An Embedded Antenna for Mobile DBS

James Wang
Motia, Inc.
Pasadena, CA
jwang@motia.com

Jack H. Winters
Motia, Inc.
Middletown, NJ
jwinters@motia.com

Abstract— **In this paper we describe a vehicle-mounted satellite antenna for receiving satellite TV while the vehicle is in motion. Specifically, we discuss a slotted waveguide planar vehicle-mounted satellite antenna with simultaneous dual polarization states, which uses a hybrid electronic and mechanical steering mechanism, and is operable while the vehicle is in motion. The antenna (and electronics) has a small enough profile (less than 3 inches) that it can be embedded into the vehicle roof, such that it cannot be seen either inside or outside of the vehicle, i.e., it fits between the roof and the headliner. Experimental results for this antenna in a vehicle are presented.**

Keywords-component; satellite TV, satellite antenna, mobile DBS.

I. INTRODUCTION

Back-seat video systems are among the fastest growing automotive accessories for the over 215 million vehicles currently registered in the United States. In fact, over 17 million new vehicles are added each year, with over 5 million of these being SUVs and minivans. Naturally, the killer application for consumers with video systems would be live entertainment, such as satellite television, so that they could have the same video experience in their vehicles as at home--never missing the big game, able to check the financial markets and keeping up to minute with the local or national news.

Receiving satellite television in vehicles is not a new science. It has long been known how to mount a satellite antenna (dish) on a vehicle. Recently, satellite antennas have been introduced which may be deployed on a vehicle and operated while the vehicle is in motion. These Direct Broadcast Satellite (DBS) antenna systems generally operate in the Ku band, where the antenna uses a solenoid system for aiming the antenna. The solenoid system is coupled to a feedback system and/or vehicle motion detectors in order to automatically re-aim the antenna as the vehicle is in motion. In order to reduce aerodynamic drag and protect the antenna from wind damage, an aerodynamic radome is used to cover the antenna. An example is shown in Figure 1.

However, these mobile satellite antennas are generally too large and bulky for the SUV and minivan market. To reduce the size of the satellite antenna, a fully electronic flat smart antenna, rather than a dish antenna can be used, i.e., a phased array antenna having a large number of antenna elements. Antenna aiming in the azimuth and elevation directions is achieved by passing the received signal from each antenna element through a phase shifter. The phase shifter rotates the phases of the signals received from all antenna elements to a common phase before they are combined. While such antennas can be implemented with a very low profile, the large number of microwave processing elements, such as amplifiers and phase shifters, used in the electronic beam forming network results in high implementation cost, preventing mass volume commercial use. One type of such an antenna is described in [1].

Figure 1. A fully mechanically-steerable antenna on an SUV

To keep both the antenna height as well as the cost low, in this paper we describe a vehicle-mounted satellite antenna for receiving satellite TV while the vehicle is in motion that employs a hybrid approach, using mechanical steering in azimuth, but electronic steering in elevation. Since complete coverage over the continental U.S. requires an elevation angle range of 20 degrees (for Maine) to 65 degrees (for southern Texas) with DirecTV and 15 degrees to 60 degrees for EchoStar, we consider an antenna where the look angle of the antenna is set to about 40 degrees, with electronic steering of about plus and minus 15 degrees to provide service over most of the continental US. The antenna consists of 32 ridge waveguides, with right-hand circular polarization, RHCP, and left-hand circular polarization, LHCP, output from the opposite ends of the antenna. Experimental results show that this antenna provides the required performance for mobile DBS, with a profile for the entire antenna system of less than 3 inches, which enables the antenna to be embedded in the roof of the vehicle, unseen either inside or outside the vehicle, as well as to be added with a very low profile on top of the roof of the vehicle. The antenna is capable of providing high gain and a narrow antenna beam for aiming at a satellite direction and enabling broadband communication to a vehicle. This vehicle mounted satellite antenna has a low axial ratio, high efficiency and low grating lobes.

II. System Requirements

Fixed DBS antennas generally have the following requirements. The antenna beamwidth varies from 1.6 to 3.8 degrees, with elevation angle coverage from 26 to 56 degrees with a G/T of 12.7 dB, allowing for a link margin in clear weather of greater than 9 dB. The polarization is switchable between RHCP and LHCP. The cross polarization isolation is greater than 25 dB. Reliability is greater than 99.7%, for less than 30 hours of outage per year.

For mobile DBS, we consider similar characteristics, but with a slightly lower reliability of 99%, which decreases the required link margin by 2.5 dB and the required G/T to 11 dB. In motion tracking in vehicles requires an elevation tracking rate of 20 degrees/sec with an acceleration of 50 degrees per second squared. In azimuth, the tracking rate needs to be 45 degrees/sec with an acceleration of 60 degrees per second squared. The tracking accuracy needs to be about 0.5 and 2.0 degrees in elevation and azimuth, respectively.

