Characterization of coaxial cables and improvement of their performance for automotive applications

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Abstract. The present work aims at defining a methodology of electrical test of the Car antennas (Data cables), while respecting the internal conditions of production and use. This microwave approach makes it possible to analyze the coaxial cables throughout their validation / manufacturing processes in order to detect any anomalies related to their operation and thus to predict the limit values of the efforts beyond which the products are judged to be faulty, which will allow more benefit to improve their quality. This article consists in carrying out the various test methods aimed at knowing the failure modes, a study of the behavior of the transmission line RTK031 which is one of the most efficient coaxial cables as well as the development of a more optimal model at the level of the losses. Of insertions modeling under CST-Studio which makes it possible to extract the limit value VSWR Voltage Standing Wave Ratio from which a reflection is produced. To characterize and validate these transmission lines to achieve optimization and improvement of their performance.

1 Introduction

For several years now, there has been a trend in the automotive and aeronautical sectors to replace hydraulic and pneumatic systems with electrical systems. This choice is guided by transport performance and safety criteria. Indeed, electrical systems not only allow mass savings that translate directly into fuel savings, but also financial savings by simplifying and shortening maintenance operations.

These developments are combined with the continuous development of new comfort and connectivity offers for crews in their mission. This leads to an inevitable increase in the number of connectors and wired connections in the electrical network.

TE Connectivity Automotive strives to provide the best infotainment technology to support high-speed data communication in the automotive industry. Optical, coaxial and shielded electrical physical layers based on data communication are supported by a wide portfolio of automotive quality connector systems. With a thorough understanding of the technical properties and signal integrity requirements and application knowledge, both in the vehicle and in the supply chain, TE Automotive is well positioned to offer the right solution for all current and next generation DATA CABLES systems.

2 Related works

In the current context of increasing numbers of on-board electrical systems, wired networks play an important role, particularly in the automotive and aeronautics industries. Indeed for a car and, as several accidents in recent history have shown, the failure or damage of an electrical wiring can lead to catastrophic damage to equipment, as well as serious hazards to human lives, and the impact of wiring faults on electrical systems that affect the proper functioning of the dedicated application.

The detection and localization of faults as well as the validation analysis of new products have been of major interest for product engineers and researchers in the electrical field for many years. Given the importance of the validation part they have thought of orienting the tests in a more sensitive direction to move to a much more advanced phase which is the global analysis of the cable in the RF domain with a well-structured test procedure and requirements as well.

Cables can be found in all electrical and electronic systems, whether it is a power supply for transporting power or for data transmission.

However, their maintenance is often neglected and no system exists to provide a quick and accurate diagnosis of their condition. With the increase in cable length and number of cables. Faults are generally classified into two categories in terms of severity:

- Free" faults (short circuit or open circuit) which lead to a significant alteration of the reflectometry signal along the line.
- Non-obvious faults" defects (an inhomogeneous or deteriorated dielectric insulator, a damaged metal core, etc.).

Which result in a very small local variation of the physical and electrical characteristics, as a consequence of the discontinuity on the line. Non-frangible faults have been less studied than obvious faults and may be the cause of system malfunctions with serious consequences.

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Coaxial cable is a cable with two conductors of opposite poles separated by insulation. It is used for the transmission of digital or analog signals at high or low frequencies, especially between TV antennas and TV sets. It was developed by the American Herman Affel, who obtained a patent for this invention in 1931.

The cable consists of a central conductor called the core, usually made of copper, which is embedded in a dielectric insulating material. This core is surrounded by a shield that acts as a second conductor. This shield can be a copper braid or aluminum foil. The whole is protected in an insulating sheath. This configuration is designed to ensure that the conductors do not produce and undergo any disturbance to and from the outside. The slightest deterioration of a coaxial cable will affect its operation and performance.

1.1 Traditional technical drawing of the RTK031

As already mentioned in the previous section, TE Connectivity has a variety of cable families, we will focus on one of the cables belonging to the Coax family, RTK031, which is validated and produced only at TE Connectivity Morocco.

