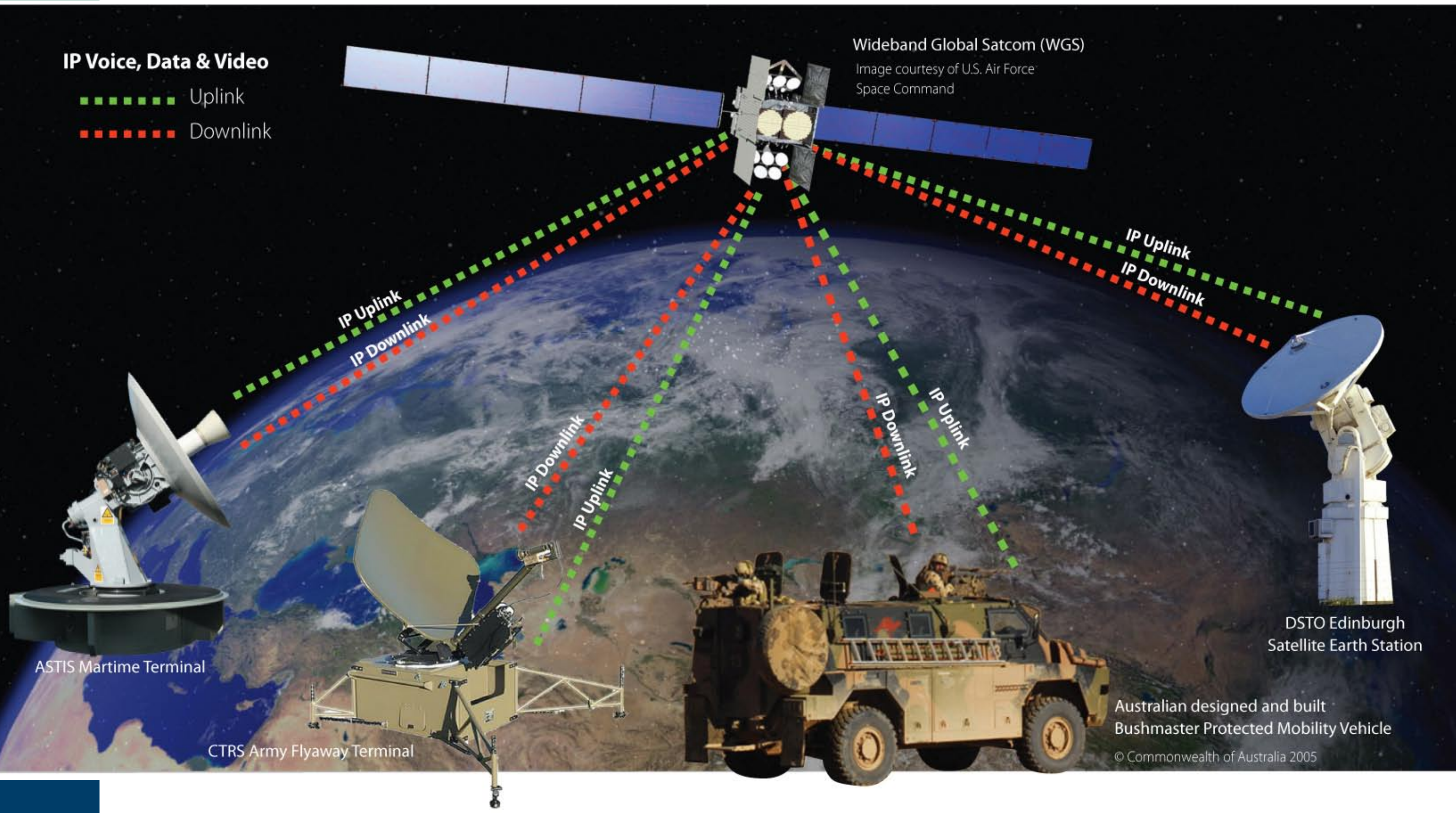
em Solutions
Innovation in Microwave Communications



Challenges in Satellite Tracking for Ka-band On-The-Move

White Paper *Created February 2010*

Challenges in Satellite Tracking for Ka-band On-The-Move

Overview

There are many X-band and Ku-band satellite tracking antennas for On-The-Move (OTM) applications, but only a few products have been developed for Ka-band. With the deployment of the Wideband Gapfiller Satellites (WGS) the demand for OTM Terminals at Ka-band will increase.

