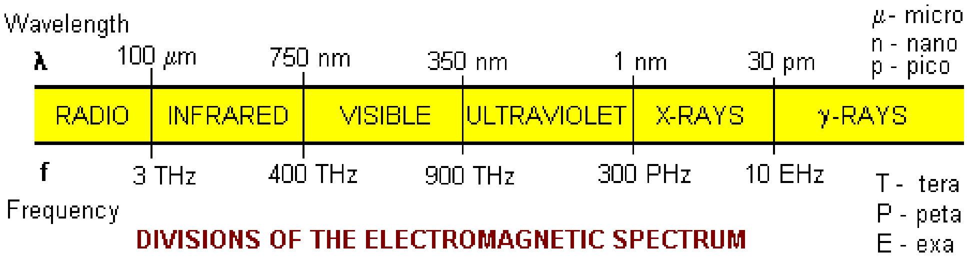
Anything in the Universe warmer than 10 degrees kelvin (-263 degrees Celsius) emits terahertz radiation. Our bodies emit Terahertz radiation and Terahertz imaging systems are used for airport security.

Sub millimetre observations are also done from Mountain based observatories on earth including the Caltech Observatory in Hawaii,[19] the Atacama Observatory in the Atacama Desert in Chile (at 5000 metres)[20] and the Heinrich Hertz Telescope in Arizona.[21]

On the other side of visible light an increasing number of measurements are being made from earth orbiting space based telescopes and deep space missions at x ray and gamma ray (also known as y ray) wavelengths.

[16] http://science.nasa.gov/science-news/science-at-nasa/2008/06may_carringtonflare/
[17] http://news.nationalgeographic.com/2015/04/150423-hubble-anniversary-webb-telescope-space/
[18] http://www.jwst.nasa.gov/
[19] http://cso.caltech.edu/
[20] http://www.almaobservatory.org/
[21] http://aro.as.arizona.edu/smt_docs/smt_telescope_specs.htm

The table summarizes this ‘EMC spectrum of interest’



This is not absolute. Radio could be defined for example from 30 KHz (a wavelength of 10 kilometres) to 3 THz (a wavelength of 100 micrometres) but longer wavelength measurements may also be important. Gravitational waves may have frequencies measured in days, months or millions of years and we still need to understand magnetic fields in more detail.

To put the EMC spectrum into perspective, gamma rays/y rays at <0.01 nanometres are about the size of an atomic nucleus and are the result of nuclear reactions. They are emitted from pulsars, quasars and black holes (see August and September Technology topics).

X rays from 0.01 to 10 nanometres are about the size of an atom and are generated from exploding stars and quasars where temperatures are between a million and ten million degrees. India has just launched an X ray space telescope.[22]

Ultra violet radiation has wavelengths from 10 to 310 nanometres, about the size of a virus. Young energetic stars produce large amounts of ultra violet light.

Visible light from 400 to 700 nanometres has a wavelength equivalent to a molecule or protozoan (a single celled microscopic animal). Conveniently our sun radiates most of its energy in the visible range.

Infrared wavelengths from 710 nanometres to 0.1 millimetres (400 THz to 3 THz) are equivalent to the width of a pin point through to the size of a small seed plant. At 37 degrees Celsius our bodies emit infra-red energy with a peak intensity at 900 nanometres – that’s how all those infra-red presence detectors work.

The infrared band could also loosely be described as the sub micrometre band. 750 nanometres is 0.75 micrometres, 0.1 millimetres is 3 THz. The micrometre also known as the micron is used to scale biological cells and bacteria and silicon chips.

Then we have the top end of the radio band also described as the sub millimetre band. The band from 300 GHZ to 3 THz is also described as Terahertz radio (See airport security above).

Then radio as we know it at wavelengths of one millimetre (300 GHz) to several kilometres (30 KHZ=10 kilometres).

Radio waves therefore have the longest wavelengths and hence lowest energy and are therefore associated with the lowest temperatures. As discussed in the two previous Technology Topics, radio waves come from all parts of the Universe including background radiation, the inter stellar clouds and the cool remains of supernova explosions, red shifted from visible to RF wavelengths.

