LOW PROFILE MOBILE SCANNING PHASED ARRAY ANTENNA SYSTEM FOR DBS RECEPTION

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ABSTRACT

The paper presents circularly polarized scanning phased array antenna terminal, developed for ground DBS reception in the frequency band 12.2 – 12.7GHz. Design of the antenna utilizes microstrip printed circuit technique to achieve thin flat profile of the product, easy manufacturing and compatibility with MMIC phase control devices. The array is electronically steerable in elevation, as the phase control is realized with 5-bit phase shifters. Scanning in azimuth angles is mechanical. Amplitude control is not applied. The grid shape and spacing are considered to cover large tilt angles (up to 65deg). Radiating elements are circular probe-fed patches. The antenna is purposed to the ground mobile users and provides hand over from beam to beam, depending on which particular beam provides the best link margin. Main components and blocks of the antenna terminal are discussed in the proposed paper, including radiating element, feed network, vertical structure, microstrip layers, LNA design, beam coverage. Measured antenna patterns and parameters are presented.

1. INTRODUCTION

Nowadays, the interest in mobile satellite communications has been growing rapidly. The contemporary satellite services available could be generalized into two main groups. The first one comprises narrowband systems that could offer high mobility to the end user, and the second one contains broadband systems, which are fixed or with limited mobility, most often as portable systems. An emerging task is to provide affordable solutions for delivering broadband satellite services to highly mobile users, such as in a personal vehicle. There are many controversial requirements to that type of systems as the size, weight, gain, tracking capabilities, price etc. The most challenging part of the realization of such a system is the antenna, which should possess capabilities to track the satellite with high speed and relatively narrow beam, to keep the service quality in wide field of view, to recognize and switch between satellites, having a price acceptable for commercial applications.

This paper presents one solution of electro-mechanically steerable flat antenna with extremely low profile, purposed for roof mounting on vehicles, such as cars, vans etc. It is designed to provide continuous reception of digital TV satellite programs and Internet throughout the continental territory of US, aiming the three GEO satellites at 101°W, 110°W, 119°W, with dual circular polarizations. Linear polarization can also be formed, which makes the system suitable to the European market. The satellite acquisition and tracking are fully automatic with no need of additional human intervention. In order to make the system practical for the mobile ground user, the main requirements to the design are small antenna thickness, eased installation and replacement, as well as inexpensive operation and maintenance.

2. SYSTEM OVERVIEW

Presented antenna system if a fully functional outdoor unit, that could be used in combination with any conventional DVB receiver for satellite reception. The system parameters are targeting to the US market, so the working frequencies are in the Ku band – 12.2 to 12.7 GHz. The Field of View (FOV), that maintains acceptable reception quality is 360° in azimuth and 35° - 90° in elevation. The azimuth coverage is mechanically steered while the elevation coverage is electronically steered. The cross-polarization is below 20 dB in the area of the beam been set, and the level of the sidelobes is below 20 dB in the GEO arch, except the first sidelobes, which are below 12 dB. The scan losses of the antenna are close to the theoretical cosine steering performance. The main system parameters are summarized in Tab. 1. The system consists of two main modules. The stationary part is the housing of the device, comprising power supply, computer unit and module for satellite recognition. The second module is a rotationally moving part comprising the antenna array, downconvetrer, movement sensors and digital control circuit. A schematic block description of the system is shown on Fig. 1.

The antenna rotary part is built out of four layers of printed circuit boards (PCB). The RF feed is composed of microstrip lines and the connections between the layers are made with specially designed proprietary transitions.