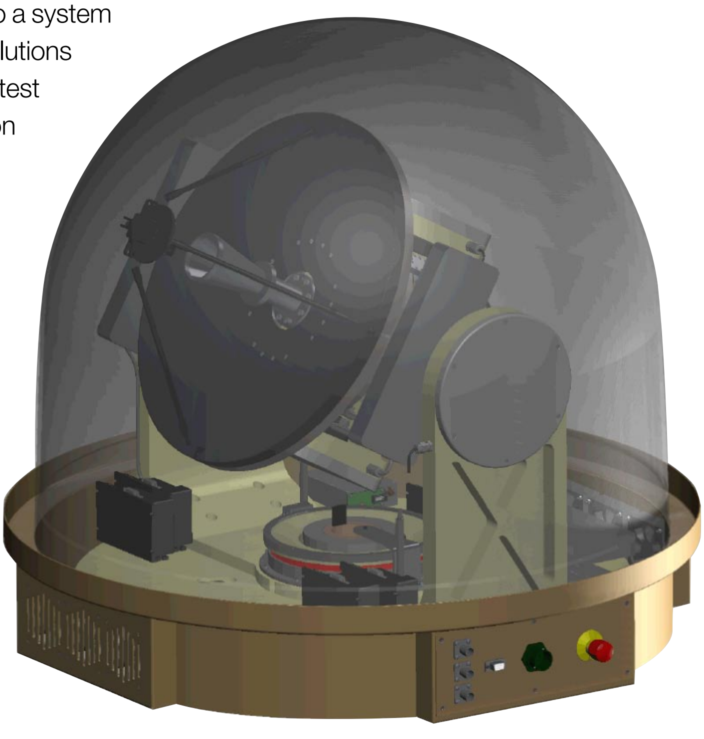
EM Solutions is currently developing a Ka-band On-The-Move Satellite Communications System under the Australia's Defence Capability & Technology Demonstrator (CTD) Program. The CTD program is designed to investigate and demonstrate technology, and EM Solutions has taken the opportunity to explore a number of innovations to determine the performance thresholds for a Ka-band OTM Antenna system. Some of the challenges in working at Ka-band are presented in this article.

Mechanical Design to Physical Control System Modelling

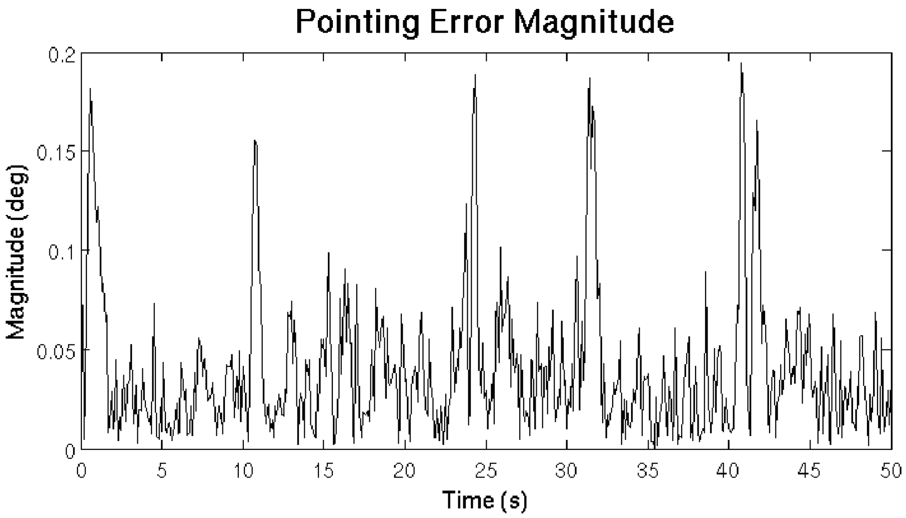
Design simulation tools today will import mechanical designs, created using a 3-D CAD package, into a physical model of the control-system. This modelling extracts mass and inertia properties, joint locations and the physical appearance. EM Solutions used SolidWorks and CosmosWorks for mechanical design, and Simulink and Matlab (MathWorks products) to create mechanical and system control models. This provided a design platform to optimise and update the system.

