A Novel Hybrid Dual Polarized Waveguide Phased Array Antenna for Mobile Satellite Communication

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Abstract

This paper presents novel Ku-band waveguide phased array antenna concepts for Mobile Satellite Communications. The array is based on multiple layers hybrid mechanical electronic steerable solutions. The design provides transmit and receive functions. The forward link of satellite communication is 12.25 to 12.75GHz, and the return link is 14.0to 14.5GHz, which is for a bi-directional communication link between the satellite and user terminals. The product is designed for integration in land vehicles and aircrafts.

1. Introduction

In the last few years more and more satellite mobile applications require high data rate in electronic systems ranging from digital radio and TV broadcast to broadband internet services [1]. Among existing satellite systems, Ku-band capacity is widely available all over the world and can be easily controlled with low cost.

Traditional mobile antenna systems which are available, normally track the satellite by means of (partly) mechanical steering: the antenna is in general mounted on a two-axis steering system adjusting the orientation of the antenna in such a way that the antenna beam is continuously pointing towards the satellite. Such systems with mechanically moving parts are however heavy and/or bulky, subject to forces and maintenance intensive [2]. The internal momentum of mechanically steered antennas can be detrimental to their tracking accuracy, especially when operating on-the-move. Phased array technology for mobile satellite telecommunication (SATCOM) applications is an increasingly interesting and growing commercial market for mobile satellite terminals. Some of applications to satellite communications were developed for land-vehicular use under the MSAT-X program since the 1980s. Two different 19-element phased arrays were constructed, a cavity-baked crossed-slot array by Teledyne Ryan Electronics [3] and a microstrip patch array by Ball Aerospace [4], both in co-operation with Jet Propulsion Laboratory (JPL). A further example is the 12-element stacked-patch array for use with the Optus Mobile Sat service, developed in [5]. Satellite communications can be classified according to communication link (unidirectional and bidirectional communication) and mobility (fixed and mobile communication). In particular, bidirectional communication using a satellite has been recently studied in many satellite companies and laboratories [6]. Until now, a mobile antenna for satellite communication generally uses two types, a mechanically tracking antenna and a fully electronic tracking antenna. The former has the main disadvantage of a slow tracking speed and the latter has high cost.

This paper introduced a kind of novel Ku-band waveguide phased array antenna commonly used in satellite communication. The radiation element is waveguide which the horizontal and vertical polarization ports are excited by the common main channel. In this kind of antenna, the vertical polarization signal is produced by waveguide impedance transformation, while the horizontal polarization signal is realized by slot coupling feeding which the original signal is still the vertical polarized form. The designed antenna has a wideband with VSWR<2 in 12-15GHz band, low cross polarization below -25dB, high gain beyond 8dBi and half-power pattern angle over 60°. The results obtained from the simulation model and the manufactured agree much well. And the antenna arrays not only can be applied in single beam system but in the phased scanning occasion. The antenna works at Ku band and spans the receiving and transmitting frequency band of the satellite communication, and can be as the common antenna for satellite communication, especially for on the move communication.

2. System Design

In this paper, integrate waveguide antenna structure is studied to realize radiation in a wide frequency band, and the horizontal polarized feeding port of slot aperture is adopted to increase the impedance bandwidth of antenna and overcome the disadvantage of narrow bandwidth of traditional waveguide antenna. The dual polarization is realized by use of directly feeding and slot coupling to improve the efficiency of frequency band. The shape of antenna array is adopted by multiple stack structure.

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A. Antenna Structure

According to the requirement of antenna system, a new type of antenna is designed to steer its beam electronically in elevation and semi-electronically in azimuth using 12 active phased array elements. The system consists of 12 antenna sub-arrays, a radiation part, control part, and a mechanically driven part. Each sub-array of the waveguide structure has a directly feeding port for vertical polarized signal and a slot coupling feeding port for horizontal signal on the satellite communication). The forward and return link transmitting channel is a common port on satellite communication. The antenna radiation frequency band is ranging for 12GHz to 15GHz covering the receiving and transmitting frequency band.

In order to fabricate the waveguide antenna, multiple layers technique is adopted to reduce the difficulty. And the array is arranged to an oblique status with every layer interlacing upwards and backwards, as shown in Figure1. The purpose is to reduce the total height of all antenna system. The structures of layers are as described in Figure2.

