MULT-SYSTEM AUTOMOTIVE ANTENNA FOR MOBILE SATELLITE COMMUNICATIONS APPLICATIONS

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ABSTRACT

This paper presents two multi-system antennas designed for automotive mobile satellite communication applications. The antennas are optimized for the new European S-band mobile satellite systems and in addition they include also the capabilities for GPS and GSM/UMTS bands. The first model implements an S-band Receive-Only radiating element for broadcasting applications while the second one contains also an S-band transmit element allowing interactive services via satellite. The achieved structures can be easily installed on cars or integrated in the plastic structures of the vehicles. The details of the design of the antennas and a summary of their performances are described.

1. INTRODUCTION

The commercial application of Mobile Satellite Systems is continuously growing for different type of services. Typical applications include digital audio broadcast, mobile office, goods tracking and M2M communications. In different regions of the world portions of the S-band spectrum have been allocated for MSS and in particular for hybrid systems combining a concurrent use of a space segment and Complementary Ground Components (CGC) to guarantee at the same time wide area coverage and the continuity of service also in urban and shadowed areas.

Also in Europe a frequency band has been assigned to MSS to support pan-European services. Additional applications like digital television broadcast, transport monitoring and management, safety and emergency communications, automatic tolling and dangerous goods tracking are targeted. The satellite segment will ensure these services across the entire European territory without issues of coverage.

The European S-band MSS spectrum comprises two bands of 30 MHz: 1980-2010 MHz for the transmit (Tx), i.e. the uplink from the user terminals, and 2170-2200 MHz for the receive (Rx) band. To facilitate the application of this band in mobile devices the frequencies have been placed adjacent to the UMTS spectrum (see Fig.1). Two exploitation licenses of 15+15 MHz each have been awarded respectively to Solaris Mobile and Inmarsat.

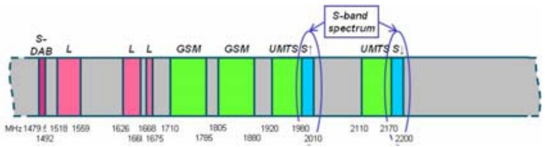


Figure 1. European S-BAND MSS Spectrum

For the successful commercial deployment of services in this new band there is a need of low-cost hardware for different types of mobile user terminals and in particular for the automobile market. Antenna performances and installation are very critical for MSS and require dedicated solutions. Ensuring the satellite link with a geostationary satellite from all over Europe requires antennas capable to cover any azimuth angle and with the maximum of gain at medium-low elevation angles. Moreover, the application to the automotive market demands low-cost, small size, ease of installation and an aesthetic integration in the design of the vehicles. The advent of Satellite Digital Audio Radio System (SDARS) systems in USA has already generated several antenna models suitable for MSS [1], however the European S-band has even more challenging requirements due to the wider coverage and the need for bi-directional links.

In the frame of the S-band initiative, the European Space Agency (ESA) is actively supporting the development of user terminals. In particular ESA has co-funded the STREAM project [2] targeting the development of a low-cost antennas for the automotive market. Thanks to this activity two antennas have been developed, one with a satellite Rx-only element for broadcasting services and one with Tx/Rx capabilities for interactive services. The design and the results of these two antennas are presented hereafter.

2. S-BAND RX-ONLY ANTENNA

The S-band Rx-only antenna (JMO1-R) provides the front-end functions for 3 systems: S-band downlink, positioning and navigation and terrestrial mobile communications. It is composed of three different radiating elements which provide omnidirectional coverage for the abovementioned services (see Fig.2). The annular patch antenna covers the S-band receive band, the ceramic patch is tuned for the GPS/Galileo L1 frequency and the vertical monopole serves the GSM/UMTS bands. The radiating elements are tightly integrated to minimize the size of the antenna. The final dimensions of the structure including the radome are 140x110x55 mm.

