Experimental Demonstration of Test Cap Design for Space Transponder Applications

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***Abstract*—Antenna test caps allow the testing of transmit and receive functionality of complete end-to-end radio frequency (RF) space systems in flight configuration outside anechoic environment. The test caps are made of two off-centered cylinders. The upper cylinder contains a probe, corresponding port, as well as a tuning screw. The lower cylinder contains absorbing material, the antenna under test. A full design and its experimental validation are demonstrated for a Martian X-band radio science payload.**

***Index Terms*—Electromagnetic interference (EMI), monopole antenna, space application, test cap, X-band.**

I. Introduction

ELECTROMAGNETIC interference (EMI) reduces performance in sensitive electronic systems because it affects the signal strength and clarity. In particular, EMI is a specific issue when testing on the ground antenna systems devoted to space-based communication or sensing. An example of such system is a transponder. The laboratory testing of such system entails the replacement of free-space propagation by guided propagation, through coaxial transmission lines, for instance, and the proper connection of the antennas to the transmission lines. In practice, this means testing the whole system on a table or on the final platform, while placing the TX (Transmitter) and RX (Receiver) antennas in shielded boxes that contains absorbers, while making sure that the connections between the antennas and rest of the system do not change (e.g., same cables and connectors as in the final system), as illustrated in Fig. 1.

Such devices are named "caps" or "hats," but should not be mistaken with Wheeler caps [1], [2], which correspond to conducting enclosures without absorbing material, designed to measure the antenna efficiency.

The following three criteria will need to be satisfied by the test cap.

1) Enclosing the antenna properly, so no huge radiation leakage will occur. This leakage could affect the neighboring devices.
2) Preserving a good antenna matching. At the same time, the level of attenuation through the box should be controlled within a few dB.

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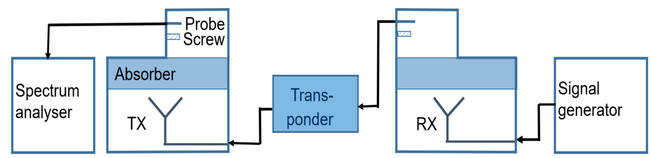

Fig. 1. Test cap principle.

3) Avoiding disturbance of the whole system in terms of mechanical arrangement (for testing on final platform).

Such test caps are not described in the literature, such that this letter presents for the first time the test cap principle, specifications, and descriptions. Commercial test caps are produced for instance by Haigh-Farr [3] and RUAG Space [4], but very few details are provided.

The rest of this letter is organized as follows. Section II will present the test cap design for the transmitter and receiver. Section III will provide the test cap measurement validation, and finally, Section IV concludes this letter.

II. Proposed Test Cap Arrangement

In the rest of this letter, the design and experimental verification of test caps will be studied in the framework of the Lander Radioscience (LaRa) project [5]. LaRa is a Belgian radio science experiment that will be placed onboard the Kazachok surface platform, planned to be launched in 2022 toward Mars. LaRa aims at a better knowledge of the internal structure of the red planet through precise measurements of the planet's rotation and orientation by monitoring the two-ways Doppler shift [5]. The LaRa transponder electronics box will upconvert the receiving signal from the DSN ground station by the LaRa receiving antennas at 7.174 GHz and transmit it directly back to Earth with one of the two LaRa transmit antennas at 8.428 GHz. A dedicated autocompatibility test is needed to test the compatibility of LaRa with the rest of the surface platform. The LaRa antennas' structure and dimensions are presented in detail in [6]. Special test caps are needed to fit the LaRa antenna structure, with a mechanical interface suitable for mounting on the surface platform. The single channel hats presented in [3] do not have the proper dimensions to enclose the LaRa antennas. Also, their configurations differ from the mechanical arrangement configuration of the LaRa space platform. The test caps proposed in [4] fit the X-band helix and waveguide pipe antennas, and they are not suitable for LaRa antennas. The test cap considered here is made up of two parts: one containing the test probe, which

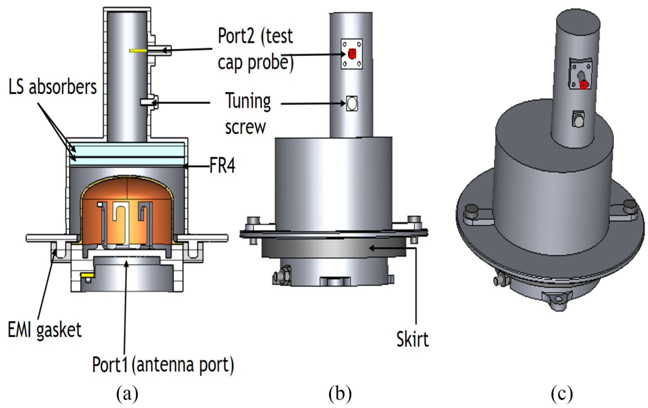

Fig. 2. (a) Cut-out view of the TX test cap with the antenna. (b) Front view of TX test cap showing the test cap port and tuning screw positions. (c) Perspective view of the test cap assembly with the antenna.