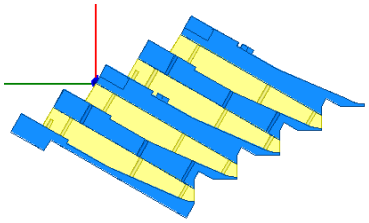

Figure 1 the structure of array

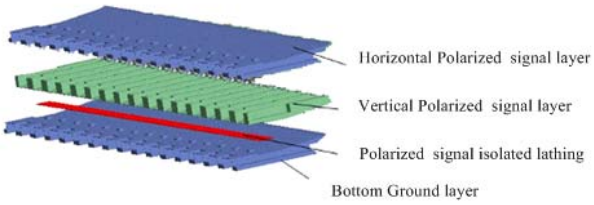

Figure 2 layers delamination of antenna array

A small size array is modeled in simulation to evaluate the performance large size antenna array. Due to the large distance of units, the sidewall of bottom layer will affect the performance of top layer. Therefore, a concave slot is constructed at the sidewall to improve the radiation pattern. The reason is that the angle between the antenna radiation aperture and the horizontal line is 30 degree. In our design, it is desired that the radiation direction of the main beam is as close to ±30 degree as possible. The voltage standing wave ratios (VSWR) of both ports are less than 1.3 and the isolation ratios of both ports are below -40 dB as in Figure3.

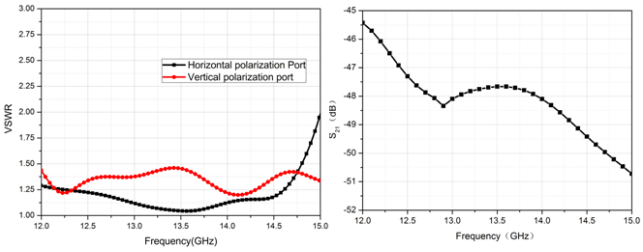

Figure 3 VSWR and S-parameters of dual polarization ports

The simulation results show the variation of antenna gain for both ports with working frequency. It is found that the gain increases as the working frequency grows. The cross polarization for the ports is below -30dB, as shown in Figure 4 and Figure 5.

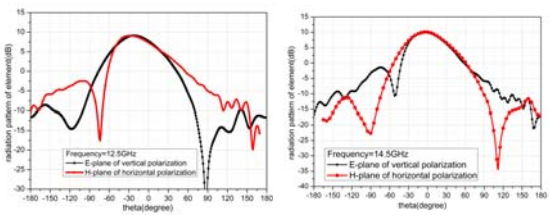

Figure 4 Radiation patterns of element at 12.5GHz and 14.5GHz

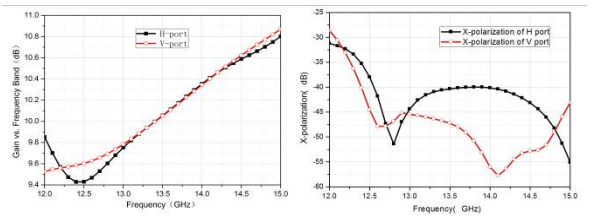

Figure 5 Gain and isolation of dual polarization ports

B. Feeding network

The phase array feeding network is a key component to ensure the required excitation amplitude and phase, in order to achieve the desired radiation pattern or optimize a certain antenna character. H-T waveguide power provider is the main part of feeding network. It helps to reduce the height of waveguide feeding network and make the arrangement much easier. Some matching components are also used to control the input standing wave and the output power.

In the design stage, a 1:16 equal power provider whose model in Figure 6 is used. The top-bottom double layer parallel

waveguide is placed inside the shell for excitation. As the number of power splitting is huge, the standing wave ratio in receiving band and transmitting band is below 1.28 and 1.2, respectively. The insertion loss of most ports is below 0.2dB, with some ports reach 0.3dB, and the variation of insertion phase of all the ports is within 1 degree as shown in Figure 7.

The simulation model is shown in Figure 6, and it is divided into three layers, which every layer is fabricated with metal materials. In the stack arrangement, the top and bottom layers are used as covers to prevent the electromagnetic wave leaking, and the middle layer is as signal channels to transmit energy for power distribution.

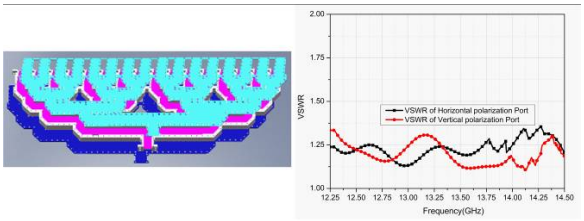

Figure 6 simulation model of feeding network and simulation VSWR of dual channels input ports

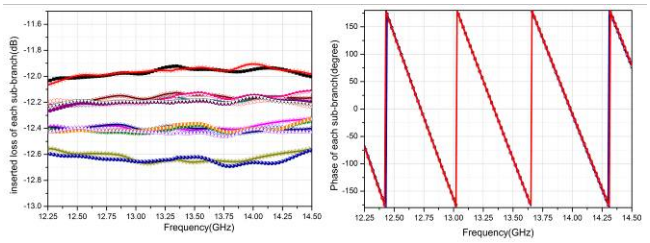

Figure 7 insert loss and phase values of each output sub-branch

3. Antenna Measurement Performance

A 4×16 waveguide array is fabricated for experimental measurement. In order to validate the performance of actual array whether satisfy with the requirement of system, it needs to measure the electric parameters, including VSWR of elements, pattern and so on.

