Effect of Microwave Absorbing Material on the Straight-Through Performance of Millimetre Wave Coaxial Attenuator

Yanchu Zhang¹ and Zhigang Kong¹,*

¹Research Laboratory of Reliability of Electrical Connection and Connector, Beijing University of Posts and Telecommunications, Haidian District, China
*Corresponding Author

Abstract. This paper takes the attenuation unit of the millimetre wave coaxial attenuator working in the through state as the research object. The 3D model of the attenuation unit was created. The insertion loss and the VSWR of the attenuation unit were simulated with the help of the HFSS software. The consequences of signal integrity issues were analysed with transmission line theory. The insert loss and VSWR of attenuation unit were simulated by adding a ferrite microwave absorbing material to the model and the thickness of the absorbing material is taken as a variable at different thickness. The relationship between the insertion loss and the VSWR and the thickness of the absorbing material are fitted by numerical fitting and the thicknesses of the absorbing material which optimizes the insertion loss and the VSWR are obtained respectively.

1. Introduction

With the rapid development of wireless communications, especially personal mobile communications, the low frequencies of the radio spectrum have been saturated. Though Gaussian Filtered Minimum Shift Keying or other Multiple Access technologies are used to expand the capacity of the communication system and increase the utilization rate of the spectrum, it is unable to meet the needs of future communications development. Therefore, it is necessary to develop new spectrum resources in the microwave high frequency band in order to realize high-speed and broadband wireless communication [1,2]. Due to the short wavelength and frequency bandwidth of millimetre wave which, plenty problems faced by high-speed broadband wireless access can be solved effectively, has a promising prospect in short-distance communication [3]. Millimetre wave coaxial attenuator, as a passive device providing attenuation, has been widely used in Radio Frequency and microwave technology [4,5]. Research on the signal integrity parameters of the attenuator has also become one of the hot spots nowadays.

This paper is mainly focused on the effect of microwave absorbing materials on the straight-through performance of millimetre wave coaxial attenuator. Frequency domain simulations on models with different thickness of microwave absorbing materials are performed. The effect of the thickness of the absorbing materials on its absorption performance is compared from the scattering parameters, and the thickness of the absorbing material which leads to the optimal performance is selected.

2. Model Creating and Simulation

2.1. Model Creating

The attenuation unit is the most basic structure in the millimetre wave coaxial attenuator, which can be regarded as several units and coaxial input/output connectors connected in series [6]. The unit working
in the straight-through state is taken as the research object. The 3D model is created in SOLIDWORKS 2019. Exploded view of the unit in through state is shown in Figure 1 (the metallic shell is compressed). The attenuation unit is in through state when the moving reed on both sides are in connection with the through plate.

![Exploded view of the attenuation unit in through state](image)

**Figure 1.** Exploded view of the attenuation unit in through state

2.2. Simulation without Absorbing Material

The model of attenuation unit is imported in ANSYS Electronics Desktop 2019 R3 HFSS and then simulated. The material settings of each component in the model are shown in Table 1. The settings of simulation is shown in Table 2.

| Order | Name            | Material | Relative Permittivity | Relative Permeability | Dielectric Loss Tangent |
|-------|-----------------|----------|-----------------------|-----------------------|--------------------------|
| 1     | Moving Reed     | Copper   | 1                     | 0.999991              | 0                        |
| 2     | Through Plate   | Copper   | 1                     | 0.999991              | 0                        |
| 3     | Dielectric Base | PEI      | 3.15                  | 1                     | 0.0013                   |
| 4     | Metallic Shell  | Copper   | 1                     | 0.999991              | 0                        |

**Table 1.** Materials Used in Attenuation Unit

| Project                      | Settings          |
|------------------------------|-------------------|
| Solution Frequency           | Broadband         |
| Low Frequency                | 0.5GHz            |
| High Frequency               | 26.5GHz           |
| Maximum Number of Passes     | 15                |
| Maximum Delta S              | 0.01              |
| Sweep Points                 | 1301              |
| Sweep Type                   | Interpolating     |
| Excitation                   | Lumped Port       |
| Port Impedance               | 50ohms            |
| Size of Airbox               | 1/4 wavelength    |
| Boundaries of Airbox         | Radiation         |

**Table 2.** Attenuation Unit Simulation Settings

Insertion loss $S_{21}$ is defined as a ratio of the signal output in port 2 and input in port 1. The ratio can be either voltage or energy. The relationship between two kinds of ratios are shown below [7]:

\[
\text{Voltage Ratio: } S_{21} = \frac{V_2}{V_1}
\]

\[
\text{Energy Ratio: } S_{21} = \frac{P_2}{P_1}
\]
The simulation result of insertion loss of the attenuation unit is shown in Figure 2. As for the insertion loss, the bigger its absolute value is, the greater the loss of signal caused during transmission. Therefore, in the Figure 2 the minimum points need to be focused. It can be easily observed that there are 3 minimum points on the curve and listed respectively:(1) When the frequency equals to 3.50GHz, insertion loss has a minimum value of -0.05dB. (2) When the frequency equals to 14.78GHz, insertion loss has a minimum value of -0.34dB. (3) When the frequency equals to 26.50GHz, insertion loss has a minimum value of -0.37dB.