The coaxial cable RTK031 is a transmission line used in high frequencies. Its particular shape allows to produce (and to capture) no external net flow. This type of cable is used for the transmission of information (data) from a transmitter to a receiver; it is often used in radio frequency applications because it ensures the interchangeability of RF connector systems. The implementation of the RTK031 to the FAKRA system has been designed to meet or exceed ISO20860-1 (50 Ohms Impedance Radio Frequency Connector System Interface), SAE / USCAR-17 (Performance Specification for Automotive RF Connector Systems), SAE / USCAR-18 (FAKRA SMB RF Additional Connector) and SAE / USCAR-2 (Performance Specification for Automotive Electrical Connector Systems). Data transmission systems consist of a source or transmitter (TX), a load or receiver (RX), and a transmission line (TL) that interconnects the source and the load (see Figure if below). Coaxial transmission lines are the most efficient type of transmission line for analog RF signals.

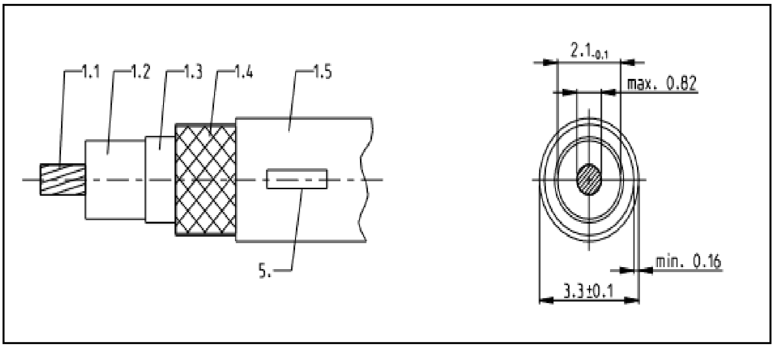

Fig. 1. Traditional technical drawing of the RTK031

1.2 Improved technical drawing of the RTK031

After the analysis of the test results of the RTK031 we found ourselves in a critical phase because we could not validate it, given the non-conforming values of the VSWR throughout the dedicated frequency band, which directly impacts the operation of this cable, so it was necessary to proceed towards improving its performance by varying the main parameters of this product, Since this attenuation has a direct relationship with the dielectric part (insulating part), as well as the sheath was too rigid and difficult to strip too, after several meetings with the Product Engineering team, it was decided to vary these parameters as follows: Dielectric and Sheathing.

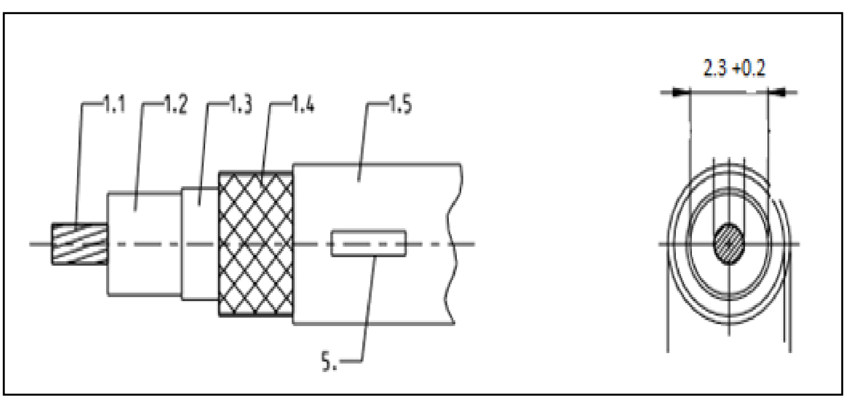

Fig. 2. Improved technical drawing of the RTK031.

Insulators or dielectrics are materials with a very high resistivity: 108 to 1016 Ωm, as they contain very few free electrons. In our case RTK 031 contains a very good insulator it is

Foam Polypropylene so after several discussions with material specialists we decided to add an external layer of the dielectric which will make it more rigid in the stripping process as well as in the crimping process which generates a compression impact as shown in the technical drawing fig 2.

3 Implementation method

3.1 The Optimum power Transfer

A voltage standing wave ratio (VSWR) is measured to quantify transmission line imperfections (RTK031)[1].
In real systems, however, inadequate impedances cause some of the power to be returned to the source (as an echo).
Reflections cause constructive and destructive interference, causing peaks and troughs in the voltage at different times and distances along the line, VSWR measures these voltage variations.
This is the ratio of the highest voltage anywhere on the transmission line to the lowest voltage [2].

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} = \frac{V_{max}}{V_{min}} = \frac{1+|S_{11}|}{1-|S_{11}|} \qquad (1)$$

Our objective in this feature ensures that the cable assembly retains its characteristic impedance to allow optimum power transfer to the receiver. The cable assemblies shall be connected to a network analyser or equivalent, using the type of coaxial cable intended for production. The network analyser must be calibrated for the frequency band of interest. The VSWR peak in the frequency band of interest shall be recorded.
- Requirement:
Initial VSWR cable assemblies shall not exceed 1,5: 1 relative to 50 ohms in the frequency band of interest (500 MHz to 2,5 GHz).