Figure 2. JMO1-R: RX-ONLY Antenna Design

The S-band Rx antenna consists of an annular patch excited at a high order mode (see Fig.3). This mode allows the generation a conical beam pattern, as described in 0, and to obtain a very good coverage of low and medium elevation angles. This pattern shape is optimized to provide good gain performances for the satellite link, but guarantees a good coverage also for the signal arriving from the CGCs. The element is dual circularly polarized to cope with the diversity applied in the different satellite beams and a switch circuit selects the polarization depending on the voltage signal provided by the satellite receiver. The active RF circuit integrated in the antenna includes two stages of amplification and filtering to minimize the interferences from other systems and in particular from the adjacent UMTS band.

Figure 3. Detail of the RX Annular Patch Antenna

The GPS-L1 band is covered by a commercial ceramic patch antenna **[4]** integrated nearby the annular patch as shown in Fig.2. High permittivity ceramic patches normally present low radiating efficiency, but the robustness of the GPS signal and the limited precision required for commercial user terminals do not require stringent gain specifications. On the other hand they provide a wide omnidirectional pattern and they are very low-cost and compact, which are the most critical parameters for the integration in the automotive market.

PARAMETER	SPECIFICATION
S-Band Annular Patch	
RX Frequency band	2170 – 2200 MHz
Polarization	Dual circular RHCP and LHCP with polarization switch. Vertical at horizon for reception of terrestrial CGC
G/T	> -19 dB/K @ 25° < elevation < 70° > -20 dB/K @ 20° < elevation < 25° > -22 dB/K @ 15° < elevation < 70°
Cross Polarization Discrimination	> 10 dB @ 25° < elevation < 70° > 7 dB @ 20° < elevation < 25° > 5 dB @ 15° < elevation < 70°
Elevation coverage	20° < α < 70°
Azimuth coverage	0° < φ < 360°
Noise Figure	< 0.8 dB at 25°C
Power Supply	+6 - 7V (RHCP) +8 - 9V (LHCP)
GPS ceramic patch antenna	
Frequency band	1575 – 1585 MHz
Polarization	RHCP
Gain	2 dBic typ at Zenith
Axial Ratio	3 dB typ
VSWR	<1.5:1
GSM/UMTS dual-band monopole antenna	
GSM band	890 – 960 MHz
UMTS band	1700 – 2170 MHz
Polarization	Vertical
Gain	4 dBic
VSWR	<3:1

Table 1. JMO1-R Antenna Specifications

A dual-band monopole antenna **[5]** has been designed to ensure the coverage of both GSM (890 – 960 MHz) and UMTS (1700 – 2170 MHz) bands. The monopole is placed in the empty space in the centre of the patch antenna, which corresponds also to the null of radiation of the conical beam pattern generated by the patch (see Fig.4). This minimizes the coupling between the two elements and the mutual interferences. A small vertical fin has been shaped in the radome to accommodate the monopole antenna, while keeping the radome aesthetics.

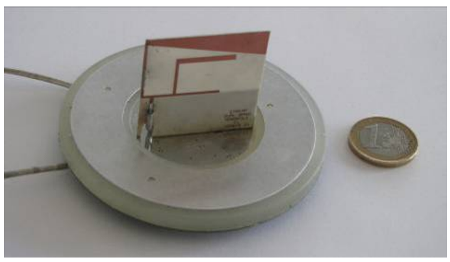


Figure 4. GSM/UMTS Dual-Band Monopole breadboard

The summary of the main specifications of the JMO1-R antenna is listed in Table 1Table 1.

3. S-BAND TX/RX ANTENNA

The S-band Tx/Rx antenna (JMO1-TR) adds to the bands covered by the JMO1-R, the capability to transmit signals in the S-band satellite and thus to establish a bidirectional link between the satellite (and CGCs) and the mobile terminal. The bidirectional link enables a large set of interactive services that can be offered continuously and homogeneously all over Europe.

A sketch of this multi-system antenna is presented in Fig.5. It consists of four different radiating elements which provide omnidirectional coverage for the diverse systems. The elements have been placed in order to minimize interferences between the different systems while looking for the smallest possible size. The S-band Rx element, the GPS and the monopole are the same radiating elements used in the JMO1-R antenna. The S-band Tx element is based on a Crossed-L dipole and has been designed to cover the up-link of the S-band spectrum. The radiating element consists of four symmetrically-arranged L-shaped monopoles over a round metallic ground plane. The four monopoles are excited equally in amplitude and with relatives phases 0°, 90°, 180° and 270°, respectively, in order to obtain the dual polarization. A picture of the realised element is shown in Fig. 6 and more details about the element design can be found in [6].