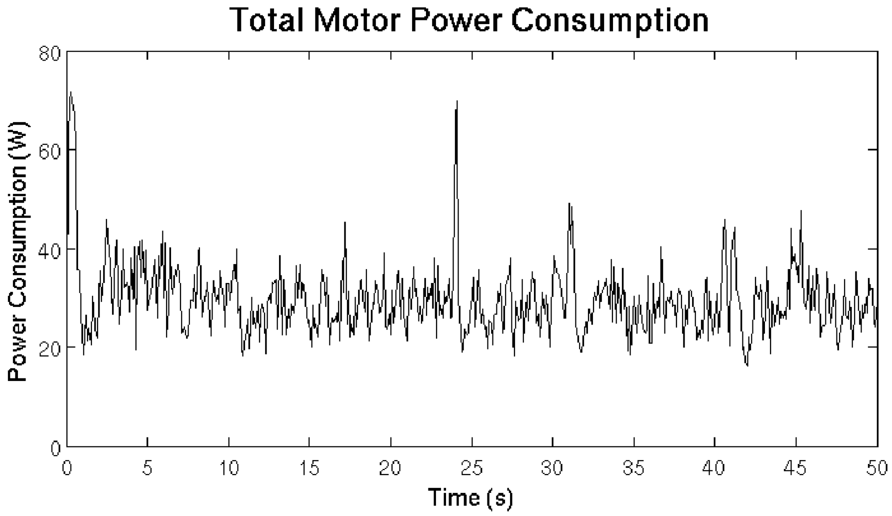
The entire antenna control system was incorporated into the model including non-linear effects such as noise and bearing friction to make an accurate physical model. The design process was iterative where the model was updated to match measurements made on constructed jigs.

Recorded data (real or simulated) can be fed into a system model in order to verify performance. EM Solutions used recorded vehicle motion data from a test vehicle (Bushmaster) in the system simulation model. Typical simulation inputs included limits up to: 65 degrees per sec for velocity; 300 degree per sec^2 for acceleration; and 10Hz frequency response. Simulations allow the control loop design to be optimised. The following image shows plots of the pointing error magnitude and motor power consumption of a Ka band tracking antenna simulation model.



Ka-band On-The-Move Satellite Communications Antenna Terminal being developed for the ADF by EM Solutions


Pointing Error Magnitude


Total Motor Power Consumption

Antenna Tracking Mount

Motor/Amplifier combinations need to be optimised as part of the control loop design. This process involves sending test waveforms through each motor in order to characterise the motor response to various inputs. Modifications to the amplifier circuit may be required to meet design control loop parameters of the tracking mount.

Encoders are required as part of the motor drive circuit and to determine axis position. There are two options for rotary encoders - absolute and incremental. Absolute encoders have the advantage that they provide axis position at any instant without needing to move the axis. The drawback is that absolute encoders are more complicated and they are mostly optical, which may not be robust enough for certain applications. Incremental encoders need to have some sort of homing (e.g. a limit switch or another encoder head) in order to determine the absolute axis position. In addition the control system will generally integrate the pulses coming from the encoder to determine the absolute axis position. Noise which causes pulses to be missed or add will gradually deteriorate the measured position and cause inaccuracies. There are also more options available for incremental encoders compared to absolute, including magnetic and inductive forms.

Physical Effects - Friction and Balance

Friction causes the tracking mount to lose its pointing angle during vehicle motion, so the motors must apply torque to overcome the friction. High friction within the motor and bearings result in the motors having to use more power to overcome the friction. Having some friction in the bearings/motors however does alleviate power consumption as the motors need to compensate for any out of balance effects and friction will tend to hold mount still.