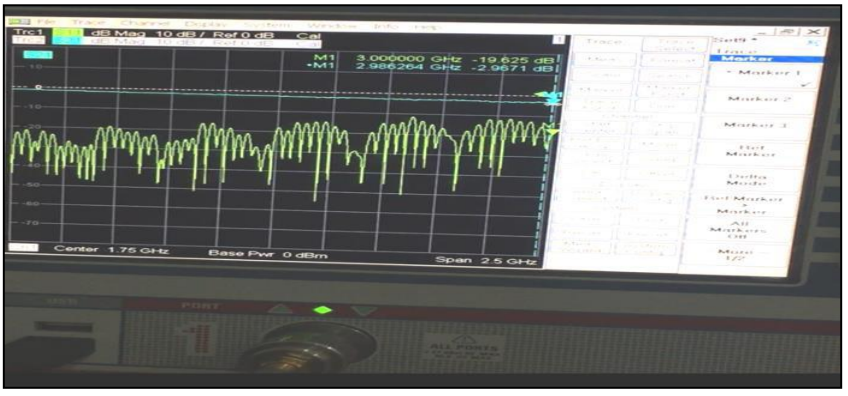

Fig. 3. VSWR before improvement.

3.1 Procedure for improving the performance of the coaxial cable RTK031 :

For the design of the antenna, a resonant frequency and substrate material were selected according to the product specification. Then, using the associated formulas, the dimensions of the antenna were generated through the 3D interfaces of CST-Studio.

Table 1. Conception parameters.

Parameter	Value	Unity	Equipment
Inner conductor	7 thread , 0,82	mm	Cu
Dielectric Core	2.3	mm	PP polypropylene
Foil	0.11	mm	AL + PET
Outdoor Driver	0.16	mm	CU-ETP1
Sheath	3.3	mm	PVC sans plomb
Resonance frequency	2.1	GHz	--

Based on the design specifications, this model was designed using CST MWS 2018 software. The performance of the RTK031 coaxial cable was simulated and the antenna performance parameters were studied. The return loss diagram, the VSWR diagram, is shown in the following figures.

According to the figure below, the return loss of the RTK031 has been established at -3.1842 dB at the resonant frequency (Fr) of 2.43 GHz. At -10 dB, it was found that the lowest frequency (Fl) was 2.384 GHz and the highest frequency (Fh) was 2.4952 GHz. From this figure the fractional bandwidth (FBW) can be calculated as follows [3]:

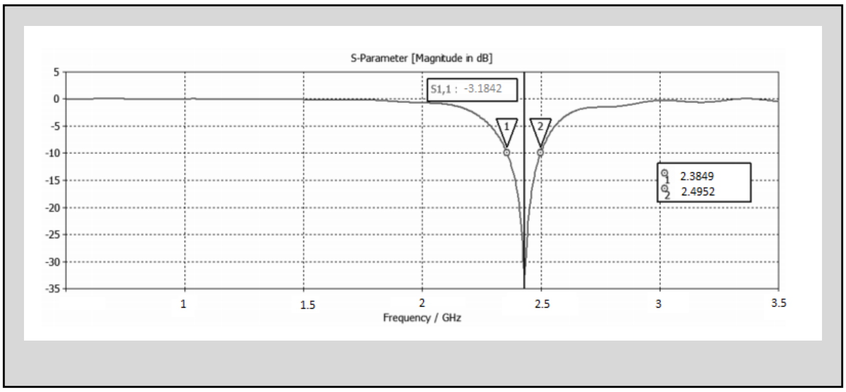

Fig. 4. S11 parametter and bandwidth (FBW).

$$FBW = \frac{Fh - Fl}{Fr} * 100 = \frac{2.4952 - 2.384}{2.43} * 100 = 41.15\% \qquad (2)$$

The figure below shows the VSWR at the resonance frequency which is equal to 1.05 and lowers than 2. This result is sufficient to continue the improvement and validation process of the new RTK031.