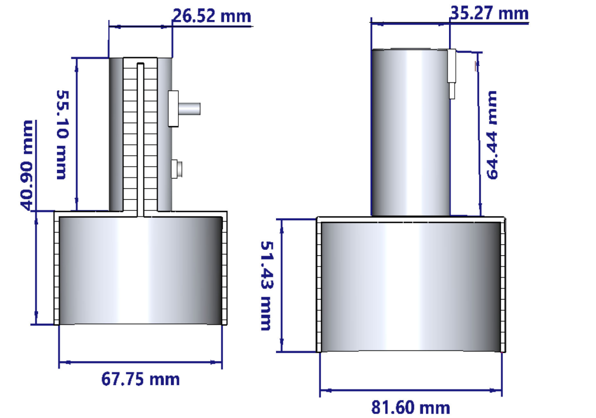

Fig. 3. 2-D cut-out view of the upper part of test cap dimensions for (a) TX and (b) RX.

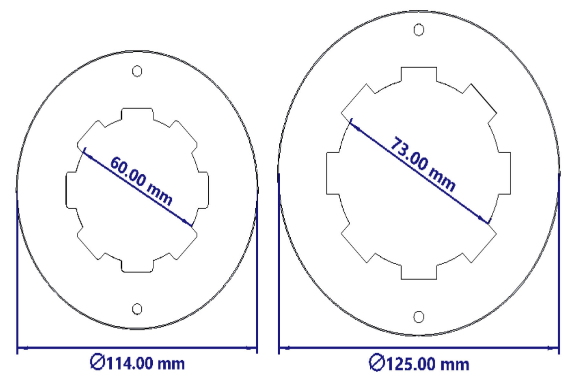

Fig. 4. Lower part of test cap dimensions for (a) TX and (b) RX.

can be viewed as a kind of "internal antenna," and the other containing the antenna of the system to be tested, as shown in Fig. 2(c). The first part needs to be decentered w.r.t. to the second part in order to provide a good coupling between the two parts. Indeed, if the upper part is centered, given the monopolar aspect of the LaRa antenna, the transmission from the top will be extremely small. One may argue that low coupling is looked for, but a centered arrangement would produce a very low coupling with a level strongly dependent on fabrication tolerance. Hence, the part with the test probe is off-centered. It needs to be wide enough to allow the propagation of the first mode TE10 toward the second part. The transition between the two parts happens through an absorber, to conform to the end-to-end attenuation prescribed by the team performing the test of the whole system (30 dB attenuation for the system considered here). The test cap probe being surrounded by a metallic cylinder, it has a relatively narrow bandwidth, so it is challenging to obtain a good matching at the frequency of interest. The metallic screw provides an important degree of freedom to facilitate the test cap matching; it can be added near the test cap probe.

The LaRa antennas consist of parasitic elements above a ground plane placed around a centrally fed monopole. They can be seen in the "bulb-shaped" radome, inside the test cap, in Fig. 2(a).

The assembly of the TX test cap with the LaRa antennas is shown in Fig. 2. The test cap upper part (TCUP) consists of two connected metallic cylinders of different diameters, two absorbing layers, an SMA connector, a metallic tuning screw, and an FR4 layer. Fig. 3 shows the TCUP main dimensions for TX and RX antennas. The lower metallic cylinder covers the TX antenna radome. The cylinder radius is chosen to be as close as possible to the antenna choke-ring radius. The upper cylinder is optimized in height and diameter to have good matching at the test cap port, which is independent from the antenna matching, thanks to the absorbers. The SMA connector is used as a test cap probe. The length of the SMA connector is set to 10 mm, and the tuning screw to 3.6 mm. The absorber Eccosorb LS-26 from Emerson & Cuming Microwave is added inside the metallic cylinder to limit the impact of the enclosure, and keep the good antenna impedance matching. The relative dielectric permittivity is 9.6, and the loss tangent is 1.14. The absorbers need to be sealed on the bottomside to prevent absorber dust falling on the FM radome, hence assuring stringent contamination requirements. We use an FR4 layer to cover the absorbers inside the test cap to ensure that no dust will fall down on the antenna flight model radomes. A thin FR4 layer of 0.8 mm is chosen among other materials due to its well-known procedure for bioburden reduction and well-known losses.