Figure 5. JMO1-TR: TX-RX Antenna

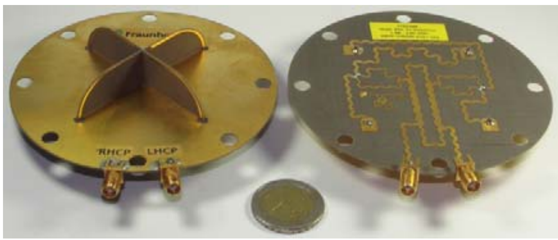


Figure 6. TX Crossed-L Dipole

Thanks to the low-loss design of the crossed L-dipole, the overall realised gain of the antenna is sufficient to fulfil the system requirements and there is no need to integrate a transmit amplifier. As for the S-band Rx element, the element is dual circularly polarised and a switching circuit (driven by the transceiver) is implemented at the element input for the selection of the polarization. The final dimensions of the structure are 270x140x39 mm. A summary of the main specifications of the JMO1-TR antenna is listed in Table 2.

PARAMETER	SPECIFICATION
S-Band antennas	
Tx Frequency band	1980 – 2010 MHz
Rx Frequency band	2170 – 2200 MHz
Polarization	Dual circular RHCP and LHCP with polarization switch Vertical at horizon for reception of terrestrial CGC
Tx Gain (without cable)	> +3.5 dBic @ 80° < elevation < 90° > +2.0 dBic @ 25° < elevation < 80° > +1.5 dBic @ 15° < elevation < 25°
Tx Cross Polarization Discrimination	> 10 dB @ 40° < elevation < 90° > 7 dB @ 30° < elevation < 40° > 5 dB @ 20° < elevation < 30°
G/T	> -20 dB/K @ 25° < elevation < 70° > -21 dB/K @ 20° < elevation < 25° > -22 dB/K @ 15° < elevation < 70°
Rx Cross Polarization Discrimination	> 10 dB @ 25° < elevation < 70° > 7 dB @ 20° < elevation < 25° > 5 dB @ 15° < elevation < 70°
Elevation coverage	20° < α < 70°
Azimuth coverage	0° < φ < 360°
Noise Figure	< 0.8 dB at 25°C
Power Supply	+6 V (RHCP) +9 V (LHCP)
GPS & GSM/UMTS antennas, see 0	

Table 2. TX-RX Antenna Specifications

4. MEASUREMENT RESULTS

All the radiating elements, but the commercial GPS patch, of the two designs have been characterised, independently and combined (see Fig.7) in order to take into account coupling effects and ensure the good performances of the complete antennas.

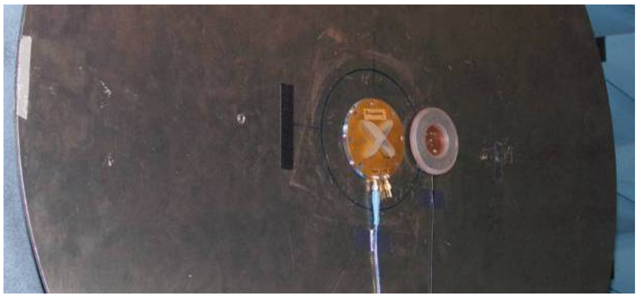


Figure 7. Measurements of S-Band RX and TX antennas in anechoic chamber

4.1 RX Annular patch antenna

Fig.8 presents the Return-Losses and the isolation between ports of the passive version of the annular patch antenna. The measured return loss of the annular patch presents a level below -20 dB in the band of interest (2.17 – 2.20 GHz). The wideband behaviour is due to the presence of the 90° combiner applied to generate the circular polarisation. For the same reason, the isolation between the two ports is actually representative of the return loss of the radiating element which remains always below -10 dB.

