Volume 59, Number 1, 2018

ACTA TECHNICA NAPOCENSIS
Electronics and Telecommunications

DESIGNING STRAIGHT COAXIAL CONNECTORS FOR FEEDER AND JUMPERS IN CELLULAR MOBILE BASE STATIONS

Mahdi BAHAGHIGHAT[1,*], Arash NAGHDEHFORUSHHA[2], Mohammad Reza SALEHIFAR[1], Mehdi MIRFATTAHI[1]
[1]Engineering Faculty, Raja University Of Qazvin; [2]EE Faculty, Amirkabir University Of Technology
**Corresponding author: M.Bahaghighat@raja.ac.ir*

Abstract: RF coaxial products are used in wide range of applications in cellular mobile telecommunication technology. In this paper, a coaxial telecommunication connector is designed for coupling to feeders and jumpers in BTS Mobile sites. The desired frequency range for this connector is 1.7 to 5 GHz. In terms of power transmission, especially when a high power is considered, one of the most important issues is the impedance matching; so designing and implementing a connector with an optimal VSWR is targeted in our work. To this end, we have tried to examine the effect of dimensional changes as well as material changes on this important parameter. Parametric study is used for various dielectric constants to show the VSWR behavior. Our simulation results clearly show that the proposed scheme can be used in practical applications.

Keywords: *VSWR, Passive Connectors, Coaxial Connectors.*

I. INTRODUCTION

Today, wireless telecommunication networks are widely developed all over the world [1, 2]. These networks cover a variety of applications such as cellular mobile networks, satellite networks, sensor networks, and so on. Throughout these networks, the quality of data transmission is the most important challenge and has brought many efforts to improve the quality of service (QoS) and the quality of experience (QOE), especially in high data rate multimedia applications [3-5]. In the meantime, the cellular mobile networks are of great importance due to their worldwide developments and a huge number of users. In the evolution of these networks from 1G to 4G, increasing the efficiency of the data transmission system is the main concern of the mobile operators. These affairs in 5G, which is fundamentally based on the Cognitive Radio (CR) [3, 4] and Software Defined Networks (SDN), will be more important than ever.

Telecommunication networks have a hierarchical multi-layered structure, the lowest of which is the physical layer. In this layer there are a lot of passive and active devices and transmission infrastructure that have a significant impact on the quality of service, as well as the power efficiency in the network. Either non-optimized or inappropriate design of the passive telecommunication devices can result a lot of degrading effects. For example, the VSWR, which is a very important quality metric in the signal propagation, can be caused by impedance mismatch. In addition to VAWR, there is another challenging issue which is called the insertion loss (IL). Both VSWR and IL can decrease a signal strength and subsequently reduce the Signal-to-Noise ratio (SNR). Any reduction in the amount of SNR can lead to an increase in the transmission error rate of data in telecommunication networks and consequently reducing the quality of service on the network. There are several passive devices which are widely used in mobile cellular networks such as connectors. Connector failures may alter the signal that is being transmitted and it is one of the major causes of low communication quality [6].

The appropriate design of passive telecommunication equipment that is used in the physical layer can increase the efficiency. Therefore, an optimal design of a telecommunication connector, which can be used with the least amount of VSWR, is targeted by us. The proposed connector is used in mobile BTS to couple with feeders and jumpers. Figure 1 shows an example of these types of connectors. The rest of the paper is organized as follows:
In section II, designing of a coaxial connector and related challenging issues are presented. In section III, our proposed coaxial connector design is introduced then in section IV, the proposed connector is simulated by CST software and finally in section V, conclusion and results are discussed.

II. DESIGNING A COAXIAL CONNECTOR AND ITS CHALLENG ISSUES

RF coaxial products are used in wide range of applications such as cellular technology and telecommunications, industrial and data systems and aerospace engineering with comprehensive product range consisting of connectors for all globally accepted conventional series from simple adaptors to cable, panel and PCB connectors and tools right up to accessory components.There are many challenging issues to consider in designing a telecommunication connector. We mention some important items as below:

- Passive intermodulation (PIM)
- Insertion Loss (IL)
- Component material
- Component dimensions
- Voltage Standing Wave Ratio (VSWR)

In telecommunication systems, widespread radio

Manuscript received January 21, 2018; revised March 28, 2018

frequency devices such as passive telecommunication connectors and antennas are deployed. The nonlinear behavior of these elements can lead to an especial distortion which is well known in related literature as Passive intermodulation or PIM. It is believed that, most of the time, PIM has almost a low impact, due to mixing products more than one hundred decibel down from the generating signal that is often negligible in comparison to the nonlinear distortion levels generated by active electrical and electronic components such as amplifiers.

