AUTOMOTIVE S-BAND RECEIVE TRANSMIT ANTENNA

34TH ESA ANTENNA WORKSHOP AND 2ND EVOLUTIONS IN SATELLITE TELECOMMUNICATIONS GROUND SEGMENTS WORKSHOP

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ABSTRACT

The activities described in this paper were carried out by Calearo in the frame of the COSTARS [1] project (low COst S-band receive/Transmit Antenna for vehiculaR applicationS), financed by ESA-ESTEC. The key objectives of the project were oriented to develop automotive antennas specifically designed to receive and transmit S-band signals: an RX-only antenna and a RX/TX antenna were required. The paper describes the design, manufacturing and test of a switchable dual polarised automotive Tx/Rx antenna usable for S band applications. The compact antenna designed enables the use of the satellite S-band communication channel to provide interactive services and contents on board of vehicles. The present paper gives an overview of the RX and TX antenna/RF front-end design, as well as antenna and RF front-end measurements. The paper also includes a description of the antenna production line and the related validation tests performed during the project.

1. INTRODUCTION

The key objectives of COSTARS project [1] were oriented to develop automotive antennas specifically designed to receive and transmit S-band signals: an RX-only antenna and an RX/TX antenna were required. The paper concentrates on the more complex RX/TX antenna, being the RX-only antenna a deriviation from this solution.

The S-Band technology creates the possibility to have a single network able to provide a full European coverage using a combined Satellite and Terrestrial network. In urban areas, terrestrial transmitters take over from satellite to provide effective indoor coverage. Elsewhere, vehicles and residential gateways can receive signals directly from the satellite. The S-Band forward link is based on the DVB-SH standard (Digital Video Broadcasting-Satellite Handheld [5]), the satellite system delivering optimized broadcasting of mobile radio, TV and data content for terminal devices (domestic or mobile) using the mentioned hybrid satellite and terrestrial network.

The S-band return link is based on ETSI S-MIM standard (S-band Mobile Interactive Multimedia [6], [7]) based on a new spread spectrum protocol: Enhanced Spread Spectrum Aloha (E-SSA) [8], allowing to the end users (i.e. vehicles) with the possibility to start the communication when data are available to be transmitted to the satellite, as for any other CDMA based system (i.e. UMTS).

In this paper we present the final details of the RX and TX antenna, previously introduced in [8]. The highly integrated shark-fin-like antenna designed in the project is fully automotive compliant. The electronic and
mechanical achieved performances are well in line with the requirements agreed with ESA and Satellite Operators, as reported in the following Table 1.

The present paper is organized as follows. The next section will give an overview of the Antenna and the RF front-end design process. Section 3 will give some details of the industrialization design. Section 4 will give some measurement results related to G/T value and RX and TX radiation pattern. Finally, the conclusions are detailed.

2. ANTENNA AND RF FRONT-END DESIGN PROCESS

According to the requirements provided by ESA, the designs of the antennas have been optimized in order to arrive to an RX-only and a full RX/TX antenna product. Moreover, the antennas have been designed in order to be upgraded with additional functionalities, such as GPS/Galileo and Telephone (3G). As more general case we will further refer to the more complete RX/TX antenna, because the RX-only version can be seen as a subset of functionalities.

Both RX and TX sections might be seen as composed by an electromagnetic section and electronic section, as schematized below in Figure 1.

![Figure 1 - Main sections of the RX and TX blocks](image)

The mentioned sections evolved during the project in order to be compliant with the specifications in terms of performances and costs and optimized for the mass production.

The design of the radiating section was done trading-off RF performance, mechanical profile/envelope and realisation costs. For such a reason patch structures have been selected as electromagnetic elements to be implemented. The patches used in the antenna have been identified as a compromise between a dual feed rectangular patch and a dual feed circular patch. Moreover, more patch structures have been simulated, breadbored and measured during the project, by changing the geometry, feeding concept, the mutual position of the patches (RX and TX element in order to increase decoupling hence avoiding saturation in the RX section while transmitting signals in the TX section) and materials.

The patch feeds in the RX section have been designed and used to receive the signal from the terrestrial network too, by avoiding the necessity to add a second RX section optimized to receive such signals.

Main drivers for the design of the electronic section were to provide the receiver terminal with the amplified and properly polarized signal, filtering out-of-band signals and to transit to the satellite a return signal strong enough to close the link.

For the RX section the following elements have been designed and implemented:

- **RF Front-End**: used to combine and provide left-hand or right-hand polarization, to amplify the signal, to filter out-of-band signals;
- **Polarisation switching elements**: used to detect a 22kHz tone and allow polarisation switching;
- **Power supply section**;
- **RX circuit switch off block**: used to switch off the RX section while transmitting.

The 22 KHz switching policy has been implemented to stabilize the power dissipation in both right-hand and left-hand configurations; this implementation reveals to be more efficient compared to a voltage level policy implemented in previous RX antennas [8]. In detail the presence of a 22 kHz tone signal will switch the RX/TX elements to LHCP, while the RHCP signal is obtained without tone.