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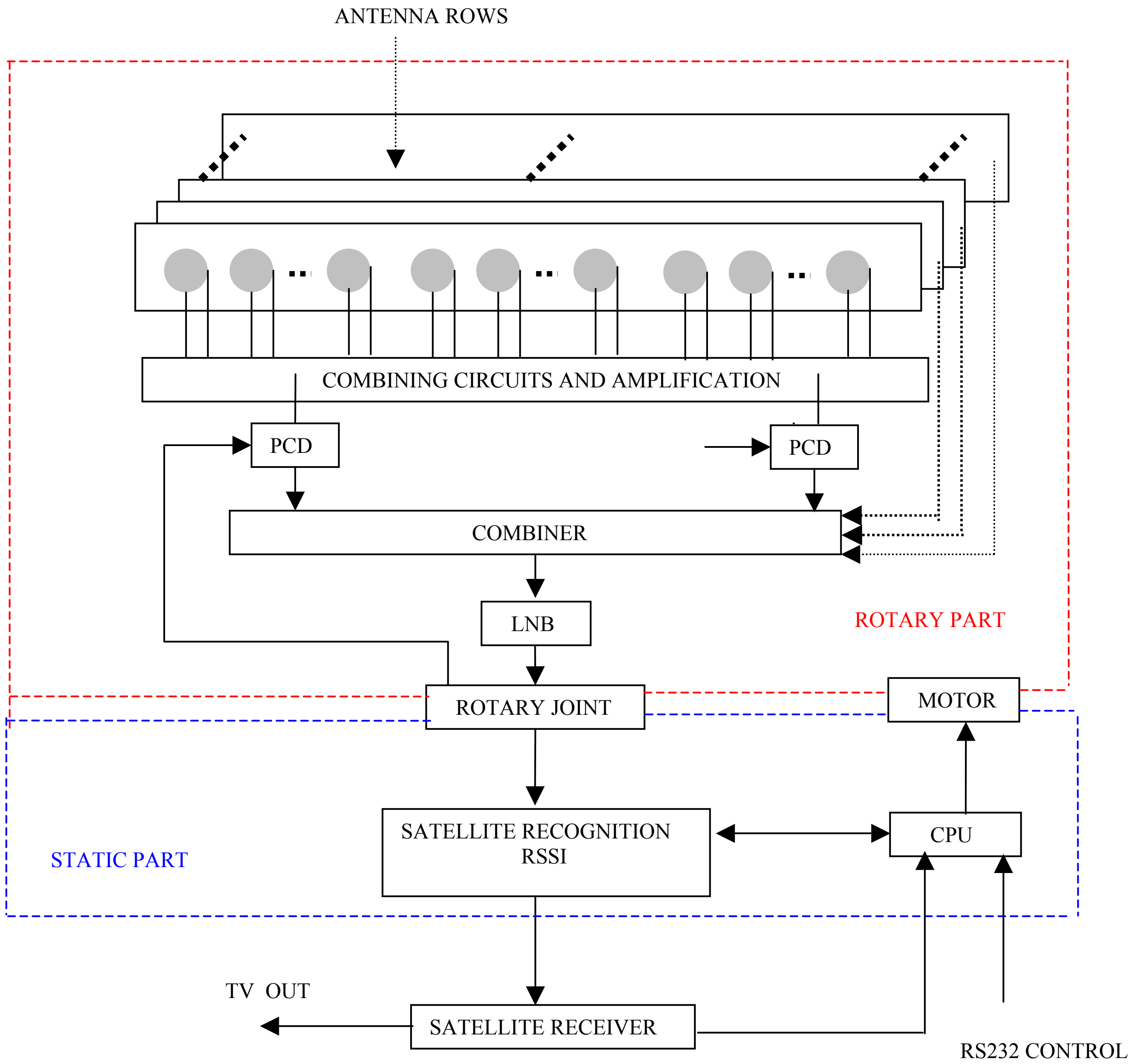

Figure 1. Schematic block description of the system

The first layer is populated with dual port radiating elements, grouped row by row, perpendicular to the elevation plane. The grouping is done combining the identical ports of the radiating elements, as different Phase Control Devices (PCD) control every group. The next two layers provide combining and amplification of the received signals from the radiators up to the input of the 5-bits PCD.

The fourth one comprises the phase shifters and final combining (summation) of the signals of all rows. The connections between the moving and the static parts are maintained from a low profile custom designed rotary joint. It passes digital control, power supply and RF signal to the moving part of the device.