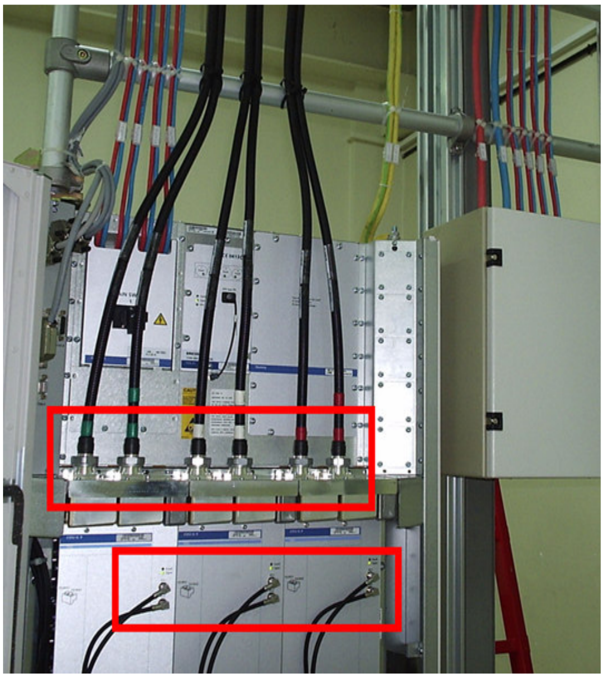


Figure 1. An example of coaxial connector application within a mobile cell base station

In spite of that, the high nonlinearity of active devices can generally be controlled or reduced by some advanced filtering approaches. Unfortunately, distortion generated by PIM cannot always be eliminated by some filtering techniques and it is often the mainstream of nonlinear distortion source in particular in a high power communication system. As a result of the great difference in power between transmitted and receive signals, PIM distortion levels as low as 115 dBm are potentially problematic sources of interference in many systems as the nonlinearity of passive components causes power on transmit frequencies to mix into the system's receive band [7].

In cellular mobile communications, coaxial connectors are frequently the dominant contributors to passive intermodulation (PIM) distortion in high-frequency networks. Studies have found the PIM from coaxial connectors to be generated by point-source, as opposed to distributed, nonlinearities [7-10], i.e., the nonlinear distortion in a connector occurs at a specific point along the length of the connector (most likely at the metal–metal junction between the adapters).

Another important issue that should be considered is Insertion loss (IL). It indicates the power loss directly resulting of insertion a coaxial connector in a transmission line. It usually is interpreted as a signal power decay and is expressed in decibels (dB) that the lower values referring lower insertion loss. A very important point in this regard is that its value does not remain constant and some changes can affect its value. For example, in [6], it was shown that the degraded connector exhibits an insertion loss increase. This is due to the energy loss that results from the increased contact impedance. The combined effect of the energy reflection and energy loss produce the insertion loss increase. Thus, as the contact ages, the high frequency electrical characteristics of the connectors will change. A degraded connector could lead to the increase of the VSWR and insertion loss, with a corresponding decrease in the signal energy of the load [6].

For designing a coaxial connector, we should consider not only the design criteria such as PIM, IL and VSWR, but also its practical application.

We offer the material selection in relation to overall design considerations based on categorized parameters presented from table 1 to 4. First of all, we list the important parameters such as the Maximum operating temperature, Resistivity, Average tensile strength and Flexibility in table 1. In the next table, similar parameters are compared with various metal types for outer conductor. Finally, in the table 3 and 4 the perfect comparison is presented by us for the dielectric selection among PE, FEP, PTFE and BUTYL RUBBER.