The RX circuit switch off block has been implemented to be compliant with the requirement to switch off the RX element while transmitting TX signals. This requirement has been introduced during the project because the operators (i.e. Solaris Mobile, Inmarsat) and the Agency itself have relaxed the requirement to have simultaneous RX and TX signals, as automotive requirement. In fact, the TX signals will be short asynchronous messages transmitted few times a day. Automotive applications will use SS1 and SS2 messages normally sent via a “Store and Forward” mechanism allowing the transmission of few tens of short messages per day per user (within a population of terminal that can reach millions of units per spotbeam). The duration of the messages is 240ms: during this slot the lost of communication in the RX channel will not significantly affect the quality of the received signals.

A special band pass filter has been designed in order to decrease the interference of adjacent UMTS signals in the RX S-band one. The filter has been industrialized and integrated inside the RX section of the final product.

For the TX section the following elements have been implemented:

- **RF Front-End**;
- **Polarization command**;
- **Power supply command**;
- **RF to DC block**.
The RF Front-End has been designed in order to be compliant with the requirement of the project. Moreover, the outcomes and recommendation related to DENISE project [11] have been taken into account in order to be compliant with the various automotive terminal classes. The RF to DC block has been implemented in order to “probe” the TX signals returning as output a DC signal proportional to the main signal. This DC signal will be available to the user terminal.

As a result of the design and subsequent industrialisation of it, Figure 2 shows the antenna with its shark-fin form factor.

![Figure 2 - COSTARS antenna.](image)

3. INDUSTRIALIZATION DESIGN PROCESS

The industrialization process designed during the project put in action lessons learned from years of production experience of automotive antennas and the concept to automatic assembly of PCB (Printed Circuit Board), cables, zamak base and cover and testing activities. The introduction of a relevant automation in the production process has the following benefits:

- Reproducibility and uniformity of assembly;
- Reproducibility and uniformity testing (anechoic test chamber tests);
- Reduces assembly time;
- More effective and timely controls;
- Waste reduction and quality increase for the antenna.

According to the main elements in automotive shark-fin antennas, the usual assembly procedure requires the cables to be soldered to the PCB, which will be screwed to the zamak base; finally the cover will be screwed to the pre-mounted part and the antenna tested.

In order to assemble the product with the improved process as described before, some operations have been designed to be done with the aid of an automatic production line or stations by moving a pallet where the pre-mounted part is fixed. The complete production process is composed by the following operations, where (M) stands for ‘Manual operation’ and (A) stands for ‘Automatic operation’:

1. (M) Load the zamak base and the antenna cover parts;
2. (M) Load the PCB and the cables parts;
3. (M) Insert and sold cables to PCB
4. (M) Load zamak base with PCB and cables and cover to the pallet
5. (A) Fix the PCB to the zamak base
6. (A) Fix the cover to the zamak base
7. (A) Test the antenna
8. (M) Release the antenna
9. (M) Separate any not compliant product for further activities

So, the line has two manual stations:
- Manual station for parts loading, used to support operations 1, 2, 3 and 4
- Manual station for antenna release, used to support operations 8 and 9

During each automatic operation of the procedure the parts are transported in a pallet, which is a base support designed to accept the mentioned assemblies. Moreover, the same pallet is designed in order to be used for both antennas:

- RX-only antenna
- RX/TX antenna

The pallet will be moved from the manual and automatic stations using an anthropomorphic robot, as further detailed. The following figure details the production line used to produce the antenna.
The line consists of a protected area where automatic operations (stations 3, 4 and 5, and robot 6) will be performed, while manual activities (stations 1, 2) will be performed outside that area.

Here a short description of the elements detailed in Figure 4 are reported:

- Block #1: parts loading;
- Block #2: assembly release;
- Block #3: station used to fix the PCBs to the zamak base;
- Block #4: station used to fix the cover in zamak base;
- Block #5: station used to test the assembly;
- Block #6: robot to move the pallet between the stations.

Inside the protected area three main automatic process operations are then implemented. The anthropomorphous robot manipulates.

4. ANTENNA AND RF FRONT-END MEASUREMENTS

The antenna has been submitted to a full RF test campaign where the below parameters have been characterised:

- RX LNA gain
- RX LNA noise figure
- RX LNA Input P1dB compression point
- RX LNA input third-order intercept point (IIP3)
- RX LNA output VSWR
- RX active antenna G/T
- RX radiation patterns (passive and active)
- TX attenuation
- TX output VSWR
- TX section, RF to DC conversion
- TX radiation patterns

In particular, Section 3.1 will describe the details of G/T measurements while Section 3.2 will discuss RX and TX radiation patterns.