![Figure 2](image)

From formula (3), it can be calculated that when the signal passes through the unit where the signal is input from port 1 and output from port 2 the amplitude of the signal becomes 95.83% of the original, and a 4.17% loss is caused by the unit during transmission.

Voltage Standing wave ratio is the ratio of the maximum value and minimum value of the voltage or current on the transmission line. When there is a reflected wave due to impedance mismatch on the transmission line, the in-phase superposition of the incident wave and the reflected wave will cause the antinode on the composite wave, in the same time, the anti-phase superposition will lead to node. Therefore, the larger the amplitude of the reflected wave is, the larger the voltage standing wave ratio will be, which means the worse signal quality.

The result of voltage standing wave ratio simulation of attenuation unit is shown in Figure 3. It can be observed that there are 4 minimum points on the curve and listed respectively:(1) When the frequency equals to 3.02GHz, VSMR has a maximum value of 1.14. (2) When the frequency equals to 7.84GHz, VSMR has a minimum value of 1.05. (3) When the frequency equals to 14.50GHz, VSMR has a minimum value of 1.63. (4) When the frequency equals to 26.50GHz, VSMR has a minimum value of 1.62.

\[
\frac{P_a}{P_b} = \left(\frac{V_a}{V_b}\right)^2 = S_{ab\ mag}^2
\]

(1)

\[
S_{ab\ dB} = 20 \log S_{ab\ mag}
\]

(2)

As a consequence:

\[
S_{ab\ mag} = 10^{0.05S_{ab\ dB}}
\]

(3)
Judging from the simulation result of the attenuation unit, when the signal with several frequencies pass on the transmission line, reflected wave is generated in the transmission line due to the impedance mismatch, which reduces the effective power and affects the working efficiency [8]. Similarly, the generated reflected wave will also be superimposed with the incident wave, causing the distortion of the signal amplitude and phase. Therefore, it is necessary to reduce the absolute value of the insertion loss and VSMR of the unit when working in the through state.

Ferrite is currently a widely used magnetic wave absorbing material [9,10]. The coating made of ferrite is known as of strong wave absorbing ability, effective wave absorbing frequency bandwidth and thin coating thickness [11].

Ferrite is used as the microwave absorbing material in the paper. The coating is covered on the dielectric base and the simulation is performed in ANSYS Electronics Desktop 2019 R3 HFSS. The settings are shown in the Table 3.

| Project                              | Settings                         |
|--------------------------------------|----------------------------------|
| Solution Frequency                   | Broadband                        |
| Low Frequency                        | 0.5GHz                           |
| High Frequency                       | 26.5GHz                          |
| Maximum Number of Passes             | 15                               |
| Maximum Delta S                      | 0.01                             |
| Sweep Points                         | 1301                             |
| Sweep Type                           | Interpolating                    |
| Excitation                           | Lumped Port                      |
| Port Impedance                       | 50ohms                           |
| Size of Airbox                       | 1/4 wavelength                   |
| Boundaries of Airbox                 | Radiation                        |
| Minimum Thickness of Coating         | 0.025mm                          |
| Maximum Thickness of Coating         | 0.200mm                          |
| Delta Thickness                      | 0.025mm                          |

The simulation results of insertion loss and VSMR are numerically classified with Microsoft Excel, and their scatter plots are drawn respectively in Figure 4 and Figure 5.
It can be seen from the figure that no matter how the thickness of the absorbing material changes, the number of extreme points in the simulation results of insertion loss and VSMR always remains the same. Only the extreme values corresponding to the extreme points change, which also shows the change of the thickness of the absorbing material has an effect on the ability of the absorption.

3. Discussion

3.1. Analysis of Simulation Results of Insertion Loss

According to the simulation results in Figure 4, it can be observed that no matter how the thickness of the absorbing material changes, the number of extreme points is always three, and the coordinates of the three extreme points change within a small frequency range. 0.5GHz-26.5GHz frequency band can be divided into 3 small segments: (1) 0.5GHz-5GHz, the first extreme point is in this segment. (2) 10GHz-20GHz, the second extreme point is in this segment. (3) 20GHz-26.5GHz, the third extreme is in this segment.