Balance is a critical factor in tracking mount design, as having a balanced system (ie the axes sit on the centers of mass) may aid in reducing power consumption and increase system performance. In an unbalanced mount linear acceleration of the vehicle will translate into rotational motion about axes, so the motors must consume power in order to maintain the desired pointing angle. The more balanced the mount less this effect occurs.

Keyhole Effect

A problem within satellite tracking mounts is keyhole effect, which occurs when the mount is required to track a satellite at an elevation angles approaching 90 degrees from its base (referred to as looking up). This results in a blind region where the antenna is unable to see the satellite. In this region the tracking system needs to rely on non-closed-loop tracking (e.g. gyros and navigation system) to achieve an optimal position when the antenna is once again able to track the satellite. This blind region may also results in a large movement of the azimuth axis during the reacquisition process.

For example an Azimuth and Elevation (Az-El) type tracking mount will be worst case when looking at 90 degrees elevation (straight up). Pointing errors can be considered to have two components: magnitude and direction. When the Az-El tracking mount is facing straight up, the magnitude will be the amount the elevation axis needs to move, and the direction is how much the base will have to move. At high elevation angles where key-hole effects occur, the azimuth axis may need to track to a direction which could be anything in a +/- 180 degree range.

In a purely mechanical tracking platform, the most straight forward way to prevent the keyhole effect is to increase the vertical profile of the antenna mount to allow it to face straight up. However in some applications this extra vertical height may be unacceptable. In these applications more complicated approaches which include: additional axis; or some mechanical deflection of the beam will need to be considered.

A possible method for countering this effect is to add another axis to the system which is mounted at 90 degrees to the primary elevation axis. This axis may only need limited angular movement to reduce load on the azimuth axis when the mount is pointing at high elevation angles. The two elevation axes track out pointing errors, while the base is able to move to an optimal position. Tracking control loops will need sufficient bandwidth on the azimuth axis so it is able to move to a new optimal position before the angle limit on the elevation axes are reached. Adding a second elevation axis will increase the cost and height of the terminal as more mechanical and control system design is required, however may result in power savings and less wear on the azimuth axis.

Need for Closed-Loop

Ka-band SOTM operation imposes quite stringent constraints on pointing-error control. These constraints are due to a combination of regulatory and link-budget considerations. While the actual pointing-error requirement for a SOTM terminal will depend on a number of parameters, it is likely to be of the order of hundreds of milli-degrees.

Achieving this pointing accuracy would be very difficult with an open-loop tracking system that relies solely on inertial measurement systems to steer the antenna. Therefore, it is sensible to consider using a closed-loop tracking system that employs some means of directly measuring the pointing-error.

There are many well known methods for estimating pointing-error. These include:

Mechanical scanning
Monopulse
Phased array (scanning and multi-beam)

All of these approaches would normally rely on the use of a beacon on the satellite.

Mechanical Scan

A conventional reflector antenna can be mechanically scanned to estimate the pointing-error. Examples of this approach are conical scan and step-track. Mechanical scanning has two main disadvantages: it requires introducing a deliberate pointing-error, which can reduce the link budget; and it requires rapid mechanical motion so that pointing-error can be tracked during motion of the vehicle.

Monopulse

Monopulse systems are able to estimate the pointing-error without any mechanical scanning and without needing to deliberately miss-point. Monopulse antennas generally have two feeds: one feed has a normal antenna pattern, while the other has a pattern with a sharp notch along bore-sight. By comparing the signals from the two feeds, the magnitude and direction of the pointing-error can be determined.

Whilst the monopulse is an attractive solution to the problem of determining the pointing-error, it still has a number of disadvantages. Monopulse feeds are generally mechanically complex and so tend to be physically large, making it difficult to integrate one into a SOTM terminal. They also require at least two phase matched downconversion chains.

Phased Arrays

Phased arrays have many features that would be beneficial for SOTM. For example, the beam could be steered rapidly (the so called “inertia-less beam”), which would enable use of a high speed scan to estimate the pointing-error. Alternatively, a multi-beam phased array could be configured to operate in a monopulse mode.

