Investigation of a Low Profile Phased Array for Mobile Ku-Band Satcom Terminals

T.W. Ang [1], Y.Y. Huang [1] and [#]K.K. Chan [2]
[1] DSO National Laboratories,
20 Science Park Drive, Singapore 118230
[2] Chan Technologies Inc.
15 Links Lane, Brampton, Ont. L6Y 5H1, Canada, kwok-kee.chan@rogers.com

1. Introduction

This paper investigates the suitability of a waveguide phased array for use on mobile Ku-band Satcom-on-the-move (SOTM) vehicle mounted terminals. Both receive (Rx) and transmit (Tx) arrays are considered. In order to assess the international satellite systems, the Tx array must meet certain earth station standards such as the IESS-601 [1]. For phased arrays, the most stringent of these specifications is the cross-polarization isolation or discrimination (XPD) of 26 dB within the tracking beamwidth. This level of isolation can best be met within the on-axis region of a non-scanned beam. Thus two-axes, elevation and azimuth, mechanical scanned reflector antennas or fixed-beam arrays with polarization tracking are frequently proposed. Such antenna configurations do not meet the low profile requirement in many SOTM applications. However, the Tx array is still allowed to operate but at a lower EIRP density if its XPD is better than 20 dB. Even at this level, array elements investigated in the open literature such as notch or tapered slot or patch, fail to meet the isolation required for the larger scan angles at the off-principal planes. Arrays need to employ the dual-polarized versions of these elements for electronic polarization tracking, with mechanical scan in azimuth to align the satellite along the principal planes and electronic scan in elevation for beam pointing. This is one possible approach to meet the stringent XPD requirement.

In the following, we present a different hybrid array architecture using rectangular waveguide elements. The waveguide array is demonstrated to possess good polarization isolation in all planes so that 2-D electronic scan can be implemented together with mechanical azimuth rotation for polarization tracking. Dual polarized elements are thus not needed. The performance of the waveguide element in an array environment is analyzed using the very accurate mode or field matching procedure. The elements are placed in a triangular lattice of Fig. 1 and are scan matched using aperture inductive windows and an external wide angle impedance matching (WAIM) dielectric sheet as shown in Fig. 2. This dielectric sheet can also form the radome of the array. The specifications for the Rx and Tx array elements are as follows.

Uplink Band (Tx):	13.75 - 14.50 GHz
Downlink Band (Rx):	10.70 - 12.75 GHz
Elevation Scan Range:	up to 60°
Azimuth Scan Range:	0° - 360°
Cross-Polarization Isolation (Rx):	> 15 dB within tracking beamwidth
Cross-Polarization Isolation (Tx):	> 20 dB within tracking beamwidth
Active or Scan Port VSWR:	< 2:1
Polarization:	Linear for Rx and orthogonal linear for Tx

2. Rx Array Waveguide Element

For the Rx array, the wall thickness of each element is set at 0.05 inch (1.27mm) so that $dx=a+0.1$ and $dy=b+0.1$ inch. For a given set of guide dimensions a, b and WAIM sheet dielectric constant *dk*, the aperture iris window *w*, the WAIM sheet spacing t_1 and thickness t_2 are optimized such that the scan or active match meets or exceeds the requirement within the 60° conical scan coverage and across the 17.48% operating bandwidth. The thickness of the iris is set at 1 mm. Plotted in Figs. 3 and 5 is the worst case active reflection coefficient over the frequency band and scan region for various combinations of guide dimensions with low and high *dk* = 2.33 and 6 respectively. The worst case XPD values within the frequency band and scan volume are shown in Figs. 4 and 6 for the two dielectrics sheets. The higher *dk* WAIM sheet gives better match for a wider range of guide dimensions but poorer polarization isolation. In the example given here, the lower *dk* WAIM sheet is more appropriate where a maximum reflection coefficient of -12 dB and a minimum XPD of 19 dB can be readily obtained. Phi-cuts of the active element radiation patterns are shown in Fig. 7 at the mid-band frequency. They follow the ideal cos θ pattern closely. As can be seen, the XPD level exceeds the specification over a wide scan region.