For the segment (1), the increase in the thickness of the absorbing material increases the absolute value of its minimum insertion loss from 0.07dB to 0.10dB. For segment (2), the increase in the thickness of the absorbing material increases the absolute value of the minimum insertion loss from 0.36dB to 0.76dB. For the segment (3), the increase in the thickness of the absorbing material reduces the absolute value of the minimum value of the insertion loss from 0.38dB to 0.28dB, and then increases to 0.36dB. It can be inferred that as the thickness of the absorbing material increases, the frequency corresponding to its optimal absorbing performance will increase.
Compared with the simulation results without adding the absorbing material, the segment (1) has a lower frequency and the skin effect generated when the signal passes through the transmission line is weaker. So, it is not easy to cause signal integrity problems and it will not be evaluated [12]. When the thickness of the added absorbing material is between 0.025mm-0.075mm, the insertion loss close to that before the absorbing material is not added can be obtained. In the segment (3), the absorbing material with a thickness of 0.15mm has the best effect.

3.2. Analysis of Simulation Results of VSMR
Similar to the simulation results of insertion loss, VSWR has four extreme points on 0.5GHz-26.5GHz, so it is divided into 0.5GHz-5GHz, 5GHz-10GHz, 10GHz-20GHz, 20GHz-26.5GHz four Frequency segments. Segments (1) (2) due to the low frequency, VSMR is also close to 1, the signal integrity problem is not easy to occur when the signal is transmitted. In the segment (3), as the thickness increases, VSMR also increases from 1.59 to 2.01. In segment (4), the increase in thickness causes VSMR to decrease from 1.50 to 1.10, and then to 1.24.

This result also reflects that when ferrite is used as the absorbing material, the frequency corresponding to its optimal absorbing performance will increase with the thickness of the absorbing material. Compared with the simulation results without adding the absorbing material, the absorbing material with a thickness between 0.025mm-0.075mm can reduce the maximum value of the standing wave ratio in each segment.

3.3. Discussion
For the attenuation unit model, when the thickness of the absorbing material is between 0.025mm-0.075mm, its signal integrity parameters can be improved to some extent compared to the attenuation unit without adding absorbing material. When the thickness of the added absorbing material is closer to 0.025mm, the better the lifting effect for the segment (3), and the closer the thickness is to 0.075mm, the better the lifting effect for the segment (4). This is because when the thickness of the absorbing material increases, its optimal absorption frequency approaches from the segment (3) toward the segment (4).

The extreme value of insertion loss in segments (2) (3) is shown in Table 4. In order to obtain better signal integrity parameters, it is requested that the absolute value of the minimum value in the segment (2) and the minimum value in the segment (3) should be as small as possible. The data is fitted in Microsoft Excel to get the fitting equation:

\[ y = -1280x^4 + 326.4x^3 - 33.76x^2 + 1.284x - 0.759 \]  

(4)

Where \( x \) is the thickness of the absorbing material (unit: mm) and \( y \) is the insertion loss (unit: dB). When \( x = 0.03 \), the absolute value of the sum has a minimum value of 0.743.

Similarly, the extreme value of VSMR in the segments (2) (3) is shown in Table 5. The data is fitted in the table in Microsoft Excel to get the fitting equation:

\[ y = 3840x^4 - 1286.4x^3 + 138.4x^2 - 6.996x + 3.2079 \]  

(5)

Where \( x \) is the thickness of the absorbing material (unit: mm) and \( y \) is VSMR (dimensionless unit). When \( x = 0.153 \), the sum of VSMR has a minimum value of 2.874. Therefore, if both a good insertion loss and a good VSMR are wanted, the thickness of the absorbing material should be between 0.03mm-0.153mm.

| Table 4. Extreme table of insertion loss |
|----------------------------------------|
| Thickness | 0.025 | 0.050 | 0.075 | 0.100 | 0.125 | 0.150 | 0.175 | 0.200 |
| Extreme 1 | -0.3641 | -0.3892 | -0.4029 | -0.4336 | -0.4826 | -0.5478 | -0.6292 | -0.7663 |
| Extreme 2 | -0.3793 | -0.3556 | -0.3555 | -0.3178 | -0.2983 | -0.2772 | -0.2915 | -0.3611 |
| Sum       | -0.7434 | -0.7448 | -0.7584 | -0.7514 | -0.7809 | -0.825 | -0.9207 | -1.1274 |
Table 5. Extreme table of VSMR

| Thickness | 0.025 | 0.050 | 0.075 | 0.100 | 0.125 | 0.150 | 0.175 | 0.200 |
|-----------|-------|-------|-------|-------|-------|-------|-------|-------|
| Extreme 1 | 1.5938| 1.6208| 1.6241| 1.6537| 1.7078| 1.7777| 1.8626| 2.0123|
| Extreme 2 | 1.5056| 1.4506| 1.423 | 1.3202| 1.2437| 1.1122| 1.0962| 1.2408|
| Sum       | 3.0994| 3.0714| 3.0471| 2.9739| 2.9515| 2.8899| 2.9588| 3.2531|