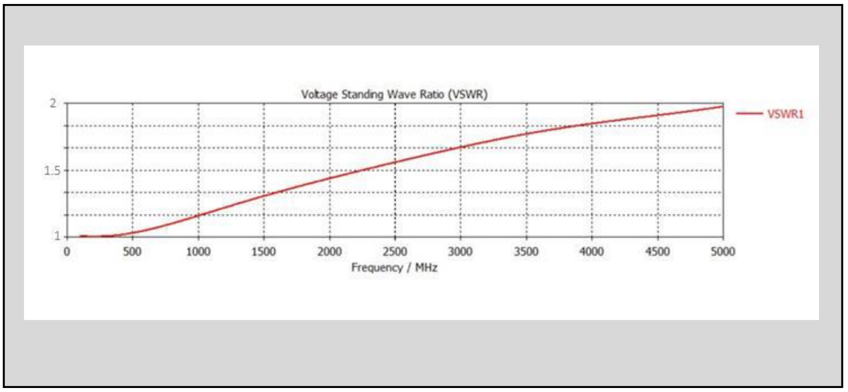

Fig. 5. VSWR at the resonance frequency.

4 Experiment results and discussion

After the successful simulation of the main parameters (S11 Loss of return, VSWR) which leads to the validation procedure of the new and improved RTK031, also based on the conformity of the prototype parts along the production process (Stripping, Crimping, etc.), the new RTK031 is now ready for use in the production process.), and after a presentation made with the customers who invest their projects on the basis of this product (Ford, VW, Audi...), it was necessary to continue the diagnosis and analysis as well as the measurement of the improved condition, moving on to the concrete and indispensable part, which is the setting up of the tests in the two sophisticated laboratories (Techno centre, Edag Engineering GmbH) for the start of the production of the new improved coaxial cable.

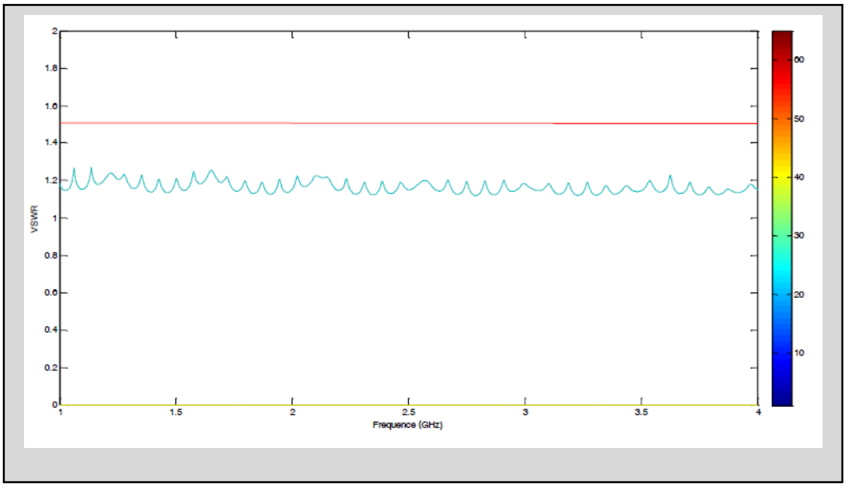

Fig. 6. VSWR after improvement.

We ploted the diagram using Matlab, makes it possible to have more precise results since we will use mathematical equations to manipulate the matrix [S].

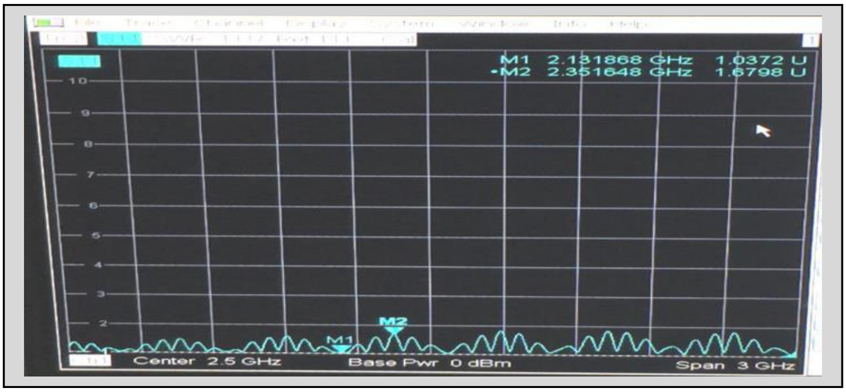

Fig. 7. VSWR after improvement.

After the analysis of the new test results of the RTK031 it was concluded that it complies with the specification as well as ensuring a good transmission of information along the cable without generation of parasitic reflection which influences the original signal, since the minimum VSWR=1.03 and the maximum VSWR=1.64 and if the VSWR is less than 2, the antenna matching is considered to be very good.