Unfortunately, phased array operation at Ka-band presents many technical difficulties. In particular, it is very difficult to share the physical aperture between transmit and receive because of the large frequency separation between the bands. This means the phased array antenna must be nearly twice the size of a conventional reflector, if it is to achieve the same gain. Other challenges are also introduced by use of a phased array. For example: ensuring that transmit and receive beams point in the same direction; and proving that regulatory requirements, such as antenna sidelobes, are satisfied for all possible pointing angles.

The technical challenges of phase array operation at K-band make the conventional reflector antenna a more attractive solution.

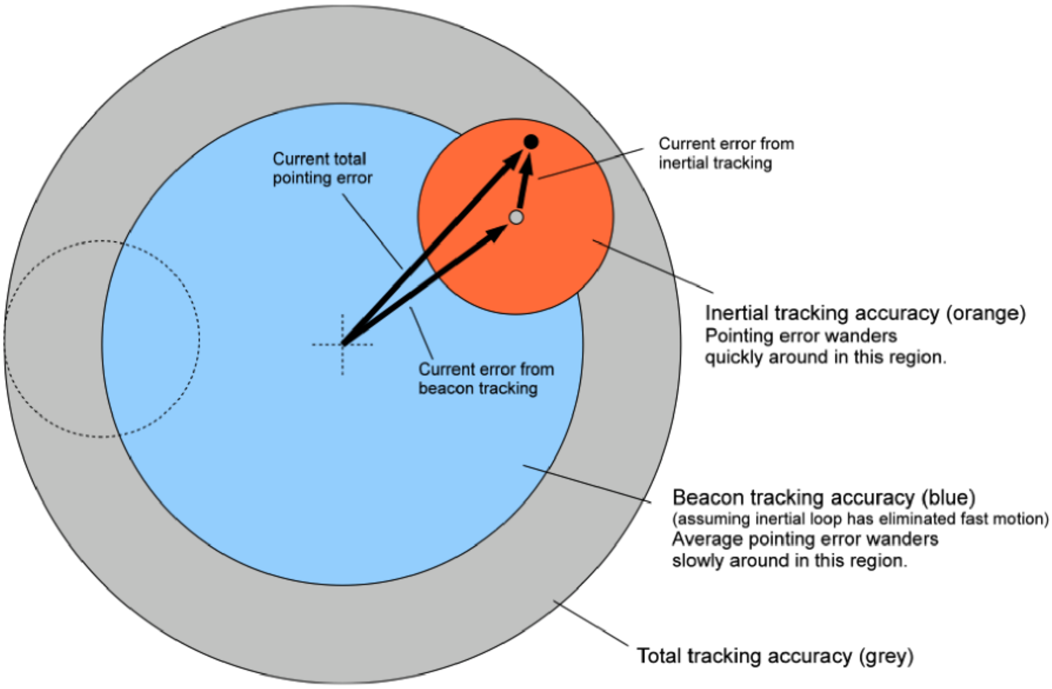
Noise and Pointing-error Estimation

Thermal noise from the antenna and LNA will cause noise on the estimated pointing-error, no matter which of the pointing-error estimations techniques are adopted.

Noise on the pointing-error estimate will induce real pointing-errors. The antenna control loops treats the noise as a real pointing-error and will try to track it out, thus inducing a real pointing-error. The antenna control loops can only track the noise at frequencies up to their loop bandwidths. Therefore, they are effectively a low-pass-filter on the noise.

Filtering of the beacon signal is still normally required because; in general there will be a carrier-to-noise threshold at which pointing-error estimation will fail completely. Choosing the filter’s bandwidth is a compromise. It must be narrow enough to reduce noise to a tolerable level, yet it must not be so narrow that it upsets the stability of the antenna control loop. The actual bandwidth required is a function of many system parameters, but values are likely to range from hundreds of Hertz to a few kilo-Hertz.