4. Conclusion
In this paper, through the simulation of the attenuation unit working in the through state, the following conclusions are obtained:

(1). For the attenuation unit without adding the absorbing material, the absolute value of the insertion loss has a maximum value of 0.37dB, which appears at 26.50GHz.

(2). After adding the absorbing material, it can be found that as the thickness of the absorbing material increases, the optimal absorbing frequency also continues to increase, so in the simulation, as the thickness of the absorbing material increases, the low-frequency signal integrity parameter becomes worse, while the high-frequency signal integrity parameter tends to be better first. When the optimal absorbing frequency exceeds the simulated frequency, the parameter tends to become worse.

(3). The insertion loss corresponding to the thickness of the absorbing material is numerically fitted, and the relationship between the insertion loss and the thickness of the absorbing material is obtained:

\[ y = -1280x^4 + 326.4x^3 - 33.76x^2 + 1.284x - 0.759 \]

When the thickness of the absorbing material is 0.03mm, the best insertion loss can be obtained.

(4). Numerically fitting VSMR corresponding to each thickness of the absorbing material to obtain the relationship between VSMR and the thickness of the absorbing material:

\[ y = 3840x^4 - 1286.4x^3 + 138.4x^2 - 6.996x + 3.2079 \]

When the thickness of the absorbing material is 0.153mm, the best VSMR can be obtained.

5. Acknowledgements
The study is financially supported by National Key Research and Development Project of Ministry of Science and Technology (No.2018YFF01011604).

6. References
[1] Siyue Cheng and Huasheng Li, “Research on Development Trend of 5G Technology Based on Radio Management”, China Radio, 2015(04), pp.19-20.
[2] Wenhuan Gao and Aihong Shan, “On Gaussian Minimum Frequency Shift Keying (GMSK) Modulation Technology”, China Radio, 2016(02), pp.43-45.
[3] Yanli Li, “Research status and progress of millimeter wave communication technology”, Sichuan Provincial Communication Society Annual Conference. Sichuan, Sichuan Provincial Communication Society, 2010.
[4] Effendy, A, Ali, A, The design of 5 dB attenuator in coplanar waveguide for DC to 67 GHz[P]. RF and Microwave Conference (RFM), 2011 IEEE International, 2011.
[5] Kefeng Han, Liang Zou, Youchun Liao, Hao Min, Zhangwen Tang. A wideband CMOS variable gain low noise amplifier based on single-to-differential stage for TV tuner applications[P]. Solid-State Circuits Conference, 2008. A-SSCC '08. IEEE Asian, 2008.
[6] Chunhua Wen, “Design and Implementation of 3.5mm 60dB Programmable Step Attenuator”, Electronics Quality, 2011(05), pp.29-30+40.
[7] Heshuang Zhang, “Simulation, test and optimization of 10Gbps high-speed connectors”, Beijing University of Posts and Telecommunications, 2019.
[8] Xiangde Lin and Liping Zhou, “The harm and treatment of standing wave ratio alarm”, Telecommunications Information, 2016(01), pp.41-43.
[9] Fusheng Wen, Wenliang Zuo, Haibo Yi, Nan Wang, Liang Qiao, Fashen Li. Microwave-absorbing properties of shape-optimized carbonyl iron particles with maximum microwave permeability[J]. Physica B: Physics of Condensed Matter, 2009, 404(20).

[10] Yuchang Qing, Wancheng Zhou, Fa Luo, Dongmei Zhu. Microwave-absorbing and mechanical properties of carbonyl-iron/epoxy-silicone resin coatings[J]. Journal of Magnetism and Magnetic Materials, 2008, 321(1).

[11] Yue Feng and Guangming Fu, “Research status of ferrite absorbing materials”, National Defense Science & Technology, 2015, 36(04), pp.27-30.

[12] Guanlin Zhu, “Research on the Influence of Skin Effect on AC Signal”, Practical Electronics, 2019(22), pp.50-51+54.