The overall system consists of the antenna and radome, the PCB board with the electronics, including the beamforming network with LNAs, the power detectors, and downconverters, and the in-motion platform. Although innovations are required in each of these parts to obtain a low-cost and low-profile system, in this paper we will concentrate on describing the antenna, along with a brief description of the in-motion platform.

III. Antenna

As discussed above the antenna is mounted on a horizontal platform, which is rotatable to adjust the antenna beam in the azimuth direction driven by a motor, and is also capable of steering the antenna beam in the elevation direction through an electronic beamforming network.

To provide for electronic steering of the antenna, we consider a waveguide antenna. Waveguide antennas are typically less than one wavelength in height and provide signal combining along the waveguide longitudinal axis. Many forms of waveguides can be used for microwave energy transmission. Rectangular waveguides have currents flowing on its interior wall and interrupting those currents by cutting through the waveguide wall can cause radiation into the exterior. A radiating aperture is achieved when that aperture is approximately one-half free space wavelength long and one twentieth of a wavelength wide, which is cut through the broad wall of that waveguide. The aperture is described as a "slot" through the waveguide wall. Locating such a slot at various positions on the waveguide wall achieves varying degrees of excitation of microwave fields emanating from the slot. The microwave fields from the simple slot are characterized as being linearly polarized microwave fields.

For DBS in the US, the signals are circularly polarized. A widely used technique for producing a circular polarized radiating element is the cutting of a pair of slots through the broad wall of a rectangular waveguide. The two slots typically cross each other at ninety degrees and at the center of each slot length. Further, the crossed slot is normally placed on a line that is parallel to the waveguide axis and is a distance of approximately one quarter of the waveguide width away from the waveguide axis.

We consider the use of a ridged waveguide instead of a conventional rectangular waveguide to alleviate the effects of grating lobes. The ridge waveguide provides a ridged section longitudinally between walls forming the waveguide. Multiple radiating elements are formed in a radiating surface of the ridged waveguide. The use of a ridged waveguide reduces the width of the waveguide, and thus, the spacing between the antenna slots, which suppresses the strength of the grating lobe. In conventional approaches, the length between cross slots along the waveguide is approximately one waveguide. The resultant beam points upward in the plane orthogonal to the waveguide axis. Here we consider reducing the length between cross slots along the waveguide to further suppress the grating lobe. This results in further beam tilting away from the plane orthogonal to the waveguide axis. However, as long as the beam can be pointed to highest required elevation angle, the beam tilting does not have adverse effects on the overall system performance.

The waveguide couples the EM energy from all radiating elements in the waveguide axis direction and combines the energy together. It has been found that the loss through the waveguide coupling and combining is significantly lower than that using the conventional approach utilizing passive microwave processing elements printed on the circuit board at the DBS operating frequency. In addition, this waveguide antenna allows the reduction of the number of low noise amplifiers used in the antenna system because only one set of low noise amplifiers for each waveguide can be used, as opposed to the conventional use of one set of low noise amplifier for each radiating element.

The ridged waveguide produces a more concentrated field line near the center line of the broadwall, thereby reducing the width of the broadwall from a typical value for a conventional rectangular waveguide to about 0.398 inches at the broadcast satellite range of about 12.2 GHz to about 12.7 GHz.

Figure 2 is a diagram of antenna system. The waveguide antenna consists of an antenna array formed by 32 waveguides positioned parallel to each other on a horizontal platform. Note that the horizontal platform is rotatable under mechanical steering and motion control for aiming the antenna in the azimuth direction.

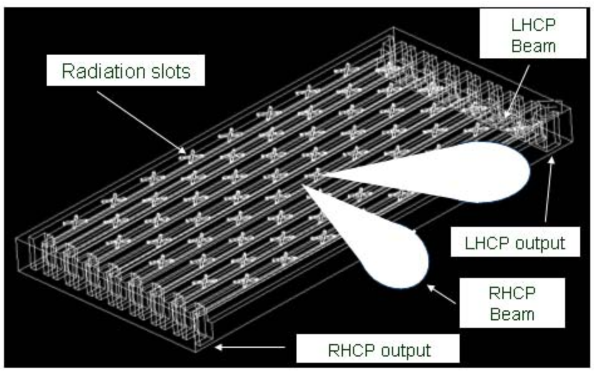

Figure 2. A section of the antenna

The waveguide axis is in a direction perpendicular to the antenna aiming. The radiating surface is the broad side facing the zenith direction. The radiating surface of the waveguide antenna uses multiple radiating elements distributed at uniform spacing along the waveguide axis. The radiating elements provide coupling of electromagnetic (EM) energy between the waveguide and free space. Specifically, in our antenna, the radiating elements are X-shaped cross slots, as shown in Fig. 3. The waveguide couples the EM energy from all the radiating elements in the waveguide axis direction and combines the energy.

The radiating elements are positioned along the direction of waveguide axis with the phase centers of the cross slots of the radiating elements positioned along a straight line along the waveguide axis and in between the center line of the waveguide ridge section and one of the walls. This offset creates circular polarization. The radiating elements are placed about half a waveguide wavelength apart.