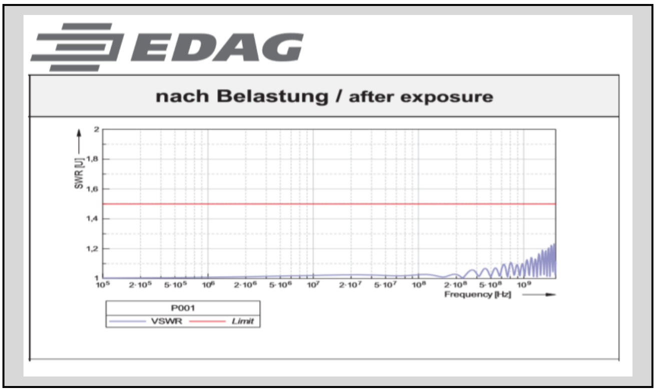

Fig. 8. VSWR results of tests carried out at the Ensa techno centre and at the Edag Laboratoire.

After a comparative study with the results of tests carried out at the Ensa techno centre and at the Edag Laboratory, which are in compliance, the final validation of the improved product was carried out.

Dielectric shielding effectiveness is the relative ability of a shield to filter out unwanted interference, as well as the rigidity against compression (ferrule crimping process).

In this enhanced coaxial cable RTK031, the dielectric provides a shield that prevents unwanted signals from entering and prevents signals from leaking out to avoid unwanted interference and will ensure the proper transmission of information.

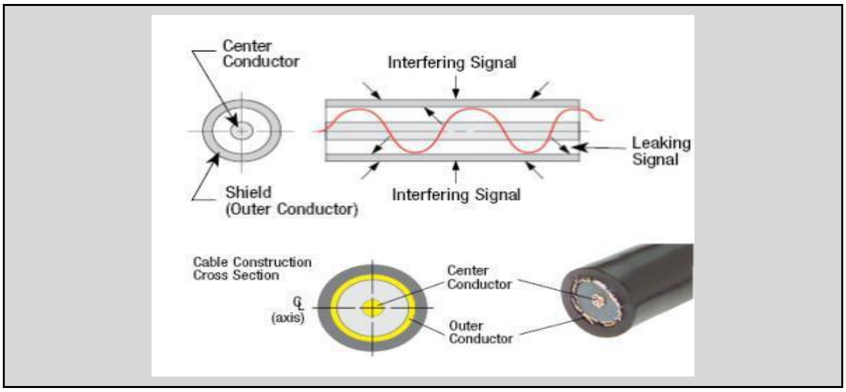

Fig. 9. Coaxial cable components.

The study conducted throughout this end-of-study project concluded that damaged dielectric is an unacceptable failure mode that can cause serious damage given the implementation of this coaxial cable at the vehicle level and with respect to the dedicated application.

There are three types of gains to be achieved based on the "Standard Before Validation" simulation & test method.

1. Gain in terms of production:

The simulation will allow to verify the right dimensions that will generate the right transmission all along the RTK031 coaxial cable, then validate its use and consequently increase the production of parts respecting the requirements of the specifications.

2. Gain in terms of cost:

The concrete approach (tests) allows the developer to make a change of dimensions with a large margin of freedom, which in the end allows the most optimal changes to be made without having to correct all the deviated dimensions by producing validation prototypes.

3. Time savings:

We have already noted in the first chapter of this project that TE Connectivity's engineering department validates any corrective action with the help of certain developers & researchers who work for another Tyco Electronics subsidiary located abroad, however the lead times can be as long as several weeks or even months, as is the case for the product that was studied and for which a request for validation support was made about 7 months ago and there has still been no response. Therefore, the method

that has been developed will indeed allow speeding up the process of modification and improvement of products and also avoid any production stoppage.

5 Conclusion

The aim of this project was to develop a validation methodology specific to TE CONNECTIVITY TANGIER, which is used to simulate and test the electrical behavior of coaxial cables, i.e. car antennas.

Through this article we have been able to establish a follow-up of the performance of this method, we first simulated the part containing geometrical defects at the dielectric level which generates intermittent short circuits, the comparison of these simulation results with those of the laboratory that we carried out in the Techno centre Ensa of Tetouan as well as those of the Edag Engineering Lab GmbH allowed us to ensure the reliability of the methodology, therefore the "check" phase of the project has lead to it's success and the efficiency of the improved coaxial cable RTK031 was confirmed, by making adjustments to the dielectric level.

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