Design of a Low-Profile Ku Band Phased Array Antenna for Mobile Platforms

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Abstract

Ku band reception systems for mobile platforms demand stringent requirements for the electrical and mechanical characteristics of the antenna. Limitations on height and weight for a rugged antenna design require a careful phased array antenna design. We present a new phased array antenna design capable of mechanical scanning in azimuth and electronic scanning in elevation. Non-resonant slot coupled patch antenna with a parasitic element on top is designed for wideband operation, which covers entire Ku band allocated for TV reception, and high gain. Single element, then, is formed in an array to meet target design specifications. The antenna has overall 31 dBi of gain when its beam is tilted to 45^o elevation. Its feed network is optimized for this particular scanning angle and wideband operation. Considering the limited dimensions of the antenna, it exhibits excellent performance in terms of match, gain, and isolation among its polarization ports.

1.Introduction

Over the last two decades, scientists and engineers have been working on satellite TV reception for mobile platforms due to increasing demand for information, entertainment and comfort on the move. Different antenna types and systems have been proposed [1]-[6]. Many of the earlier designs concentrate on either the upper or lower portion of the Ku-Band dedicated for TV reception. Our design, on the other hand, covers both bands and it is dual polarization along with other design criteria.

The receiving antenna system is usually composed of three major parts; reception, tracking and antenna control. Tracking and antenna control is based on finding and locking on to the satellite using powerful control algorithms equipped with motion sensors, GPS information, mechanical and electronic position control of the antenna for good reception. The reception part of the system is made up of the antenna and the RF front-end, which includes and LNB, phase shifters and gain/phase equalization circuits. The simplest and the most used form of Ku band antenna is the dish antenna. However, dish antennas are hardly used for moving platforms due to their large dimensions. Our work presented here primarily focuses on the design of low-profile phased array antenna for mobile satellite reception in Turkey. Therefore, we fixed the elevation tilt angle to 45^o (Turksat). However, the antenna element and the array design can be easily modified for electronic elevation scan or modified to another fixed elevation angle for a different application. Azimuth half-power beamwidth of the antenna must be less than 6^o as this is the angle of separation between the geostationary satellites for TV broadcasting. The design specifications of the antenna are summarized in Table 1.

Table 1. Design Specifications for Low-Profile Ku Band Phased Array Antenna

Frequency Band	*10.9 GHz – 12.77 GHz*
Polarization	*Linear Polarization (V and H)*
Cross-Polarization	*min 20 dB*
Elevation Scanning	*±12°*
Azimuth Scanning	*±3°*
Elevation Tilt Angle	*45 °*
VSWR	*<2 (50 Ω Reference)*
Gain	*min 31 dBi*
Mechanical Dimensions	*Height<15 cm, Diameter<1m*

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2. Single Element Design

The element antenna should have a nearly flat gain characteristic, higher than 8 dBi and a very good impedance match (VSWR<2), throughout the whole frequency band. Besides gain impedance and bandwidth properties, the structure of the antenna must be as simple as possible due low-cost and ease of manufacturing. With these considerations in mind, we designed an aperture coupled patch antenna. The antenna is illustrated in Fig. 1. Microstrip feedline on a 20 mil Rogers 3003 dielectric material feeds a slot on the ground plane, and this slot is coupled to a resonant patch. To improve gain and impedance match, a parasitic patch is placed on top of the driven patch. The shape of the slot is optimized to have an hour-glass shape to increase the coupling from the feed line to the radiating patch. The non-resonant dimensions of the slot increase the fractional bandwidth of the antenna significantly. The radiating and parasitic patches have resonant dimensions at the lower and higher frequencies of the operation band, respectively. Optimization of the antenna has been made by the use of a commercial 3D EM field solver, FEKO. Simulation results are presented in Figures 2 and 3. The gain of the antenna is nearly flat and higher than 9.5 dBi. Its VSWR is less than 1.5 over the target frequency band (23% fractional bandwidth). HPBW along excited polarization is 75º.