3. Tx Array Waveguide Element

For the Tx array, the wall thickness of each element is set at 0.04 inch (1.02mm) so that *dx*=*a*+0.08 and *dy*=*b*+0.08 inch. For a given set of guide dimensions *a*, *b* and WAIM sheet dielectric constant *dk*, the aperture iris window *w*, the WAIM sheet spacing t_1 and thickness t_2 are optimized to give the best scan or active match within the 60° conical scan and the 5.3% operating bandwidth. Plotted in Fig. 8 is the worst case active reflection coefficient over the frequency and scan coverage for various combinations of guide dimensions with *dk* = 2.33. The worst case XPD values within the frequency band and scan zone are shown in Fig. 9 for the WAIM sheet with *dk*=2.33. Active reflection coefficient of -12 dB and a minimum XPD of 22 dB can be readily obtained with the larger *a* values. Phi-cuts of the active element radiation patterns are plotted in Fig. 10 for 14.25 GHz. The XPD level is low, greater than 25 dB over a wide scan region. The worst case XPD occurs at 14.5 GHz.

4. End-Launched Coaxial Transition

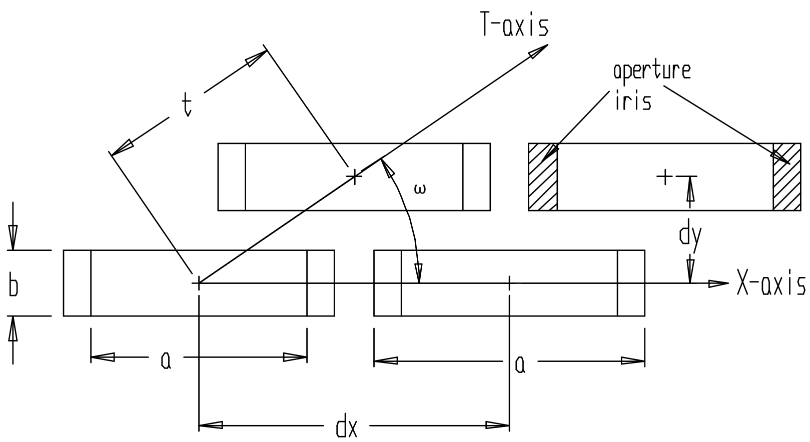
To keep a low profile, each element of the array must be fed by a planar beamforming network using an end launch coax-to-waveguide transition as depicted in Fig. 11. The transition consists of a snap-on 50-ohm coaxial connector, two rectangular coaxial guide sections and two ridged waveguide sections. In the rectangular coax, the size of the centre conductor must be such that both the TEM and the TE10 modes must be propagating so that there is field cancellation at the lower half of the guide. The field at the top half of the guide transitions smoothly from coax to waveguide. The design variables here are the size and length of the centre conductor as well as the height, width and length of the ridges. The excellent match of the transitions across the Rx and Tx bands are plotted in Figs. 13 and 14 showing a maximum value of -24 dB and -30 dB respectively. The total length of the transition, waveguide and matching WAIM sheet is approximately 1.35 wavelength at the respective centre frequencies. This allows a low profile array to be realized.

5. Conclusion

The waveguide phased array has been shown to be well matched and fully meet the XPD requirement under very wide 2-D scan across both the operating Rx and Tx bands. It is thus an excellent candidate for use in a SOTM array.

References

[1] IESS-601 (Rev. 12), Standard G, “Performance Characteristics for Earth Stations Assessing the Intelsat Space Segment for International and Domestic Services Not Covered by Other Earth Station Standards," Intelsat, March 2005.