Table1. Inner conductors

	Resistivity at 20°C, ohms circular mil / ft.	Average tensile strength psi (1,000)	Flexibility	Remarks
SOFT BARE COPPER	10.371	37	Excellent	Most popular for extra flexibility use stranded
TINNED SOFT COPPER	11.133	37	Excellent	for added resistance to oxidation and easy solder ability, best for low frequency application
SILVER PLATED COPPER	10.371	37.5	Excellent	elevated temperature use in aircraft, missile, and electronics, easy solder ability
NICKEL PLATED COPPER	12.5	37.5	Excellent	extra high temperature use
TINNED CADIMUM BRONZE	11.92	45	Good	High tensile strength with flexibility
COPPER WELD®	25.928	130	Good	Extra high Tensile strength

Table2. Outer conductors

	Maximum operating Temperature	Flexibility	Remarks
SOFT BARE COPPER	200°C	Excellent	most popular in braid, minimum .004" to .010", add second shield to improve flexibility
TINNED SOFT COPPER	150°C	Excellent	most popular in braid, minimum .004" to .010", add second shield to Improve flexibility, better for low frequency
SILVER PLATED COPPER	200°C	Excellent	most popular in braid, minimum .004" to .010", add second shield to improve flexibility, for high temperature
ALUMINUM TUBE	-	Poor	for high tensile and crushing loads and lower attenuation
COPPER TUBE	-	Poor	for high tensile strength and crushing loads

Table3(a). Primary dielectrics

	POLY ETHYLENE (PE)	Fluorinated Ethylene Propylene (FEP)
Maximum operating temperature	-65°C to 80°C	-65°C to 200°C
Average tensile strength psi (1,000)	1.9	3.6
Flexibility	Good	Excellent
Cutthru resistance	Good	Good
Water Resistance	Excellent	Excellent
Resistance to organic solvents	Poor	Excellent
Resistance to acids and alkalies	Excellent	Excellent
Remarks	80°C maximum	high temperature to 200°C

Table3 (b). Primary dielectrics

	Poly Tetra fluoro ethylene (PTFE)	BUTYL RUBBER
Maximum operating temperature °C	-65 to 260	-40 to 80
Average tensile strength psi (1,000)	2.7	1.1
Flexibility	Good	Excellent
Cutthru resistance	Fair	Excellent
Water Resistance	Excellent	Good
Resistance to organic solvents	Excellent	Good
Resistance to acids and alkalies	Excellent	Good
Remarks	for high temperature use to 260°C	for pulse cables and extreme flexibility

Table4. Dielectric Properties

Dielectric Material	Dielectric Constant (E)	Power Factor (p)
Polyethylene cellular foam (PE)	1.40 2.10	0.0003
Polyethylene solid (PE)	2.3	0.0003
Poly Tetra fluoro ethylene (PTFE)	2.1	0.0002
Cellular Poly Tetra fluoro ethylene (PTFE))	1.4	0.0002
Fluorinated Ethylene Propylene (FEP)	2.1	0.0007
Cellular Fluorinated Ethylene Propylene (FEP)	1.5	0.0007
Butyl rubber	3.1	-
Silicone rubber	2.08- 3.50	0.007- 0.01

III. PROPOSED DESIGN

In order to have an efficient energy transmission, it is necessary that the characteristic impedance matches the load. In a coaxial connector, characteristic impedance is proportional to internal and external diameter of its conductors and also medium filled in. Controlled characteristic impedance is important because the source and load impedance should be matched to ensure a maximum power transfer and a minimum standing wave ratio (VSWR). The coaxial characteristic impedance and its relationship to the size of conductors and medium can be expressed as equation (1) [11]:

$$Z_0 = \frac{138}{\sqrt{\mu_r \varepsilon_r}} \log(\frac{b}{a}) \qquad (1)$$

Where a and b are the outside radius of the inner conductor and inside radius of outer conductor respectively. In addition, ε_r is permittivity of dielectric medium which is filled in.

The VSWR parameter is the ratio of the magnitude of the incident wave and the reflected one. It shows the matching degree between a connector and those devices which are connected to it. The VSWR value is more than or equal to one, with lower values indicating better matching [11]. Providing that a matching state is not achieved, reflection will not avoidable. In this case, reflection coefficient (ρ) or eauvalently VSWR and IL is used to express the mismatch degree. Reflection coefficient is defined as below [11]:

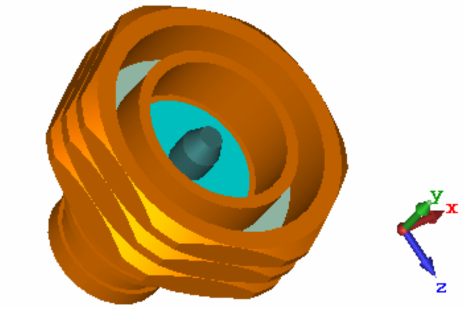
$$\rho = \frac{Z_L - Z_0}{Z_L + Z_0} \qquad (2)$$