The TCLO consists of a metallic ring with extended lips to sit on the antenna radome washer (see Fig. 4), a hollow metallic cylinder (the "skirt"), and a conductive gasket (see Fig. 2). The latter has two roles, first decreasing the radiation leakage and, thanks to its elasticity, enhancing the stability of the TCLO through slight compression against the LaRa antenna housing.

For the design, the frequency domain solver of CST Microwave Studio [7] has been used. Fig. 5 shows the simulated scattering parameters. An excellent matching of the antenna S_{11} and test cap S_{22} ports is achieved. At the frequency of interest, 8.428 GHz, S_{11} and S_{22} are close to –15 dB. The test caps introduce a loss of the order of 30 dB, mainly through the use of absorbing material. This loss is accounted for in the global system verification. Fig. 6 shows the advantage of adding the metallic screw nearby the test cap monopole port. Indeed, by increasing/decreasing its length, it is possible to tune the

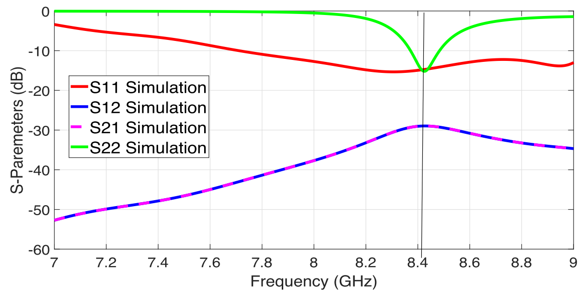

Fig. 5. TX antenna and test cap scattering parameters.

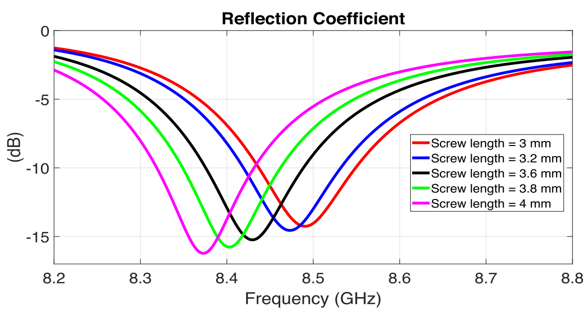

Fig. 6. Test cap port tuning with metallic screw.

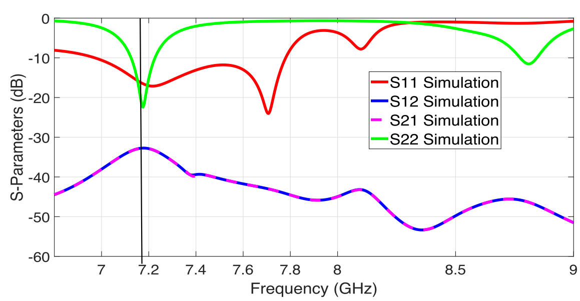

Fig. 7. RX antenna and test cap scattering parameters.

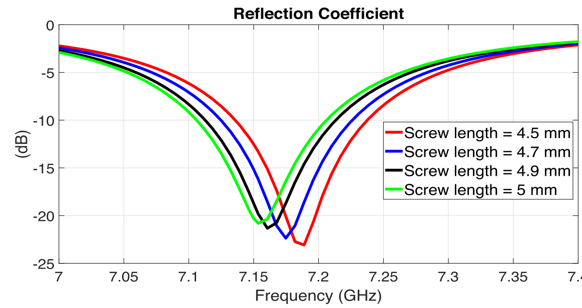

Fig. 8. RX test cap port tuning with metallic screw.

(a) (b) (c) (d)

Fig. 9. TX TCUP prototype. (a) Top view. (b) Bottom view. (c) Bottom view after adding the absorbers. (d) Bottom view after adding FR4 layer.

(a) (b) (c) (d)

Fig. 10. TX TCLO prototype. (a) Top view. (b) Bottom view. (c) Top view after assembling with TX antenna. (d) Bottom view after assembling with TX antenna.

reflection coefficient at the proper frequency. An analogy can be established with the reflector element in Yagi–Uda antennas. This configuration creates a maximum of radiation away from the parasitic element and also impacts its impedance. The optimized length of the screw is 3.6 mm, and its diameter is 3 mm.

The RX test cap is similar in design to the TX test cap for the upper and lower parts. The dimensions are different, given the different sizes of the antennas and the need for the test caps to operate at different central frequencies. Fig. 7 shows an excellent matching of the test cap port while the matching at the RX antenna port is below -14 dB. At the frequency of interest, 7.174 GHz, S_{11} is -16.44 dB for the RX antenna while S_{22} is -22.2 dB for the test cap port.