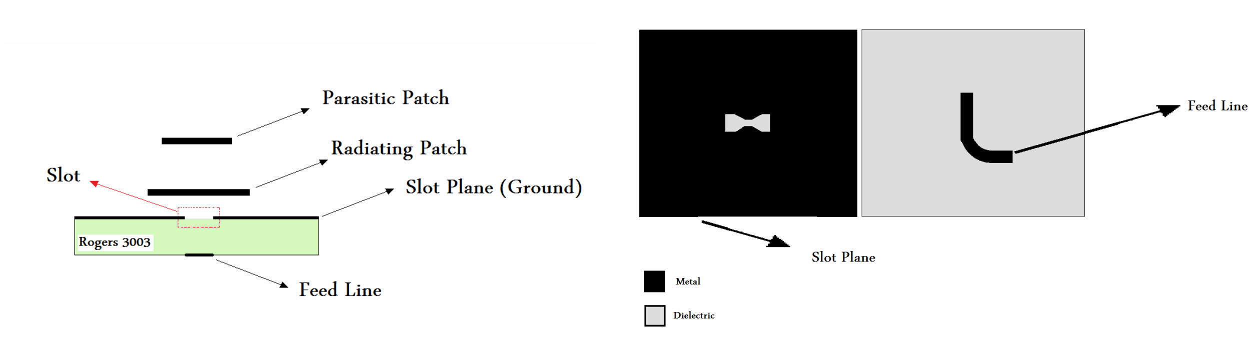
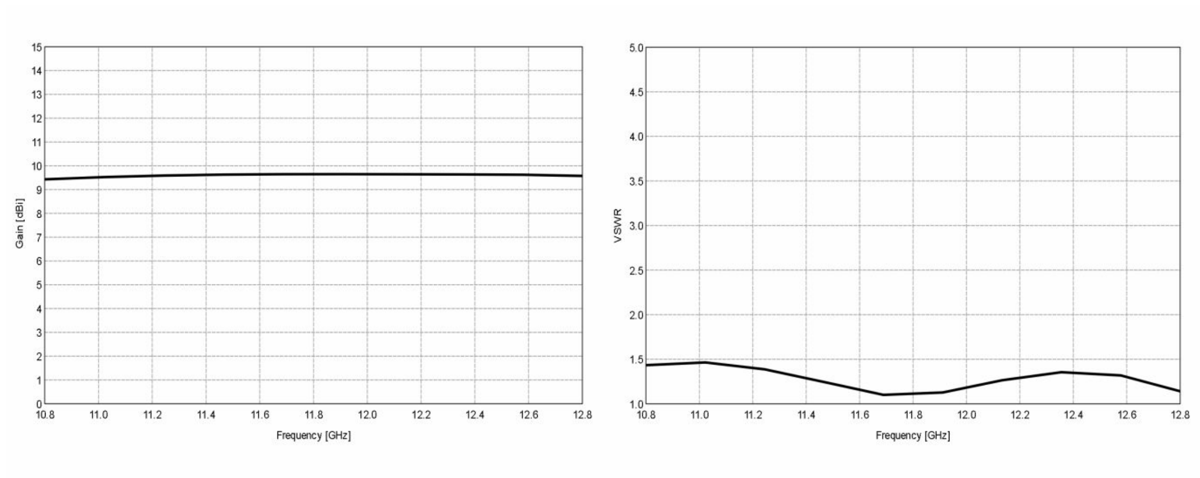