Where Z_L is the load impedance. Now, VSWR can be formulated as follows:

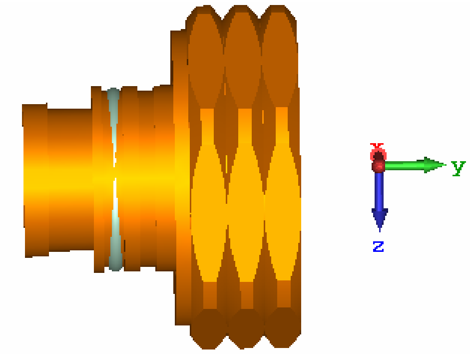
$$VSWR = \frac{1+|\rho|}{1-|\rho|} \qquad (3)$$

The coaxial characteristic impedance and its relationship to the size of conductors and medium is used based on [11].

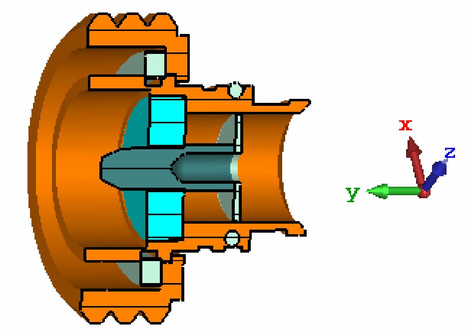
In the figure 2, the perspective of our proposed design for a 7/16” male coaxial connector is presented by its STEP file.



(a) Back view



(b) Side view



(c) Cross-section side view

Figure 2. The proposed design for a 7/16” male coaxial connector

IV. SIMULATION RESULTS

The proposed connector is simulated by CST software. To simulate, the connector is excited by the waveguide port.

At the first, we evaluate metal material variation and its effect on our design. In table 5, we define six different scenarios, then in table 6 we show the results of VSWR obtained during simulations of these different experiments. The achieved results clearly indicate that the metal replacement cannot affect VSWR value. Although, the metal change has no impact on VSWR, it has a direct impact on PIM, effective lifetime and the final cost of a connector.

At the second, in figure 3, we evaluate the impact of dielectric material on VSWR. In practice, it is essential to have VSWR less than 1.1 so obtained results clearly indicate that our design is well adapted to practical restrictions.

The combined effect of the energy reflection and energy loss produce the insertion loss increase. The insertion loss represents the power loss due to the introduction of the coaxial connector which shown in figure 4. It usually refers to signal decay, with lower values indicating lower insertion loss.

Table 5. Evaluating metal martial variation impact on VSWR

Outer Contact	Nut	Central Contact	Scenario Number
*B	*B	*PB	1
*B	*B	*Co	2
*B	*B	*Al	3
*PB	*Al	*PB	4
*Stl	*Al	*PB	5
*Stl	*Stl	*PB	6

*Note: PB= Phosphor Bronze , B=Brass (65%), Co= Copper, Al=Alumina 96%, Stl= Steel 1008

Table 6. Obtained VSWR based on six different scenarios

f=2700	f=2300	f=2000	f=1700	Scenario Number
1.3289	1.1275	1.0222	1.2076	1
1.3264	1.1273	1.0233	1.2103	2
1.328	1.1304	1.0216	1.2088	3
1.3269	1.1268	1.0232	1.2094	4
1.3278	1.1275	1.0226	1.2089	5
1.3274	1.1279	1.0223	1.2085	6

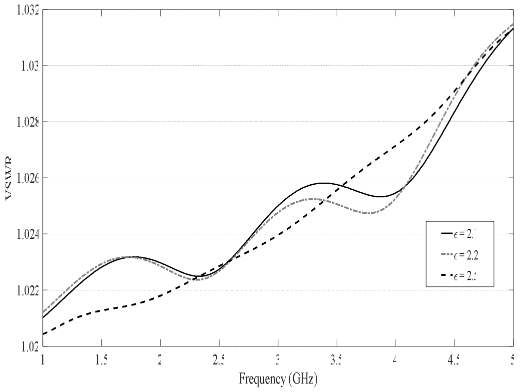


Figure 3. VSWR varies based on size of inner connector and dielectric constant, inner radius=15m, outer radius=3mm.