Fig. 8 shows the advantage of adding the metallic screw near the test cap port to tune the reflection coefficient at the required frequency. The optimized length of the screw is 4.7 mm for an M3 screw.

III. Experimental Validation of the Test Caps

This section describes the manufacturing of the two test cap parts, integration steps, and measurement results of the TX and RX test caps.

A. *Test Cap Manufacturing and Integration*

The TX and RX upper and lower parts of the test caps are fabricated from aluminum. Fig. 9 shows the pictures of the TX TCUP prototype. The TCUP integration starts from adding the SMA connector and tuning screw Fig. 9(a), then adding the two absorber layers Fig. 9(c). The absorbers are closed at their bottom by the FR4 layer Fig. 9(d).

Fig. 10 shows the pictures of TX TCLO prototype. The conductive gasket is fixed by using a standard glue, as shown in Fig. 10(b). The TCLO integration with the TX engineering model antenna is illustrated in Fig. 10(c) and (d).

The RX test caps parts have similar structures as the TX parts. Fig. 11 shows the TX1 test cap prior installation on the FM.

B. *Test Cap Measurement Results*

After installation of the test caps on the LaRa antennas, two ports are available: they are labeled "1" and "2" for LaRa antenna and test cap, respectively. All antennas measurements are carried

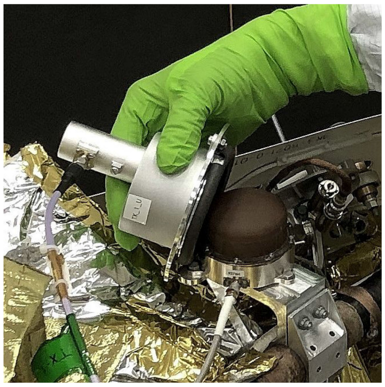

Fig. 11. TX1 test cap prior installation on the antenna FM.

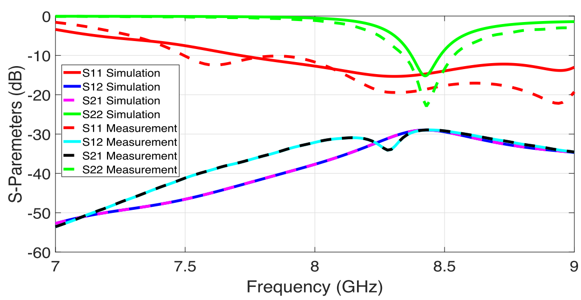

Fig. 12. TX measurement validation versus simulation.

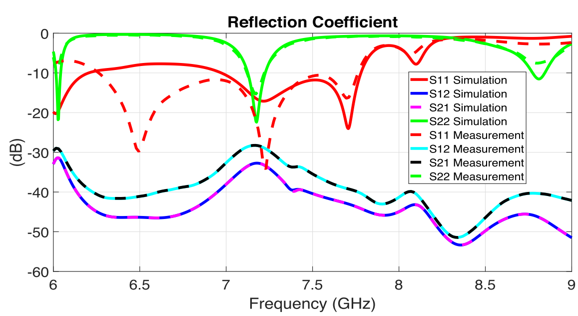

Fig. 13. RX measurement validation versus simulation.

out in the presence of the test caps. Fig. 12 shows very good impedance matching for both the antenna and test cap ports. For the TX antenna port, a bandwidth from 7.5 GHz to more than 9 GHz is observed at a threshold of –10 dB. At the frequency of interest, 8.428 GHz, S_{11} is –18.5 dB for the antenna port and S_{22} is –22.9 dB for the test cap port. For the test cap port, a bandwidth from 8.34 to 8.5 GHz is observed at a threshold of –10 dB.

The measurement results are in excellent accordance with simulation, as shown in Fig. 13. For the RX antenna port, a bandwidth from 6.8 to 7.8 GHz is observed with respect to a –10 dB criterion. For the test cap port, a bandwidth from 7.125 to 7.22 GHz is observed with respect to –10 dB. At the frequency of interest, 7.174 GHz, $S_{11} =$ –21.47 dB for the antenna port and $S_{22} =$ –15.43 dB for the test cap port.

IV. Conclusion

Two TX test caps and one RX test cap have been developed to allow testing of LaRa science payload outside anechoic environment during launch test campaign. Test caps are made of two off-centered cylinders, the upper one containing the probe and tuning screw while the lower one contains absorbing material and the antenna under test. The cylinders are off-centered to allow a good control of transmittance from the probe to the monopole-type antenna. The test cap design, manufacturing, and integration steps are explained and discussed. The measured results of the two manufactured transmitter test caps and one receiver test cap show excellent agreement with simulated results. In particular, the measurement results show that the test caps allow the required antenna matching for the transmitter and receiver.

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