Table 1. Main system parameters summary

Parameter	Value
Frequency band of operation, GHz	12.2 – 12.7
Polarization	LHCP, RHCP, VLP, HLP (switchable)
G/T at zenith, dB/K	11.5
Azimuth beam coverage, deg	360
Elevation beam coverage, deg	35 - 90
Azimuth Tracking Speed (Mechanical), deg/s	>60
Elevation Tracking Speed (Electronic), deg/s	>60
Maximum Side Lobe Level, dB	-12
Cross-Polarization Ration, dB	< -20
Power consumption, W	110
Number of Beams	115
Dimensions, mm	810 x 865 x 60

4. ANTENNA MAIN MODULES AND SUBSYSTEMS

4.1. Array design

The array aperture is approximately circular with diameter 780mm. Size of the antenna is considered in relation to G/T, necessary for acceptable TV reception and follows of the link budget. The distance between centres of radiating elements, which are perpendicular to the scanning plane, is 0.5λ in order to avoid appearance of grating lobes for large scan angles. In the other plane distance is selected to be 0.63λ. The array lattice consists of 2068 radiators, arranged in 58 rows. The radiators are dual port and the identical ports (grouped for each row), are controlled independently by different PCDs (see Fig.1). The total number of PCDs is 116, two for each row.

4.2. Single radiating element

The design of the radiating element follows the array design and system specifications. Probe feeding was chosen because of the good efficiency and less space occupied. The shape is circular in order to maintain high density of the population among the aperture. The scan behavior was investigated using embedded element pattern measurements. Main goals of the design were the scan pattern optimisation, keeping the return losses as low as possible. The VSWR in the bandwidth is less than 1.5. The gain of the single element is better than 6 dB, with beamwidth 110°.

4.3. Feeding network & LNA design

The microstrip feeding network is arranged on Rogers™ substrates. The feed lines in front of the first LNA are carefully optimized, so that the losses before the first amplification are kept well below 1 dB. For the rest of the network, the space constrains are determinative for the feed sizes, materials and layout. The RF connections between the layers are based on custom designed proprietary transitions, which could be mounted using standard SMD technology. The amplification stages are custom designed LNAs with gain better than 11 dB and noise figure below 1 dB for temperatures lower than 60° C. The design is also optimized for less space occupation and unconditional stability.

4.4. Rotary joint

The most critical mechanical part of the system is the rotary joint. It maintains the support of the moving part and the connections between the electrical subsystems. In the same time the height of the structure is of basic importance for the overall thickness of the antenna package. A low–cost, low profile custom designed rotary joint is implemented. It incorporates RF transition, DC power supply and digital control connection.

4.5. Digital control, tracking and acquisition

A CPU unit mounted on the static part ensures the control and steering of the device. It controls the state of the PCDs, the driving motor, and defines the antenna orientation based on the information received from the motion sensors, RSSI module and the Satellite Recognition Module. The initial acquisition time achieved is less than 30 sec after power is switched on. The satellite could be selected manually trough a small indoor terminal connected to the device by RS-232 interface.