The following Table 1 is reporting the main consolidated requirements agreed with ESA and Satellite Operators.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Consolidated Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forward Link - RX section</strong></td>
<td></td>
</tr>
<tr>
<td>Frequency band - Satellite and Terrestrial</td>
<td>SAT and Terrestrial: 2170-2200 MHz</td>
</tr>
<tr>
<td>forward link</td>
<td></td>
</tr>
<tr>
<td>Satellite Polarization</td>
<td>Dual switchable RHCP or LHCP (dynamically selectable by the terminal)</td>
</tr>
<tr>
<td>Coverage angle</td>
<td>Elevation from 25° to 60°, Azimuth from 0° to 360°</td>
</tr>
<tr>
<td>Terminal G/T</td>
<td>SAT: &gt; -26 dB/K for the whole coverage angle</td>
</tr>
<tr>
<td>Overall antenna gain</td>
<td>&gt; 25 dB</td>
</tr>
<tr>
<td><strong>Return Link - TX section</strong></td>
<td></td>
</tr>
<tr>
<td>Frequency band - satellite and terrestrial</td>
<td>SAT and terrestrial: 1980 to 2010 MHz</td>
</tr>
<tr>
<td>return link</td>
<td></td>
</tr>
<tr>
<td>Satellite Polarization</td>
<td>Dual switchable RHCP or LHCP (Dynamically selectable by the terminal)</td>
</tr>
<tr>
<td>Coverage angle</td>
<td>Elevation from 25° to 60°, Azimuth from 0° to 360°</td>
</tr>
<tr>
<td>Max power supplied to the antenna unit</td>
<td>Up to 1 W Tx power*, 200 mW mean value. (*) The RX section will be switched-off during the transmission.</td>
</tr>
<tr>
<td>Overall antenna gain from input port</td>
<td>SAT: &gt;1 dBi for the coverage angle specified</td>
</tr>
<tr>
<td><strong>Other Parameters</strong></td>
<td></td>
</tr>
<tr>
<td>Fixing, connecting and cabling requirements</td>
<td>FAKRA/SMB connections with 500cm extension low loss cable TBC</td>
</tr>
<tr>
<td>Form factor</td>
<td>The design shall be oriented to the needs of the automotive industry, e.g. GPS antenna or Shark fin</td>
</tr>
<tr>
<td>Mounting</td>
<td>The antenna shall be suitable for installations on cars, vans.</td>
</tr>
</tbody>
</table>

Table 1 – Main consolidated requirements related to the satellite reception and transmission

4.1. G/T measurement

The purpose of the test is to measure the G/T figure of merit performance of the receiving radiating section. The test is performed by using the set-up described in the following Figure 5, where the main elements are:

- the integrated LNA at satellite antenna output with known gain and noise figure;
- the spectrum analyzer with negligible noise figure.
In order to perform the calculation, two separate noise temperature measurements are required, according to the used Y-method [12]. The following Figure 6 and Figure 7 are reporting the measured values for the noise temperature, in open sky and anechoic chamber, according to the setup described in Figure 5.

According to the Y-method and the measured values, a G/T value better than -21 dB/°K at 30° elevation angle has been observed in the whole RX band, which is in line with the requirements.

4.2. Radiation patterns

The antenna has been measured using the Near Field facility available at Ce.R.Ca., the Calearo Research and Development Centre, visible in the following Figure 8.

The following Figure 9 shows the antenna and its setup inside the system. The reference coordinate are specified.

The following figures (Figure 10, Figure 11 and Figure 12) are reporting the RX active gain measurements.
The following figures (Figure 13, Figure 14 and Figure 15) are reporting the TX gain measurements.

The measured values of the antenna are well in line with the simulation results and compliant with the consolidated requirements listed in Table 1.
5. CONCLUSIONS
The present paper has described the main activities, measurements and tests carried out by Calearo in the frame of the COSTARS project.
The antennas are compliant with the requirements provided by ESA and Satellite operators.
Moreover, due to the automotive constrains, all phases of the project have been managed according to the standard automotive requirements: ISO 9001:2008 - Quality management systems and ISO TS 16949:2009 - Quality management systems for automotive production, in order to provide a "ready-to-the-market" solution.
The novelty of the antennas here described is the possibility to combine the forward link based on DVB-SH standard with the return link based on S-MIM standard, enabling interactive services and contents to the automotive market. Calearo has recently implemented additional functionalities in the same antenna, providing a full S-band RX and TX antenna with the integration of Telephone and GPS/Galileo functionalities.

The described antennas are used in Field tests confirming and validating the product, both for RX and TX sections Calearo is involved in projects and joint trials with OEM customers interested in the technology. Moreover, Calearo is exploring other markets where S-Band seems to be attractive, like M2M, Maritime, and Communications for Special Vehicles.

6. ACKNOWLEDGMENT
Calearo is thankful to the European Space Agency and its staff for the support in the project, as well as the Italian Space Agency, ASI.
Moreover, we thank the staff of the Calearo Research and Development Centre, Ce.R.Ca., for their professional support delivered in all phases of the project.

7. REFERENCES
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