Low profile scanning antennas for satcom “on-the-move”

M W Shelley, J Vazquez,

ERA Technology Ltd,
Cleeve Road,
Leatherhead,
Surrey, KT22 7SA,
UK
E-mail: martin.shelley@era.co.uk
E-mail: javier.vazquez@era.co.uk

1. INTRODUCTION

There is currently a significant interest in providing high data rate communications to moving vehicles. L-Band Inmarsat systems are being used to satisfy many current requirements but, due to high air time costs, and as the data requirements increase, Ku-Band is being viewed increasingly as the frequency band of choice. In order to best exploit Ku-Band broadband communications in mobile environments, commercial and military systems integrators are looking for cost-effective low profile, high gain, scanning antennas. Until now, the only solution available has been the electronically scanned phased array, which remains too costly for high data rate communications applications.

ERA has developed a family of Ku-Band antennas using a range of hybrid scanning antennas, the first of which will be used by US consumers to receive satellite TV while driving their Sports Utility Vehicles. ERA’s low profile antennas will also soon be seen providing two way interactive services on trains. The technology used in these antennas is directly scalable to any frequency between X-Band and EHF.

The antennas rotate in azimuth and offer a wide elevation scan using ERA’s unique and patented scanning technologies, together providing near hemispherical coverage, as shown in Figure 1. The technology makes it possible to receive satellite signals down to just 20° above the horizon with no tilting of the aperture. This paper describes the key features of the different designs and discusses issues relating to alignment and tracking. It also provides measured performance for some of the Ku-Band units that have been manufactured and trialled.

2. BENEFITS OF THE HYBRID ANTENNA APPROACH

Hybrid antennas have a number of key benefits which make them ideally suited to both commercial and military mobile applications. First, they are very low profile; typically, a Ku-Band antenna has a profile of only 100mm, including positioner and radome. In addition, it is possible to achieve near hemispherical coverage by scanning a high gain beam with low sidelobes, controlled without using expensive electronic phase shifters.
ERA has also developed a range of low cost fabrication techniques based on the use of injection moulded plastics which make the manufacturing costs comparable to reflectors in high volume applications. The technologies are very rugged and, because extensive use is made of waveguide technologies, antennas can be designed for operation anywhere between X-band and EHF.

3. APPLICATIONS

The technology is being targeted at the following applications:

- **Commercial automotive.** Supporting live satellite TV broadcasts while on the move.
- **High Speed train.** Supporting RX-only and two way web-based services available to passengers for business and infotainment.
- **Aeronautical.** Combining the low profile of a phased array with the economics of a reflector, providing airline passengers with internet access on long haul flights.
- **Military mobile terminals.** Providing up-to-the-minute tactical and logistical information via satellite to the battlefield.

4. A RANGE OF TECHNICAL SOLUTIONS

ERA is developing three variants of its hybrid antenna technology.

4.1 Single polarisation antenna

This solution is based on an array of travelling wave waveguide radiators. A number of waveguides are fed from a common input and each has a longitudinal slot cut in one broad wall. Energy leaks from these slots and radiates in a direction which depends on the internal dimensions of the waveguides. ERA has patented a unique technology for varying the geometry of the waveguide without incurring high losses, making it possible to scan the beam in elevation between about 20° and 70° with respect to the horizon over an operating bandwidth of up to about 10%; the elevation beam exhibits some differential scan with frequency over this band. Using the continuously radiating aperture, the spurious grating lobes often suffered by conventional arrays are eliminated, resulting in excellent radiation pattern characteristics, as shown below.

![Patterns at 12.45GHz](image)

**Figure 2: Typical elevation patterns of low profile antenna**

ERA has developed its first Ku-Band product, illustrated below, based on this design approach, using an external polariser which can be configured to receive either hand of circular polarisation. The antenna is only 125mm high.
4.2 Dual polarisation antenna

ERA has also demonstrated a solution for simultaneous dual linear polarisations. This antenna provides co-located beams with horizontal and vertical polarisations using no external polariser. It uses a much simpler radiating structure which is even lower profile than the first generation design. The generation of dual linear polarisations makes this solution particularly appropriate to European applications. In addition, because it is possible to realise different designs without the need to develop very costly production tooling, it is ideally suited to lower volume requirements such as a rail application.

The design uses an alternative elevation scan technology based on changing the propagation constants of two hybrid waveguide modes in a parallel plate travelling wave beamforming structure. These generate horizontal and vertical polarised signals which radiate with variable elevation scan angle. Since there is no external polariser in the design, the profile can be reduced to less than 100mm in Ku-Band, or 75mm in Ka-Band. Other polarisations, as might be required to compensate for the polarisation twist which occurs when the satellite is not due south of the mobile, can be achieved by appropriate combination of the linear signals at RF or IF. This dual polarisation antenna again covers the scan range 20° to 70° but has an extended operating bandwidth of up to about 20%. Once more, there is some differential scan over the frequency band.