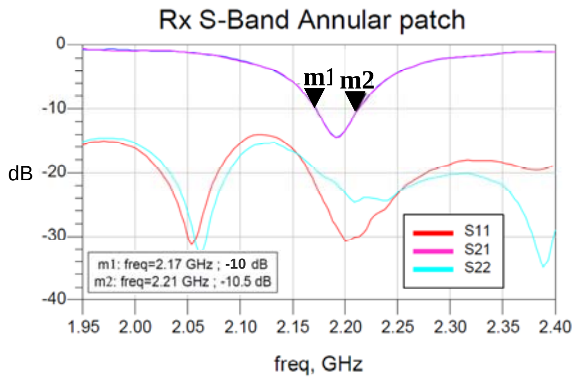


Figure 8. Passive Annular Patch antenna: Network parameters

The radiation patterns of the antennas where measured at the Fraunhofer Institute in Erlangen. An example of elevation and azimuth cuts of the radiation pattern of the annular patch antenna are shown in Fig. 9. The antenna presents a conical beam pattern with a broad lobe in elevation and an omni-directional pattern in azimuth. The average active gain is 25 dBic, including about 4dB of cable losses, thanks to the embedded amplifiers. High gain levels are achieved at low elevation angles for the both circular and linear polarizations. Cross-polar discrimination is higher than 10 dB in the typical elevation range of a GEO satellite in Europe (25° to 70° from horizon). The presence of the ripples in the measured patterns is mainly due to the scattering effects generated by the finite size (1 meter) of the ground plane used for the measurement. While this plane is typically used as reference dimension to evaluate automotive antennas, the diameter of 1 meter is close to a multiple of half-wavelength at the frequencies of interest and generates such scattering effects.

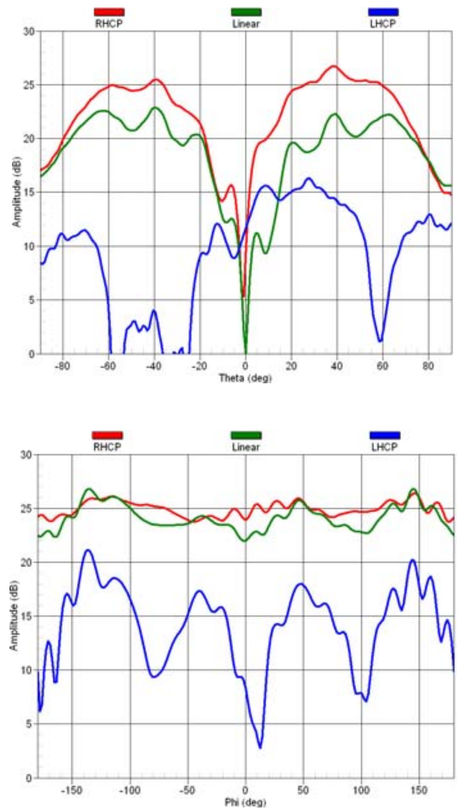


Figure 9. Active Annular Patch antenna: Radiation Pattern at 2.185 GHz for RHCP – Elevation (up) and Azimuth at 25° of elevation (down) cuts

4.2 TX Crossed-L Dipole

The measured return loss and polarisation isolation of the crossed-L element is shown in Fig.10. The element is correctly tuned at the Tx frequency band (1.98-2.01 GHz). Both ports, LHCP and RHCP, are well matched with a VSWR of <1.5:1 for both polarisations (S11 and S22). The isolation between the ports is better than 15 dB within the whole band of interest. An example of the elevation and azimuth cuts of the radiation pattern are shown in Fig.11.The antenna exhibits a maximum gain of +5 dBic at zenith for circular polarization and a value of -4 dBi for the vertical polarization at horizon. The cross-polarization discrimination for the crossed-L dipole achieves levels of 10 dB between 40° and 90°, while it decreases to 5 dB for low elevation angles.

