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**Resilience and redundancy in mobile satellite communications**

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**Mobile communications is a mission critical** requirement for all military forces, and satellite communications is an essential part of the mix, whether at sea, in the air, or in remote land areas. Defence forces everywhere are re-examining their traditional satcom operating models as they are not immune to the demand for high data rates observed in civilian markets, and satellite operators are responding to this by launching new high throughput satellites (HTS). Low Earth orbit (LEO) satellites and small satellites will definitely be a part of the future mix, and since they migrate across the sky, cost effective terminals with tracking capability, similar to today’s on-the-move terminals, will be required to communicate. Resilience and redundancy are becoming called for with almost as much urgency as higher data rates.

**Achieving communications resilience**

Assured communications are like an onion with numerous protective layers in its skin. Those layers include maximising link availability through good design, use of redundancy, frequency stealth, coding, limiting radio emissions in unwanted directions, and protecting against interferers. These are particularly difficult to achieve with satellite communications while on the move, but often it is while on the ‘run’ that communications are most critical.

Consider each layer in turn from the perspective of ground equipment. Firstly, improving link availability by maximising the link budget is a good place to start. The link budget determines the allowable fade margin, which can be maximised by using the highest power transmitters possible, most sensitive receivers, steered antennas to maintain maximum antenna gain, and best pointing accuracy to minimise pointing loss. Time on satellite is probably the biggest contributor to the availability equation: Minimising the time for an on-the-move terminal to acquire or reacquire the satellite is crucial, as is maintaining the link under violent motion conditions.

Second, redundancy can be improved in satellite communications by the use of multiple transmitters since Block Up Converters (BUCs) are usually the most failure-prone component in the ground segment; and using multiple satellite systems. Frequency stealth might entail switching or spreading either the modem output frequency or the RF frequency. Changing to a lower frequency band can also protect against weather effects that can cause loss of the satellite link at the higher Ka-band frequencies.

Third, coding and other security precautions such as...
encryption at the data layer can protect against theft of data, while fourth, ensuring the radio signal is highly directional with minimal RF spill over or sidelobes, and protecting against interfering signals through careful electromagnetic design and analysis, will avoid ‘theft’ of signals or intrusion upon the radio layer. Such signals can also be unintentional or non-hostile but still cause link failure – for example, radar systems nearby the satcom ground equipment often result in total loss of communications capability.

Mitigating by terminal design against the effects of weather, satellite congestion, frequency jamming, and motion itself all add towards the objective of resilient communications.

Maximising the data rate given the constraints of a satellite system

Consider first the ground terminal design. Shannon’s famous equation gives the maximum capacity $C$ of a general communications channel in bits per second as

$$ C = B \log_2 (1 + \text{SNR}) $$

where $B$ is the allocated transponder bandwidth in Hz, and SNR is the signal-to-noise (S/N) ratio at the receiver. Of course, $B$ also determines the receiver noise, so SNR varies inversely proportional to $B$, thus maximum capacity does not always increase linearly with bandwidth. However, for the typical values of SNR achieved at a satellite ground terminal with a geostationary satellite ($1 < \text{SNR} < 20$), Shannon’s equations tell us that if the signal power drops by half, the bandwidth needs to double to maintain roughly the same capacity $C$.

Any reduction in link gain impacts in a similar way. The simplest expression for the link equation for a one-way satellite link (in dBW) is

$$ \text{PR (dBW)} = \text{EIRP} + \text{GR} - \text{Lo} $$

where $\text{PR}$ is the received power, $\text{GR}$ is the receive end antenna gain, $\text{EIRP}$ is the Equivalent Isotropically Radiated Power (equal to $\text{GTPT}$) of the transmitter in dBW, and $\text{Lo}$ the one-way channel and spreading loss. For a geostationary satellite, the spreading loss component of $\text{Lo}$ is over 200dB at frequencies above X-band. Therefore, PR normally ends up quite close to the receiver noise floor so any increase in $\text{Lo}$ (for instance, through poor pointing or rain attenuation) or any reduction in terminal $\text{GR}$ (or $\text{GTPT}$ if transmitting) can cause the received signal power to drop below threshold, and the link will be lost or at best, severely degraded. $\text{GR}$ is determined by the size of the antenna and, in the case of flat panel antennas, the angle of incidence as well, losing 3dB at 45° orientation from normal. As Shannon’s equation highlights, such a drop of 3dB in $\text{PR}$ (the ‘S’ in S/N) either causes the bit rate to halve (eventually forcing it to zero) or requires the bandwidth (and cost) to double to maintain the same capacity. That is a critical point to remember: If the system gain drops by half (for instance, with the flat antenna), or a cloud passes over, or the terminal is backed off by 3dB to prevent interference with an adjacent satellite (e.g. when a plane with the airborne terminal banks), then either the data rate halves or the bandwidth (cost) must double to restore the system.