Space observation therefore spans the whole EMC spectrum.

[22] http://www.ibtimes.co.uk/india-successfully-launches-astrosat-its-first-hubble-like-space-telescope-1521508

EMC spectrum measurements and smart phones

On earth we are protected from ionising radiation including x ray and gamma ray radiation by the magnetosphere. The atmosphere protects us at least partially from ultra violet radiation. However as with space observation, there are many opportunities to observe and measure the physical world around us.

Contemporary smart phones[23] have CMOS imaging sensors that can capture 40 megapixel optical images. Ultra violet exposure measurement is also proposed as a standard feature in higher end devices and is already supported as an iPhone application.[24]

Low cost CMOS sensor chips are also becoming available[25] that can detect the presence and levels of particular gases in the air that we breath. This is done by constructing a micro hot plate on the chip that can be heated at anything up to 1000 degrees Celsius in 25 milliseconds. This can be used as a source of infra-red light. Alternatively gases become highly reactive at specific temperatures, the heat equivalent of spectral lines.

Metal oxide sensing of carbon dioxide for example is reactive at 260 degrees Celsius, ethanol at 260 degree and volatile organic compounds at 300 degrees. This opens up applications such as carbon monoxide sensing from smart phones, indoor and outdoor air quality measurements correlated to GPS positioning and bio sensing applications based on breath analysis. Breath analysis includes alcohol detection and acetone detection, an indicator of fat breakdown in the body, potential enablers for next generation wearable fitness devices.

Summary – the sensor web

Space observation is moving towards measuring the Universe across the whole of the EMC spectrum with measurements correlated from multiple measurement platforms including deep space exploration spacecraft, earth orbiting satellites and earth based radio and optical telescopes.

In space these multiple platforms are being connected by multiple radio links deployed across multiple paths including LEO to MEO to GSO to earth relays and repeaters using multiple radios operating across the metre, centimetre and millimetre bands.

This is sometimes described as the sensor web in space.

The sensor web on earth includes space facing optical and radio telescopes.
It also potentially includes a new generation of 5G devices equipped with chemical sensors that can be used in a broad range of body worn health monitoring or remotely installed environmental monitoring.

There is considerable innovation taking place in space spaced observation and space communication. Much of that innovation has relevance to 5G network and user device development.

At network level the space sector industry has experience and expertise integrating observation and communications systems across L band, S band, C Band, X band, KU and Ka band. This is relevant to mobile broadband operators and vendors looking to develop radio systems that span metre band, centimetre band and millimetre band spectrum.

[23] http://www.microsoft.com/en-gb/mobile/phone/lumia1020/
[24] https://itunes.apple.com/us/app/uvmeter-check-your-uv-index/id662827178?mt=8
[25] http://www.ccmoss.com/

The extreme demands of deep radio communication have required innovations at component and system level that are relevant to 5G transceiver and system design. Parallel developments in earth and spaced based radar in S band, C band, and X band and 'Micro Rain Radar' at 24 GHz in K band and 'Cloud Radar' at 35 GHz are also potentially useful.

The space sector has also been commercially innovative particularly in the development of mixed payload business models. These could be potentially relevant to 5G business modelling.

However it can also be confidently asserted that the bandwidth requirements of space observation and communication technologies including earth based space observation and communication are increasing over time.

Each new generation of radio telescope or radar or deep space or near space communications system requires more sensitivity and more bandwidth than its preceding generation.

This suggests that there will be significant resistance to mobile broadband spectrum allocation in the centimetre and millimetre bands.

The 4G mobile broadband industry had many potentially beneficial complementary technical and commercial touch points with the terrestrial broadcasting industry. The battle for spectrum in the 700 and 800 MHz bands compounded by an adversarial auction process has made it hard to realize these benefits

It would appear that there are likely to be similar tension points between the mobile broadband community and satellite and space sector due to the competing requirements for additional bandwidth in the centimetre and millimetre bands.

This tension will make it harder to realize the potential benefits to be realized from integrating space and terrestrial communication and observation technologies.

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. The first technology topic (on GPRS design) was produced in August 1998.
http://www.rttonline.com/tt/TT1998_008.pdf

17 years on there are over 200 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