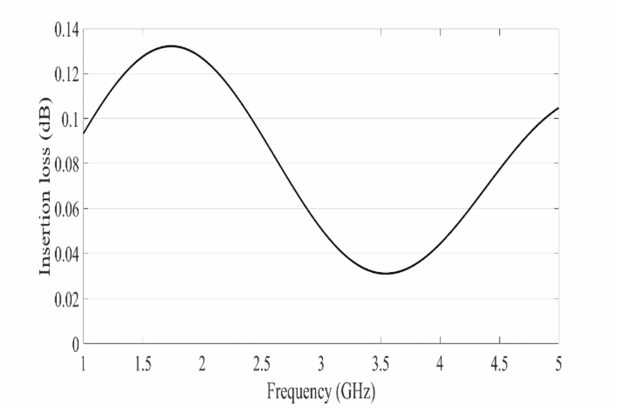


Figure 4. Insertion loss (dB) variation based on dielectric constant 2.1

V. CONCLUSION AND MEASUREMENT

In this work, a comprehensive view of the coaxial connector design is presented. All practical restrictions regarding to such design are well introduced. To evaluate our model, the effect of RF parameters on power transmission efficiency is targeted and consequently, variation of size, dielectric constant and also metal material are evaluated. The obtained results indicate that appropriate VSWR less than 1.1 can be achieved during the bandwidth 1.7GHz to 5GHz based on the optimum selection of proposed parameters in our system model.

REFERENCES

[1] S. A. Naghdehforushha, H. Oraizi, F. Hojjat-Kashani, and A. J. Deel, "Design of a rectangular metallic monopole antenna with protruding normal plates for applications in UWB communication," *Progress In Electromagnetics Research,* vol. 51, pp. 161-167, 2014.

[2] A. Jalali-Deel, V. Nayyeri, M. Soleimani, and S.-A. Naghdehforushha, "Modified current distribution for analysis of spiral antennas," *IET Microwaves, Antennas & Propagation,* vol. 11, pp. 1583-1586, 2017.

[3] M. Bahaghighat and S. A. Motamedi, "IT-MAC: Enhanced MAC Layer for Image Transmission Over Cognitive Radio Sensor Networks," *International Journal of Computer Science and Information Security,* vol. 14, p. 234, 2016.

[4] M. Bahaghighat and S. A. Motamedi, "PSNR Enhancement in Image Streaming over Cognitive Radio Sensor Networks," *ETRI Journal,* vol. 39, pp. 683-694, 2017.

[5] M. Bahaghighat and S. A. Motamedi, "VISION INSPECTION AND MONITORING OF WIND TURBINE FARMS IN EMERGING SMART GRIDS," *Facta Universitatis, Series: Electronics and Energetics,* vol. 31, pp. 287-301, 2018.

[6] R. Ji, J. Gao, G. Xie, G. T. Flowers, and Q. Jin, "The impact of coaxial connector failures on high frequency signal transmission," in *Electrical Contacts (Holm), 2015 IEEE 61st Holm Conference on*, 2015, pp. 298-303.

[7] J. Henrie, A. Christianson, and W. J. Chappell, "Prediction of passive intermodulation from coaxial connectors in microwave networks," *IEEE Transactions on Microwave Theory and Techniques,* vol. 56, pp. 209-216, 2008.

[8] B. Deats and R. Hartman, "Measuring the passive-IM performance of RF cable assemblies," *Microwaves & RF,* vol. 36, pp. 108-114, 1997.

[9] J. A. Jargon, D. C. DeGroot, and K. L. Reed, "NIST passive intermodulation measurement comparison for wireless base station equipment," in *ARFTG Conference Digest, 1998. Computer-Aided Design and Test for High-Speed Electronics. 52nd*, 1998, pp. 128-139.

[10] P. Lui, "Passive intermodulation interference in communication systems," *Electronics & Communication Engineering Journal,* vol. 2, pp. 109-118, 1990.

[11] L. Ziyu, L. Yan, H. Wei, and L. Zhibo, "Analysis on mismatch loss caused by poor contact of BNC connector components," in *Information Science and Technology (ICIST), 2014 4th IEEE International Conference on*, 2014, pp. 1-4.