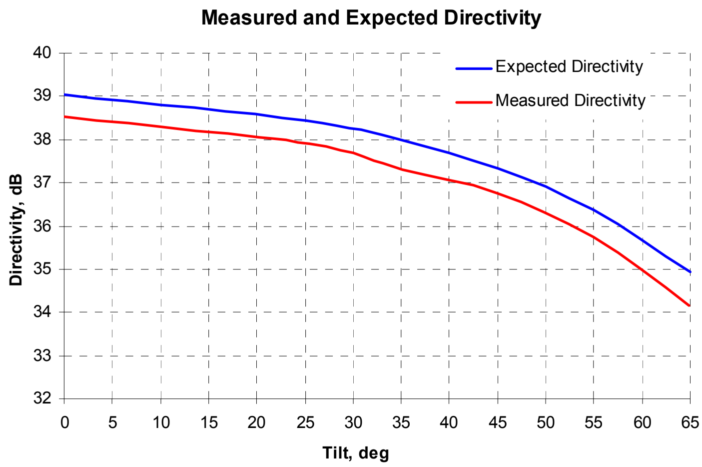

Figure 2. Measured and expected antenna directivity versus beam tilt angle

5. TEST RESULTS

Three types of tests were performed. The beam patterns, directivity, pointing accuracy and steering limits were checked in NF range. Comparison between expected and measured directivity is shown on Fig. 2. Typical beam patterns are shown on Fig. 3 and Fig.4. A good coincidence of the measured and expected performance has been observed. Next, the figure of merit of the system was tested. The results of the test are given in Tab. 2. The third set of experiments was for mobile operation capabilities. Part of the measurements was done using especially in-house developed System In-motion Tester (SIT), Fig.5. This tester simulates rotational movement around the main three axes with different controllable speeds and accelerations, which allows determining easily the limits of the tracking speed. Finally, the system was tested successfully on a car roof in different real mobile conditions in Europe and USA, Fig.6 and Fig.7.

Table 2. Measured figures of merit at boresight

Frequency, GHz	12.2	12.4	12.6	12.8
G/T, dB/K	11.25	11.4	11.9	11.3

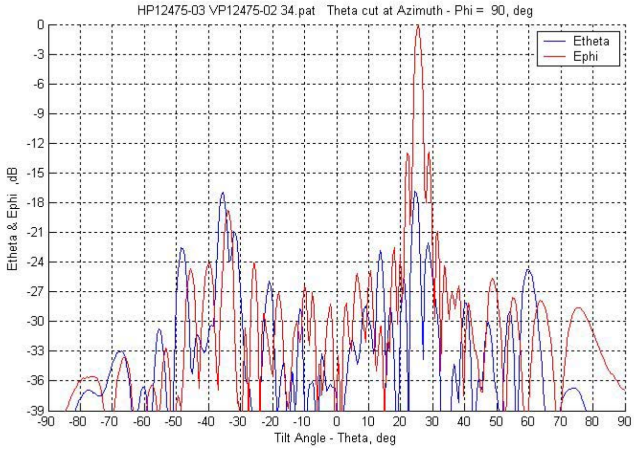

Figure3. Measured radiation pattern (Beam 35)

Tilt=25.47 deg, cut in azimuth plane

Figure 6. Antenna on a car roof ready for road tests.

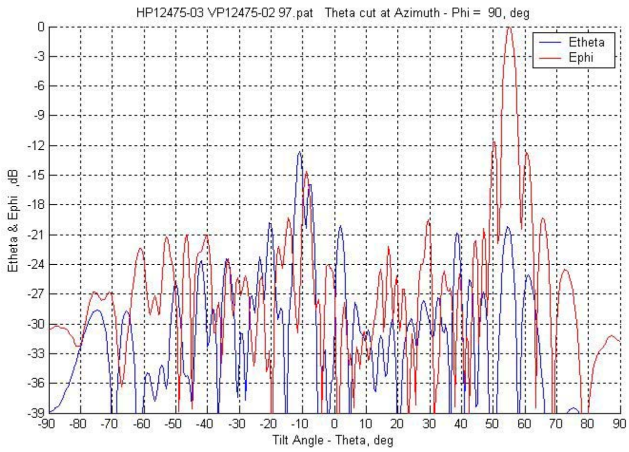

Figure 4. Measured radiation pattern (Beam 89)

Tilt =50.39 deg,, cut in the azimuth plane

Figure 7. Drive test in Nevada USA.

Figure 5. "Live" test with the in motion tester (SIT) device in RaySat facility – Sofia, Bulgaria

6. CONCLUSION

An extremely low profile antenna (less than 6 cm) with mixed mechanical and electronic beam steering for DBS TV reception on move was developed. A careful design and performance-complexity optimization as well as low cost electronic components used, makes it possible to achieve an acceptable for consumer market system cost. A dual port elements array and the implementation of two independent feed structures give an unique capability to support all possible signal polarizations and to adapt antenna easily (changing only the embedded software) for different type of services in different geographical locations, using phase controlling devices not only for beam steering but also for polarization control. During the extensive tests in Europe and USA the antenna performed very close to the design goals.