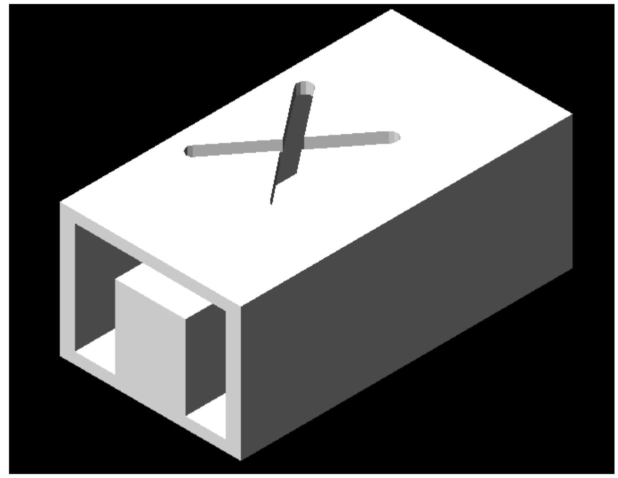

Figure 3. The waveguide with one radiating element.

The typical requirement to operate such a mobile antenna in the Continental United States (Conus) is that the antenna beam is steered from about 25 degrees to about 65 degrees in elevation. It has been found that in order to achieve high antenna gain and low axial ratio in such an operating range, the antenna gain needs to be optimized toward about 40 degrees to about 45 degrees in elevation. The axial ratio is optimized by moving the cross slot of the radiating element toward the wall. When the edge of the cross slots of the radiating elements reaches the wall, good axial ratio can be achieved. This provides an elevation operating range of about 25 degrees to about 55 degrees.

An antenna probe is located on each end of the waveguides, as shown in Fig. 4. The antenna probe located on one end is used to couple a left-hand polarization signal from the waveguide to the beam forming network and the antenna probe located on the other end is used to couple a right-hand circular polarization signal from the waveguide to the beam forming network. This beam forming network provides low noise amplification of the signal and applies progressive phase shifts to the signals from the different waveguides to compensate for the progressive signal propagation delays before the signals from the different waveguides are combined. By changing the amount of the progressive phase shifts, the beam can be steered in different elevation directions.

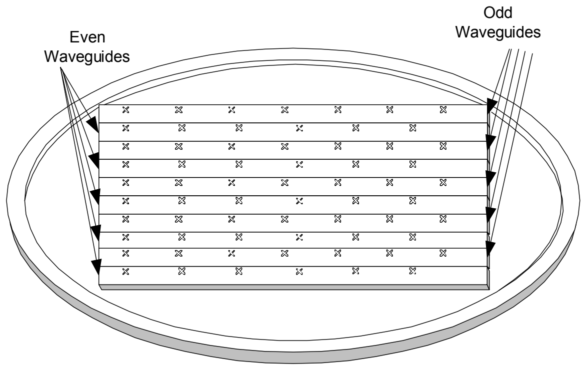

Figure 4. The waveguide antenna showing the location of the probes.

IV. TRACKING

Azimuth racking is done using a DC servo motor, which has low power and low noise. Elevation tracking is fast and robust. A single gyro is used to aide in tracking, along with a low-cost DSP.

V. PERFORMANCE

The antenna system operates over 12.2 to 12.7 GHz for the mobile DBS system, providing both RHCP and LHCP, with an antenna gain of 28-32 dB, independent of elevation. The system noise temperature is about 1 dB, with a G/T in excess of 11 dB, also independent of elevation angle, with an axial ratio less than 4.5 dB. The turning radius of the antenna is less than 16 inches.

Figure 5 shows the implementation of the antenna in the roof of a vehicle, and Figure 6 shows the implementation on top of the roof.

VI. CONCLUSIONS

In this paper we have described a vehicle-mounted satellite antenna for receiving satellite TV while the vehicle is in motion. This slotted waveguide planar vehicle-mounted satellite antenna has simultaneous dual polarization states, and uses a hybrid electronic and mechanical steering mechanism for low cost and low profile. The antenna (and electronics) has a small enough profile (less than 3 inches) that it can be embedded into the vehicle roof, such that it cannot be seen either inside or outside of the vehicle, i.e., it fits between the roof and the headliner, while meeting the requirements for mobile DBS antennas.

Figure 5. Implementation of the antenna in the roof of a vehicle.

Figure 6. Implementation of the antenna on top of the roof of a vehicle.

ACKNOWLEDGMENT

The system developed here involved the work of the mobile DBS group at Motia, along with the assistance of Delphi in the implementation of the antenna into the roof of a vehicle.

REFERENCES

[1] Peshlov, V., Traykov, R., Bozmarova, G., Popova, M., Vasilev, D., Ivanov, Z., and Alexandrov, S., "Low-cost scanning antenna for satellite reception," *IEEE International Symposium on Phased Array Systems and Technology,* 2003, 14-17 Oct. 2003, pages 441 – 445.