The added challenge of mobility or tracking a LEO satellite

Therefore, both the gain and pointing performance of a satcom antenna system are important in preserving link availability. With a mobile terminal that must point to a geostationary satellite, or alternatively a fixed terminal that must track a moving satellite such as a LEO, the tracking error measures the terminal’s ability to keep the antenna boresight pointed directly to the satellite.
during operation. However, performance requires more than that – it must include the time taken to initially acquire the satellite.

For SOTM applications, these requirements are challenging due to the complex engineering required to steer the antenna’s transmit beam directly to the satellite with high availability during platform motion. Only monopulse technology is able to maintain lock on the satellite without deliberately introducing an intentional mis-pointing error off boresight to search for the exact beam maximum, even after the satellite has been ‘acquired.’ Monopulse technology is a closed-loop system that measures the relative signal level in a higher order mode intentionally generated in the antenna feed, typically the TE21 mode. The system uses that mode’s sharp null along boresight to derive a very accurate corrective pointing vector to force the antenna back in line, without the need to introduce any deliberate pointing loss to determine whether the antenna is aligned for maximum receiver power, as happens with conical or step scan systems. Since a monopulse system directly measures the TE21 signal which is proportional to the deviation off-axis, such a technology also has the benefit of being able to accurately monitor and report the instantaneous pointing error to the user. This ensures the BUC is only muted when the antenna is confirmed as being off-axis, rather than, for instance, if the received beam is measured as temporarily weak, for instance due to a passing cloud.

**Redundancy**

However, there is still more that can be done to assure satellite communications. Redundancy in hardware, frequency and satellite selection are three other ways to introduce resilience into the link. The choice of satellites and use of multiple bands can mitigate against weather effects, jammers, interferers, congestion, and even loss of a satellite.

The approach taken at EM Solutions is to engineer a satellite terminal that automatically switches between any of three satellite bands on different satellites, even while on-the-move. Although maritime terminals already exist with either commercial or military Ka-band capability, or with dual X-band and military Ka-band capability, none offer universal on-the-move capability (on land or sea) in a convenient size package, simultaneously operating in both X- and Ka-bands, or with fall back to commercial Ka-band (such as with Inmarsat GX) on demand. This requires the use of separate BUCs for X-band and Ka-band, but this is beneficial since the pair then adds increased hardware redundancy on top of the improved link redundancy. Such a combination brings the benefits of assured communications whenever a satellite is visible without manual changeover of hardware.

**Assured communications**

In developing its assured satellite communications on-the-move terminals, EM Solutions has worked closely with its defence customer, represented by the Australian Defence Science and Technology Group (DSTG) to understand their requirements, and cooperate with several collaboration partners.

In 2017, EM Solutions completed the installation of its dual Ka-band Cobra terminals onto the Australian Border Force Cape Class fleet (Figure 1). The company’s partnerships with Inmarsat and Intellian proved productive, enabling it to certify its terminals on the Inmarsat GX network as a fall back to operation on the WGS system. EM Solutions subsequently completed installation of its leading-edge tri-band Cobra terminal (Figure 2) — which simultaneously operates in both X and Ka-bands - for the Royal Australian Navy, and followed this with trials orders for other naval vessels. The greatest innovation in that latest Cobra X/Ka-multiband terminal is its antenna feed system. Optimised for its electromagnetics, the system generates antenna pointing vectors from both the X and Ka-band beacons of the WGS satellite, and communicates in the traditional manner at Ka-band, all the time supporting simultaneous communications on the satellite’s X-band transponder, whenever required to protect against rain fade or to provide added capacity. In addition, the system can then fall back to tracking and operating on the alternative Inmarsat GX satellite system in the case of congestion or for operational reasons. This helps to provide network survivability with assured communications in a contested environment, and rapid and automatic self-healing in the event of rain fade or other link outage by switching satellites or frequency band.

Meanwhile, the company has continued to roll out its land-mobile terminal, the Taipan (Figure 3), to a major European army (in X-band) and its new amphibious Salamander variant (Figure 4) for an army in Asia. By aspiring to the level of assured communications, EM Solutions continues to cement its position as a company known for products unmatched in reliability and robustness. These two terminals can be configured for a range of platforms to suit either a small or medium vehicle or vessel, with simplified field repair and cost optimisation, and provide universal stabilisation under the most severe motion conditions, since the terminals can be used either on land or at sea.