A proof of concept breadboard antenna, shown in Figure 4 below, has been manufactured and has demonstrated co-located vertically and horizontally polarised radiation. Development is continuing and it is anticipated that production antennas operating in Ku-Band will be available at the end of 2005.
ERA’s most recent development offers full duplex operation, with both transmit and receive functions being provided from a common aperture. Azimuth mechanical rotation is retained. A novel, dual polarised, broadband radiating aperture has been designed, combining printed and waveguide components, which ensures grating-lobe free patterns over an extended elevation scan range from zenith to 20° with respect to the horizon. The bandwidth has been extended to 25%, making it possible to cover the band from 11.7 – 14.5GHz with a single aperture. The antenna incorporates independent selection of the elevation scan angle in transmit and receive, making it possible to co-locate TX and RX beams, a feature not available using the antenna configurations described above.

This configuration provides dual linear polarisations in both bands which can be combined at RF or IF to create any other arbitrary polarisation, including circular polarisation. The TX/RX antenna, shown in Figure 6 below, also has a profile of about 100mm at Ku-Band.
Prototype development of this antenna is currently underway, aimed at an aeronautical application. The first demonstration unit will be available in early 2005.

5. **TYPICAL KU-BAND SPECIFICATIONS**

The table below summarises the typical specifications that can be achieved. These are all based on a nominal requirement for an antenna with about 9dB/K worst case G/T at an elevation angle of 20° with respect to the horizon. Antennas can be designed to have different gain and G/T values, if required.

<table>
<thead>
<tr>
<th>Table 1: Typical specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Single polarised design</strong></td>
</tr>
<tr>
<td><strong>Frequency band</strong></td>
</tr>
<tr>
<td><strong>Antenna size</strong></td>
</tr>
<tr>
<td><strong>Diameter</strong></td>
</tr>
<tr>
<td><strong>Height (inc radome and positioner)</strong></td>
</tr>
<tr>
<td><strong>Azimuth scan range</strong></td>
</tr>
<tr>
<td><strong>Elevation scan range</strong> (from horizon)</td>
</tr>
<tr>
<td><strong>Gain @ 20° above the horizon</strong></td>
</tr>
<tr>
<td><strong>G/T @ 20° above the horizon</strong></td>
</tr>
<tr>
<td><strong>Polarisation</strong></td>
</tr>
</tbody>
</table>

6. **MANUFACTURING TECHNOLOGIES**

ERA’s low profile antenna technologies can be realised using CNC machined aluminium alloy parts or metallised plastic or metal mouldings. The use of plastics can provide the potential for significantly reduced mass, as well as very low manufacturing costs.

ERA’s first generation automotive antenna product is manufactured from six high precision injection moulded parts. These use a premium grade glass-filled plastic which has similar mechanical properties to aluminium, both in terms of
operating temperature range and stability, and mechanical strength. The parts are moulded and then plated using an electroless copper plating process. Extensive validation of the processes has been undertaken to ensure that they are suited to the harsh environments found in outdoor environments worldwide.

The moulding process can produce repeatable parts up to about 700mm square with a tolerance of typically 25µm over the complete part. Excluding the initial cost of production tooling, and assuming a large production run, it is possible to manufacture a complete set of parts for the antenna for a few hundred Euros.

Figure 7: Moulded plastic first generation low profile antenna

7. SATELLITE ACQUISITION AND TRACKING

The low profile antennas may be married to a sophisticated tracking system which combines use of the received satellite signal and on-board sensors. Initial acquisition is generally achieved by detecting a satellite ID code. By having prior knowledge of the satellites that are visible from the operating location, it is possible to achieve very rapid acquisition by identifying the first satellite that is detected, calculating the offset of the wanted satellite, and moving rapidly to this wanted transponder. Once acquired, tracking is maintained by mechanically dithering the antenna and monitoring signal strength.

If the satellite signal is lost, on-board sensors maintain the required look direction if the vehicle is moving, allowing immediate re-acquisition when the satellite becomes visible again. Rapid re-acquisition can take place while the on-board sensors remain sufficiently stable. Such sensors tend to drift with time, and the quality of the sensors used determines how long the satellite can be out of view before the full acquisition sequence must be initiated.

When transmit antennas are included in the system, TX beam pointing is achieved by slaving the TX and RX antennas together.

8. CONCLUSIONS

For mobile satcom applications covering a wide range of markets, low profile hybrid antennas provide an excellent compromise between the high costs of phased arrays and the high profile of a reflector.

ERA is developing design solutions which meet a wide range of operational requirements and, because they use low loss technologies, can be readily scaled to meet future requirements in bands ranging from X-Band to SHF.