Figure 1. Stack-up, top and bottom views of aperture coupled patch antenna



a) **b)**

Figure 2. a) Gain (dBi) at θ=0º **b)** voltage standing wave ratio

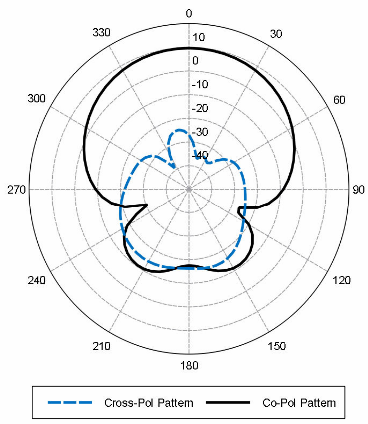


Figure 3. Principle plane gain patterns @ 11.9 GHz

3. Phased-Array Configuration

Theoretically at least 256 elements are needed to reach the minimum target gain of 31 dBi. When losses due to beam tilting and feed network are taken into account, it is necessary to increase the number of elements in the array to compensate for the losses. The general formation of the array is shown in Figure 4, which is optimized for beam tilt, gain and azimuth HPBW specifications. The complete array is made up of four sub arrays two at the top and two at the bottom, formed by 4 rows and 16 columns and two in the middle, formed by 4 rows and 24 columns. A total of 320 elements have been used. To maintain the 45º beam tilt, the element spacings in x and y directions have been optimized to be 1.16λ and 0.57λ, respectively and the inter element phase difference between rows is calculated numerically and verified by simulation to be -145º. Simulations are based on exciting all elements separately with the calculated phase and magnitude values. Simulation results are shown in Figures 5 and 6. The antenna has an overall gain of 31 dBi with a 45º elevation tilt and a HPBW of 4º at 11.9 GHz.

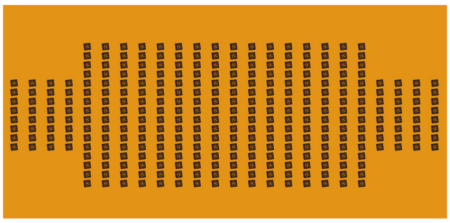


Figure 4. Array Formation

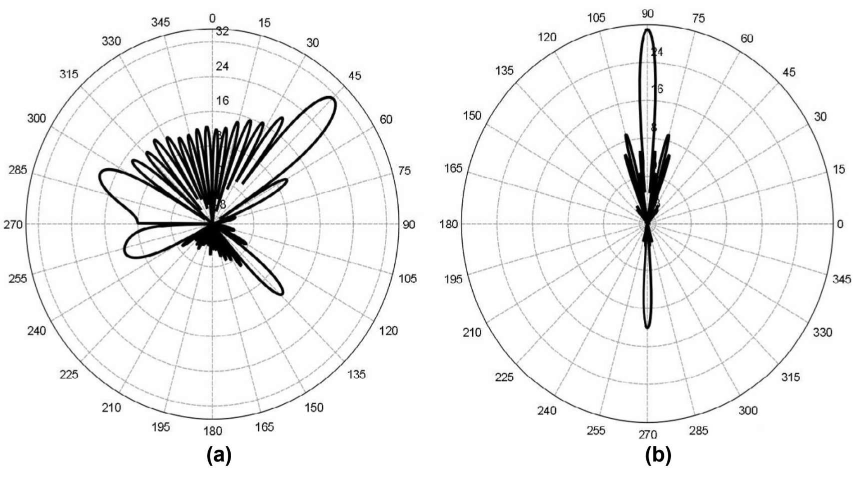


Figure 5. Principle Plane Gain Patterns (dBi) @ 11.9GHz, a) φ=90º, b) θ=45º

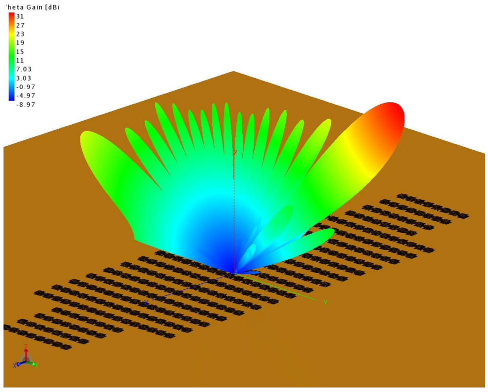


Figure 6. 3-D gain pattern of the antenna array array tilted to 45^{o} at 11.9 GHz (max 31 dBi)

5. Conclusion

The design of an aperture coupled patch antenna array for low-profile Ku band satellite receiver systems for mobile vehicles is presented. The antenna covers both upper and lower Ku bands for TV reception. It has excellent gain and VSWR characteristics. It has a gain of 31 dBi of gain with 45º beam-tilt in elevation and 4º HPBW at azimuth. It is designed for horizontal polarization only, however, the vertically polarized array can be easily formed by rotating the slots 90^{o} and slightly modifying the feed network. Two structures each dedicated to one polarization is envisioned. Target design specifications have been. Prototype design and its integration to the reception system are currently in progress.

6. Acknowledgments

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