**Flattening the antenna**

Over the past three years, the design of flat panel satcom antennas has become one of the most attractive R&D topics in industry and the research community. Although the concept of generating a focused-beam through a planar-shaped antenna is not new, it is still extremely challenging to design a feasible flat antenna solution that meets the RF constraints, matches the market needs, and is commercially profitable. A number of revolutionary antenna concepts and prototypes have been showcased by worldwide innovators (such as Kymeta, Phasor, and Isotropic), but questions remain unanswered about what compromises have been made to meet all the essential antenna pattern and RF parameters for reasonable performance at Ka-band, while maintaining reasonable cost. After all, the physics embodied in Shannon’s equation and the link budget cannot be
Achieving resilience and redundancy in mobile satellite communications can only partially be achieved through good terminal design. All links in the network chain can contribute, but ultimately there are trade-offs. For instance, the high silhouette of parabolically steered terminals is universally disliked by land forces – that is, until the alternatives that offer lower or variable gain, must be muted to avoid interference, do not track, or do not meet antenna patterns, are tested. EM Solutions has taken a variety of approaches to offer robust terminals that offer redundancy in design, exceptional tracking and mobility in multiple frequency bands, fall back to commercial satellites, and soon, flat profile. All of these help to strengthen the resiliency and assuredness of military communications.

**Conclusion**

Ultimately, there is no ‘best’ answer for antenna choice. To use a racing analogy, it is ‘horses for courses!’ Parabolic antennas offer the advantages of constant and high gain, and certified compliant antenna patterns over broad bandwidths. Flat panel antennas compromise two or all three of these advantages in favour of low profile. The optimum choice depends on the application, link budget, and the value placed on size, weight, and power.

**Chemring Technology Solutions completes successful exercise for second year at US Military’s Cyber Quest**

Chemring Technology Solutions (CTS) has completed the successful demonstration of VIPER, the world’s first Electronic Warfare (EW) manpack geo-fencing capability, at this year’s Cyber Quest. CTS’s participation in the US military’s Cyber Quest exercises followed a competitive down-select after it attended the event for the first time last year.

Led by the US Army’s Cyber Center of Excellence, Cyber Quest is a sequence of advanced technology experiments using EW war gaming. The month long exercises saw operational units participate in a series of experiments to evaluate multiple-vendor systems, and the results will be briefed to coalition partners. The current and future need for EW capability was particularly highlighted by the US Army Cyber Center of Excellence at Fort Gordon.

CTS demonstrated VIPER, its new whole-mission support and information system. When integrated into the RESOLVE EW system, VIPER delivers actionable intelligence and provides operators with pinpoint accuracy for superior target precision, significantly reducing the task, time and reporting burden.

Cyber Quest also successfully experimented with LOCATE-T, the CTS wideband High Frequency Direction Finding (HF DF) tactical system, which is fully-transportable and provides an essential complement to existing static HF sites.

Chesapeake Technology International (CTI) once again provided the core architecture and primary Cyber/Electromagnetic Activities (CEMA) operator’s display for the Cyber Quest experiments. Both LOCATE-T and RESOLVE were interfaced with CTI’s Thunderstorm architecture to help define the common operational picture using the CTI Caper plug-in for RaptorX during the exercises at Fort Gordon.

Ben Vogel, Regional Manager for North and South America, at Chemring Technology Solutions, said: “Cyber Quest supports the evolution of EW systems for US and other militaries worldwide, and provided us with the ideal platform to demonstrate how VIPER delivers a new level of EW capability. VIPER was developed by EW operators for EW operators and the Cyber Quest trials allowed us to engage with end users to show them how we have created the most capable and user-friendly EW manpack system. VIPER’s deployment at Cyber Quest has shown how it offers the next step to counter current and evolving threats.”

**Denel to participate at AAD2018**

Within the current operating context of austerity and prudent financial management, Denel’s participation at the upcoming Africa Aerospace and Defence (AAD) exhibition, has been enabled through local partnerships. AAD, Africa’s premier aerospace and defence exhibition, is a bi annual event.

“Our presence at AAD 2018 should be seen as a confident step towards turning the business around and rebuilding Denel and the confidence of the broader stakeholder environment following a difficult period of lapses in governance resulting in amongst others, reputational damage leading to liquidity challenges. Being at AAD clearly indicates that we are positive our business will turn around for the better soon”, says the Denel Group’s Acting Chief Executive Officer, Michael Kgobe.

“It has become a commonly known fact that Denel is currently faced with liquidity challenges so the decision to participate at AAD 2018 only came after lengthy discussions with our key stakeholders, including the local aerospace and defence industry and representative industry associations. Reducing the costs to a third of what it cost the company to participate at the last AAD and negotiating with the show organisers for terms are the reasons we will now be at this premier trade show,” Kgobe says.

**Figure 4. A Ku-band Salamander terminal capable of roll-on, roll-off operation on either land or sea.**

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