Actual pointing error induced by noise on the output of the beacon signal processing is only one part of the total pointing error budget. Control systems generally also use gyros to correct for higher frequency motion. The following diagram illustrates how beacon noise, and gyro inaccuracies are combined to result in the total pointing error.



Doppler Shift and Frequency Offsets

Uncertainty in the beacon frequency is quite large. This is due to drift in the satellite's LOs and Doppler shifts caused by vehicle motion. The frequency offset can be several hundred kilo-Hertz, and the Doppler shift can change at a few kilo-Hertz per second as the vehicle maneuvers. These frequency offsets exceed the filter bandwidth typically required in pointing-error estimation. This means that some form of tracking filter is required.

A conventional Phase-Lock-Loop (PLL) based tracking filter could be used to follow the wandering beacon signal. However, a Fast Fourier Transform (FFT) based approach is possible if the pointing-error calculation algorithm is relatively tolerant to small frequency offsets. With either approach, a balance must be reached between the speed, and accuracy of the filter's frequency tracking.

Summary

This article has covered some of the more challenging aspects of designing for Ka-band On-The-Move Satellite Communications Systems considered by EM Solutions within its CTD Project. At the completion of the CTD Project the Australian Defence Force expects to be better informed about potential performance and applications, and technical risks associated with possible future implementation of Ka-band OTM terminals.

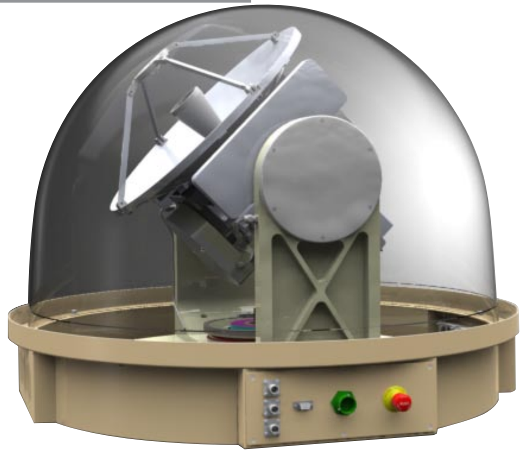
About EM Solutions

EM Solutions is a technology provider to commercial and military customers in the telecommunications sector. EM Solutions is a market leader in the supply of Ka-band products to defence and enterprise customers. Their products include LNBs, BUCs and SSPAs, and Fixed Point-to-Multipoint radios based on the WiMAX IEEE 802.16d standard.

Ka-band Mounted Battle Command On-The-Move Antenna Terminal - Preliminary Specification

Tx Frequency Band	30.0 to 31.0 GHz
Rx Frequency Band	20.2 to 21.2 GHz
Reflector Size	480 mm
Tx Saturated Power	5 Watts (inhibit within 100 msec when outside Pointing Error Limits)
G/T	>9 dB/K
EIRP	48 dBW
Beamwidth, 3dB Tx and Rx	1.5 degree (Tx); 2.2 degree (Rx)
Sidelobes (Tx)	Mil-Std-188-164
Polarisation Tx and Rx	LHCP or RHCP (Not Simultaneous, Factory Set)
Axial Ratio	Tx: <1 dB Rx: < 1.5 dB
Azimuth Tracking	360 degree continuous
Elevation	± 90 degree
Tracking Limits Tx (Inhibit)	1 dB (Tx) Pointing Loss
Tracking Limits Rx (Closed-Loop)	2 dB (Rx) Pointing Loss
Tracking Acquisition	< 5 minute cold start-up and while moving < 5 sec due to blockage after initial lock
Tracking Performance	80 km/hr Seal Road; 20 km/hr Off-road
IF Interface	1.0 to 2.0 GHz
Height	740 mm
Diameter	980 mm
Weight	< 100 kg
Power Supply Voltage and Watts	28 VDC per Mil-Std-1275, < 800 W Peak
Temperature Range	-30°C to +55°C Operational
Overall Compliance	Mil-Std-188-164

Australian designed and built Bushmaster
Protected Mobility Vehicle
© Commonwealth of Australia 2005



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