Compact Shaped Dual-Reflector System for Military Ka-Band SATCOM on the Move

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Abstract— A compact, on the move, SATCOM terminal for the military Ka-band has been successfully designed, implemented and tested. It allows two-way communications at Ka-band while the vehicle is in motion over rough terrains. A compact, complex, tracking system ensures that the antenna keeps pointing at the satellite while the vehicle is on the move.

I. INTRODUCTION

BAE Systems Australia has developed a compact high performance antenna system for military Ka-band SATCOM On-the-Move (SOTM) applications. The antenna system is designed for use in a small, mobile SOTM terminal mounted on an Australian Army Bushmaster or similar all-terrain vehicle.

One of the biggest challenges with SOTM systems is maintaining accurate pointing to the satellite whilst the vehicle is in motion, as the terminal is subject to large accelerations when the vehicle travels off-road. Operating at Ka-band exacerbates this problem due to the narrow beamwidth, the wide separation between the transmit and receive frequency bands and the regulatory requirements.

The antenna design has been demonstrated on the Optus C1 satellite but will ultimately need to be certified for use on the Wideband Global SATCOM (WGS) satellites.

After a review of possible solutions [1], a compact, shaped, dual-reflector system that includes a monopulse tracking capability was chosen for the application.

II. GENERAL ANTENNA SPECIFICATIONS

The general specifications for the antenna system are:

Operating Frequency:
- 30 – 31 GHz (Transmit);
- 20.2 – 21.2 GHz (Receive).

G / T and EIRP:
- G/T target of 12.5 dB/K;
- EIRP target of 52 dBW.

Polarization and axial ratio:
- Transmit and receive bands: Right Hand Circular Polarization (RHCP) and Left Hand Circular Polarization (LHCP), (switchable);
- Axial ratio: 1 dB (transmit); 1.5 dB (receive).

Sidelobes:
- In accordance with MIL-STD-188-164A.

III. ANTENNA DESIGN

The antenna system comprises a shaped dual-reflector system and a shaped corrugated horn, with a highly compact feed system. As well as the normal receive and transmit functions, the feed system also generates two-dimensional angular pointing error signals via a compact monopulse tracking coupler. Monopulse tracking was chosen over alternative tracking schemes, such as conical scan or steptrack, due to the challenging pointing requirements. The alternative systems generate error information by making small changes in the antenna pointing angle to modulate a received beacon signal at the cost of increasing the overall angular pointing error budget. At Ka-band this extra angular pointing error translates into a significant contribution to the amplitude pointing error in the transmit band, due to the significant difference in transmit and receive beamwidths. It is also unlikely that other tracking system would be fast enough for the application.

Another significant advantage of the monopulse system is the wide pull-in range. This allows the tracking system to rapidly re-acquire the satellite should the link be lost e.g., due to blockage by a building, dense vegetation or overhead structure.

To meet the G/T and EIRP targets as well as the sidelobe requirements, an aperture diameter of 480mm has been used for this application. This aperture diameter is just below 50 wavelengths at 31 GHz, which allows a slight increase in allowable sidelobes under MIL-STD-188-164A. A full electromagnetic analysis of the reflector and horn system was carried out during the design process to take into account the strong near-field interaction between the subreflector and feed horn. That way, as well as the gain and sidelobe levels, the mismatch introduced by the subreflector was minimized by an optimization procedure.

The theoretical radiation pattern of the antenna in linear polarization can be seen in Figs 2 and 3 for 20.7 and 30.5 GHz, respectively.

The prototype antenna system design was manufactured in late 2009. A photograph of the manufactured prototype antenna is shown in Figure 1. The prototype antenna system includes a fully-adjustable sub-reflector support system which would not be included in an operational version.

IV. TRACKING MECHANISM

The antenna feed system includes a highly compact single slot TE_{21} monopulse tracking coupler (patent pending) that is capable of tracking both linearly and circularly polarized signals (Fig. 4). Two signals are needed for tracking: sum and difference. The difference signal is provided by the tracking coupler and the sum signal is directly coupled from
the main receive channel. Typical monopulse tracking system radiation patterns for the antenna are shown in Fig. 5. This result shows both sum and difference radiation patterns. The sum pattern has its peak on boresight whereas the difference pattern has a null on boresight.

The sum and difference signals are processed by the tracking receiver which derives the azimuth and elevation angular pointing error signals. These signals can be provided to the antenna control unit to give closed-loop tracking of the satellite. Monopulse tracking operates on the ratio of sum to difference signals. Hence the pull-in range of the tracking system extends beyond the first peak of the difference pattern, but is bounded by the first null of the sum pattern. From the results shown in Fig. 2, the pull-in range is between 1.3° and 2° but in practice, this may be limited by the available signal to noise ratio. This means that once the antenna has been pointed to within plus-or-minus this range of the satellite by e.g., an open-loop system based on a low-cost Inertial Navigation Unit (INU), the monopulse system can then acquire the satellite accurately in closed-loop mode, and the system can start to transmit.

V. MEASUREMENTS

The antenna was measured in two steps. First, a number of bench measurements were conducted at BAE Systems on the various waveguide components making up the complex feeding mechanism. Then radiation pattern and gain measurements were conducted at the CSIRO ICT Centre spherical near-field antenna test range (Fig. 5).

The bench measurements as well as the radiation pattern measurements were in close agreement to the theoretical predictions and confirmed that the antenna system was behaving as designed. The measured gain patterns for the receive and delta channels at 20.7 GHz and transmit channel at 30.5 GHz are shown in Figs 6, 7 and 8, respectively.

Tests were performed with the satellite terminal mounted on a military vehicle under a variety of on-road and off-road conditions and it was confirmed that the tracking mechanism was able to maintain the link with the satellite.

VI. CONCLUSIONS

A novel antenna system has been designed specifically for military Ka-band SOTM applications. A prototype has been manufactured and tested. The prototype antenna performed largely as predicted for both the main receive and transmit functions, and for the monopulse tracking function. The antenna design has been used for a successful live demonstration of SOTM on an Australian Army vehicle. Preparations for a more complete testing of this antenna under a variety of conditions using a six-axis motion control table are underway.

REFERENCES

**Fig. 2:** Theoretical radiation pattern at 20.70 GHz.

**Fig. 3:** Theoretical radiation pattern at 30.50 GHz.

**Fig. 4:** Compact monopulse tracking mechanism.

**Fig. 5:** SOTM antenna under test in the CSIRO spherical near-field antenna test range.

**Fig. 6:** Measured gain radiation pattern for the receive channel at 20.70 GHz.
Fig. 7: Measured gain radiation pattern for the $\Delta$ channel (co- and cross-polar) relative to the $\Sigma$ channel at 20.7 GHz.

Fig. 8: Measured gain radiation pattern for the transmit channel at 30.50 GHz.