The active VSWR of 4×8 sub-array antenna units as in Figure 8 in the middle of the 4×16 array is measured. During the measurement, as in Figure 9, the untested unit is connected with matching load, and the tested unit is connected with waveguide adapter and converted to co-axial connected, as show in the following figure. The measurement results are concluded that the VSWR is less than -15dB over the low frequency band and less than -10dB over the high frequency band.

Figure 8 fabricated sub-array model

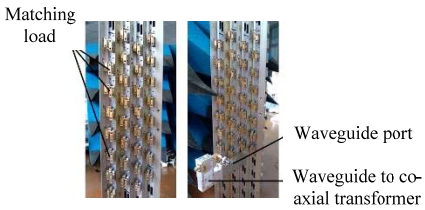

Figure 9 testing process on array units

The scanning performance of the small array is tested. It turns out that the VSWR in Figure 10 is below 1.5 for both the vertical polarization and horizontal polarization. The cross polarization is below -25dB, which fulfills the overall requirement of antenna design, which provided in Figure 11.

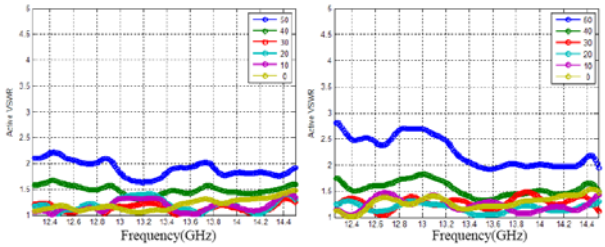

Figure 10 Active VSWR of scanning units in the array of dual polarization ports

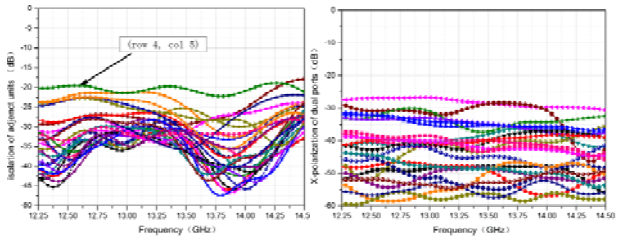

Figure 11 isolation and X-polarization of dual channel ports

The 4×16 array is then fabricated to test its beam steering capability. The measurement is carried out in a large dark room. A transmitting horn is located in front of the antenna array.

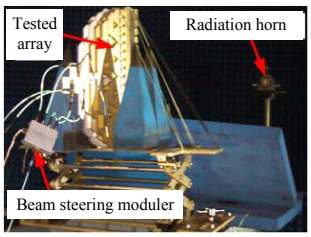

Figure 12 scanning testing of array

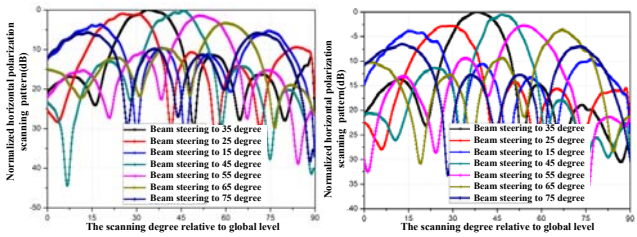

Figure 13 testing scanning patterns of dual polarization

To evaluate the scanning performance of fabricated sub-array, the measurement results are obtained after phase correction. The testing proceeding as shown in Figure 12 which all the experimentation are achieved in absorbing chamber. In the horizontal polarized H-plane, the gain decrease is 3.2dB, 1dB, 0dB, 0.1dB, 1.5dB and 3dB for 15 deg, 25 deg, 45 deg, 55 deg and 65 deg. In the vertical polarized E-plane, 3.3dB, 2.5dB, 0dB, 0.5dB, 2.5dB and 3dB. The scanning patterns of dual polarization are shown in Figure 13.Since the array size is relatively small, the array factor beam width is still large, so the beam performance at large scanning angle can merely be interpreted qualitatively.

The pervious proceeding content is only a little part for the whole project to solve hybrid scanning array in satellite communication. The above work is just done to validate the electric performance of sub-array designed in entire array. The further work is to study the hybrid mechanical and electric scanning style.

4. Conclusion

In this paper, the passive scanning of array antenna technology is achieved after the experimentally measurement of the sub-array of the hybrid scanning of 1-D phased array antenna. This technology paves the way of equipping 1-D or 2-D phased array antenna at Ku-band.

5. References

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