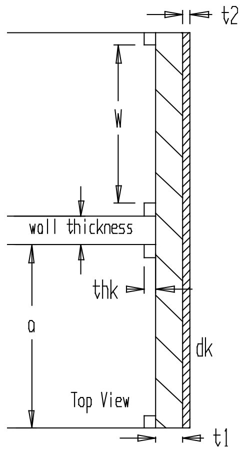
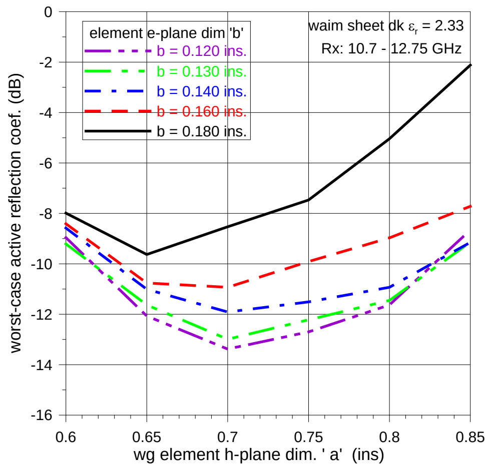


Fig. 1 Waveguide elements in triangular grid.

Fig 2 Matching using iris & WAIM sheet



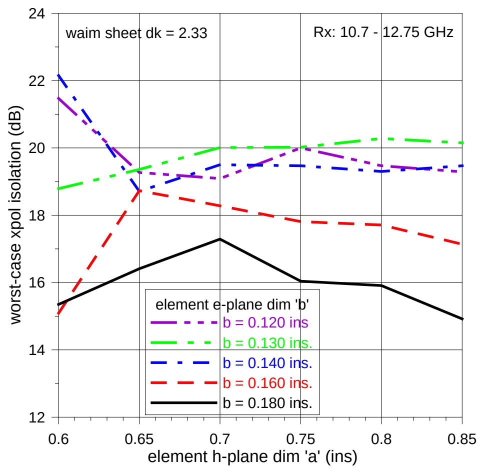
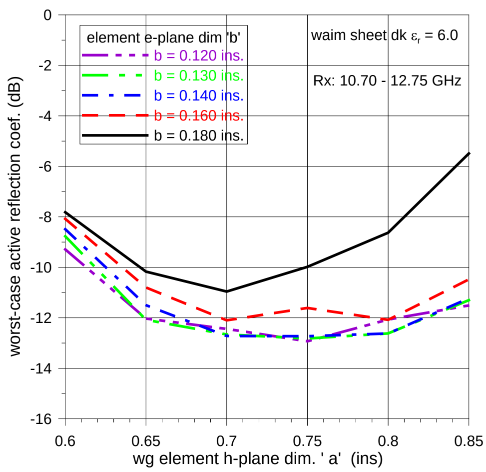


Fig. 3 Worst-case match within Rx band, dk=2.33

Fig. 4 Worst-case XPD within Rx band, dk=2.33



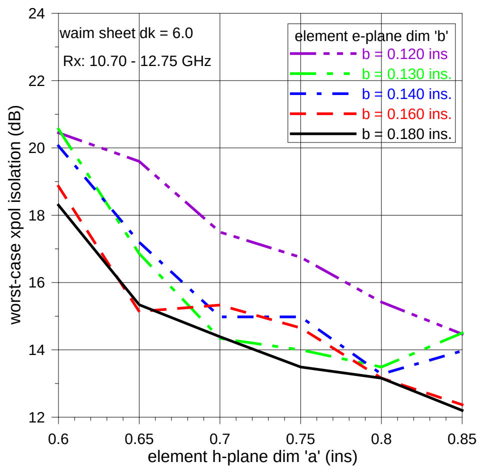
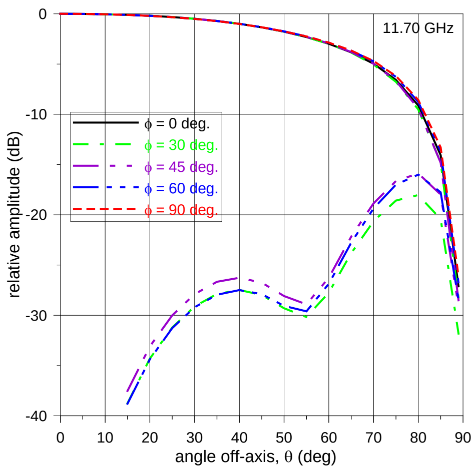