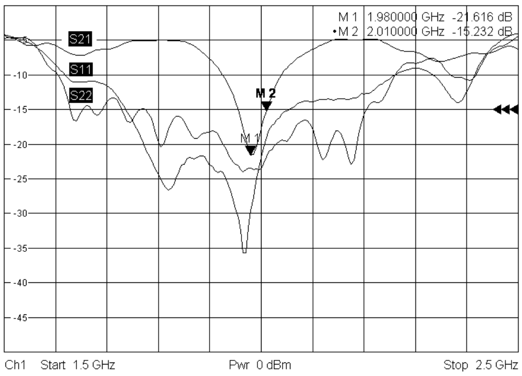


Figure 10. Crossed-L dipole: Isolation

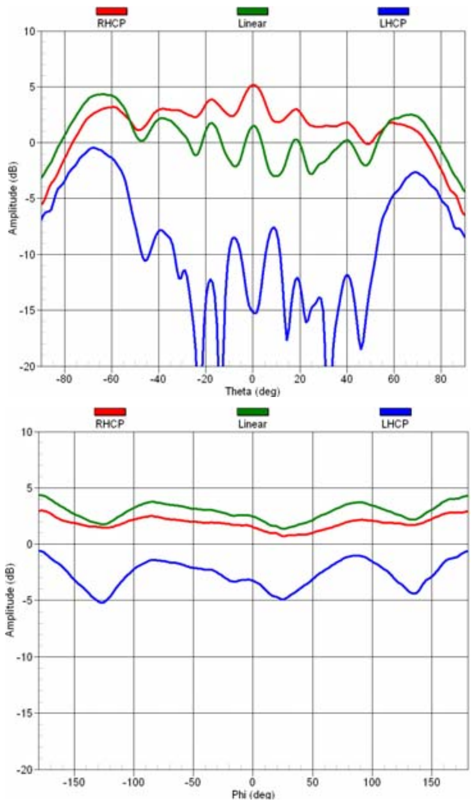


Figure 11. Crossed-L Dipole: Radiation Pattern at 1.9 GHz for RHCP – Elevation (up) and Azimuth at 25° of elevation (down) cuts

4.3 Dual-Band Monopole Antenna

The return loss of the dual-band monopole antenna exhibits two resonances to cover the GSM and UMTS frequency bands. The measured return loss of the element is shown in Fig.12. An example of the radiation pattern for the two bands is presented in Fig. 13.We can observe that at UMTS band the pattern presents some distortions due to the close integration with the S-band element.

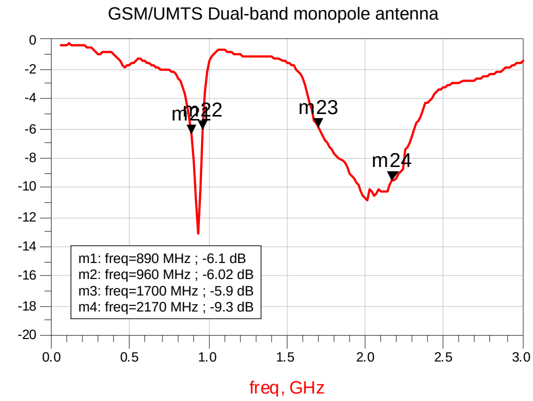
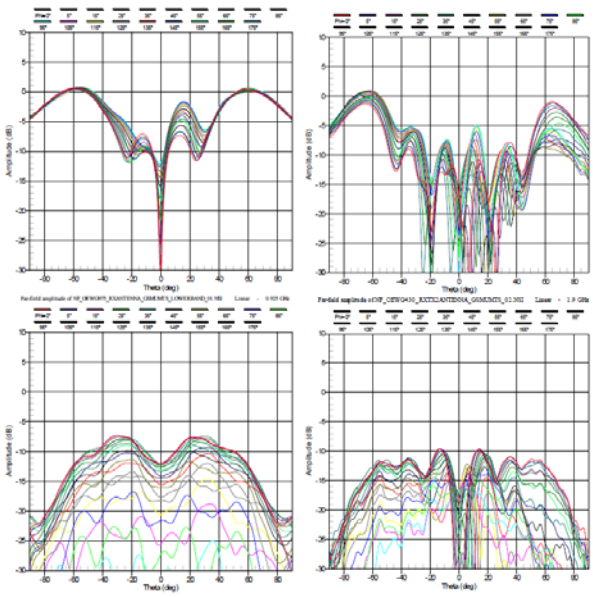


Figure 12. Dual-Band monopole antenna: Return-Losses

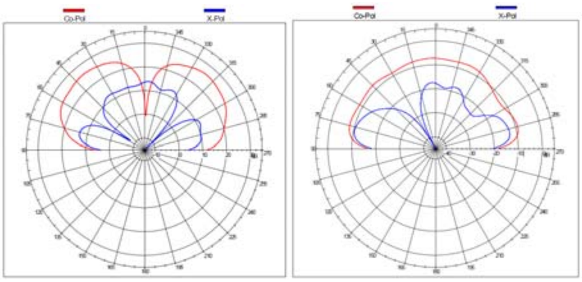


(a) (b)

Figure 13. Dual-band monopole antenna: Radiation patterns (a) GSM band; (b) UMTS band

To evaluate the distortions of the directivity caused by the arbitrary shape of a car roof, the antennas have also been tested on an external automotive spherical nearfield test facility. These measurements were performed at the ATC test range located in Itzehoe, Germany (see Fig.14). An example of the measured radiation patterns for the S-band Rx and Tx elements is shown in Fig. 15. The results have been smoothed with the MARS algorithm to remove the scattering generated by the finite metallic rotating platform. We can observe that while the patterns show some distortions, the behaviour of the antenna remains acceptable for the targeted applications.

Figure 14. Antenna measurement performed at the ATC test range located in Itzehoe, Germany



(a) *(b)*

Figure 15. Example of measured radiation patterns measured at the ATC range (a) RX annular ring antenna; (b) TX crossed-L dipole

5. CONCLUSIONS

The design of two antenna solutions covering the new S-band spectrum allocated in Europe has been proposed. The S-band Tx/Rx antenna can support a bidirectional satellite link using two independent radiating elements. The antennas provide full azimuth coverage and broad elevation beam to ensure operation over the entire European region. GPS and GSM/UMTS systems are also integrated in the antenna allowing to cover the three systems with a single antenna unit. An S-band Rx-Only design has been also implemented to provide a lower cost and smaller size solution for the market of multimedia broadcast to mobile. The antenna does not include the Tx crossed-L dipole and the other elements have been differently arranged in order to minimize the size.

The antennas are suitable for mounting on vehicles and have been already tested in laboratory and in field trials using the Solaris Mobile satellite system.

6. ACKNOWLEDGEMENT

The presented results have been obtained also thanks to the support of the European Space Agency and of the Swiss Space Office through the funding of the STREAM project (ESA contract N. 23088).

7. REFERENCES

[1] A. Petros, I. Zafar, S. Licul, "*Reviewing SDARS antenna requirements*" Microwave & RF, pp. 51–62, Sep. 2003.

[2] "*STREAM - Low Cost S-band Transmit/REceive/ Antenna for Mobile vehicular applications*", European Space Agency contract N. 23088, http://telecom.esa.int/telecom/www/object/index.cfm?fobjectid=30496

[3] John Huang, "*Circularly Polarized Conical Patterns from Circular Microstrip Antennas*" IEEE Trans. on Antennas and Propagation, Vol. AP-32, No. 9, pp. 991–994, September 1984.

[4] SANAV, San José Technology, Inc. www.sanav.com

[5] Ju-Hung Chen, Chieh-Jui Ho, Chung-Hou Wu, Shih-Yuan Chen, and Powen Hsu, "*Dual-Band Planar Monopole Antenna for MultiBand Mobile Systems*" IEEE Antennas and Wireless Propagation Letters, Vol. 7, pp. 769–772, 2008.

[6] Alexander E. Popugaev, Rainer Wansch, "*Low Profile Automotive Antennas for Digital Broadcastin,*" Proceedings, 9th Workshop Digital Broadcasting, Erlangen, Sep. 18th 2008, Germany.