Fig. 5 Worst-case match within Rx band, dk=6

Fig. 6 Worst-case XPD within Rx band, dk=6



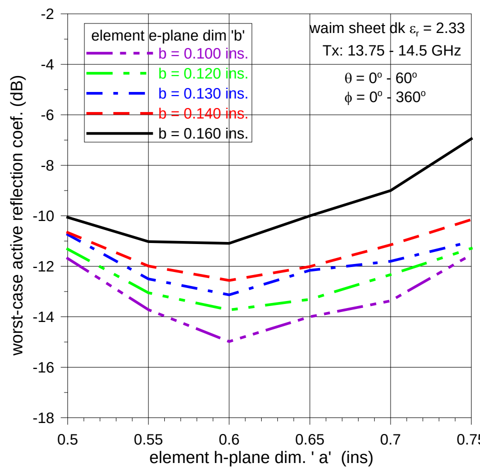
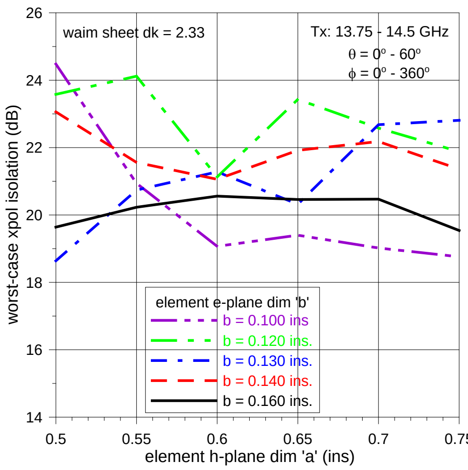


Fig. 7 Active element patterns in Rx band, dk=2.33

Fig. 8 Worst-case match within Tx band, dk=2.33



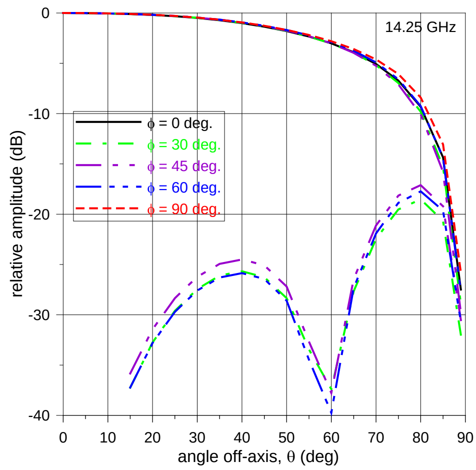


Fig. 9 Worst-case XPD within Tx band, dk=2.33

Fig. 10 Active element patterns in Tx band, dk=2.33

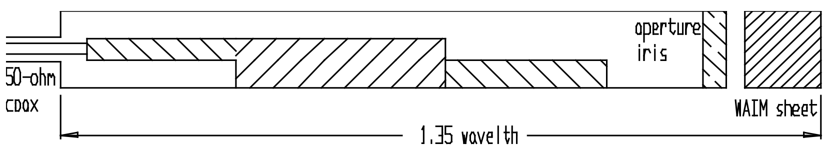
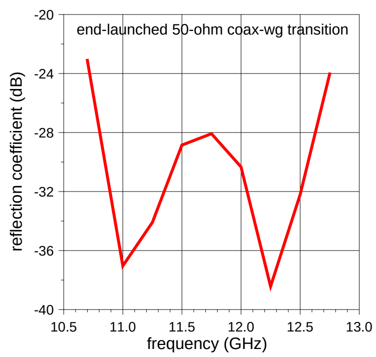


Fig 11 End launched 50-ohm coax-to-waveguide transition.



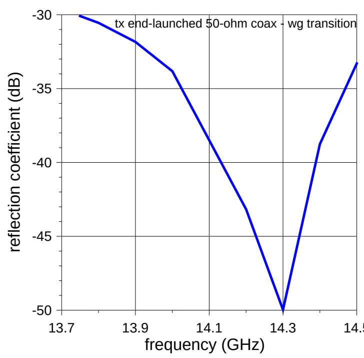


Fig. 12 Transition match at Rx band

Fig 13 Transition match at Tx band.