Analysis of signal transmission performance of radio frequency cable under the multiple factors

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ABSTRACT: Radio frequency (RF) cable is the main physical carrier of signal transmission. Signal transmission of RF performance is affected by multiple factors. In the paper, 3D finite element analysis of RF cable was built and signal attenuation characteristics of single factor for RF cable was studied, such as insulating layer thickness, the frequency and ambient temperature. By orthogonal design, insertion loss and variance analysis of nine parameters for RF cable were discussed. And results show that the more thickness RF cable insulation increases, the less signal attenuation characteristic deceases. The more signal frequency increases, the more signal attenuation characteristic increases. The higher temperature increases, the more signal attenuation characteristic increases. Insertion loss was affected by multiple factors ranked in order from big to small, signal frequency, insulation thickness, ambient temperature, maximum significant.
KEYWORD: RF cable, Signal attenuation, Orthogonality design, Regression mode

1 INTRODUCTION

RF cable are widely distributed in radio communications, broadcast and related electronic equipment, which is one of most important channels of communication cable between the transmitting equipment and transmitting antenna, with the development of design and manufacturing process technology from its creation to the present, RF cable has greatly improved in performance. RF cable has a better signal transmission performance because of its special structure, however, with the increase of modern communication and increasing the frequency of the signal related to the power consumption of electronic equipment, the signal transmission performance of RF cable has been greatly affected, it is very important to accurately transmit critical signals as the key link in the signal transmission.

At present, Scholars in rarely analysis RF cable multivariate transmission performance, Most of the transmission performance of single variable analysis, there are some scholars were studied under the temperature-signal frequency response, for the combined effects of temperature, frequency and structure of different transmission characteristics for further study. In recent years, scholars study calculated transient RF cable coupling voltage(D. J. Fernandes,2007 L. K. Kenneth,2007), operating over a proposed simplified calculation method voltage transmission cable attenuation(M. Marzinotto, 2010), analysis of the high-frequency signal in response to interconnect terminal has been studied (Zhang. J, 2014 R. Vaughan, et al, 2010), studied the integrity signal under combined Finite Difference Time Domain (FDTD) method with finite element method (Bao. G, 2005).

2 BASIC THEORY OF S PARAMETERS

Electric and magnetic fields will be formed between the inner and outer conductors of the RF cable, when signal voltage is loaded and the signal current flows through the cable inner and outer conductors. With the changes in signal voltage, electric and magnetic fields between inner and outer conductors of the RF cable are changing over time. Thus, time-varying electromagnetic fields will determine the variation of voltage and current radio frequency cable. Therefore, electromagnetic theory and distributed parameter circuit (Fig. 1) theory will be used when studied the RF cable signal transmission characteristics.

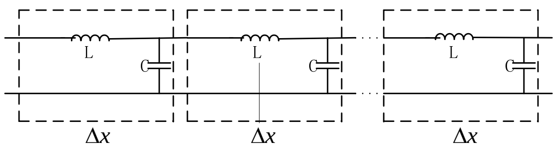

Figure 1. Total parameter model of ideal RF cable

RF cable in uniform, each circuit parameters is evenly distributed over cable, the voltage and current cable is a function of time (t) and distance(x). To take a length of Δx which is micro-segmentation to study on the RF cable, when $\Delta x \to 0$, you can ignore Δx the distribution of circuit parameters on the micro segment, and then replaced with a lumped parameter circuit equivalent, thus, the whole uniform RF cable be viewed as consisting of countless Δx. Fig. 2 is a RF cable Δx microsegment.

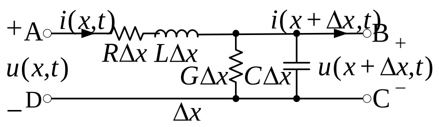

Figure2. RF cable micro segmentation equivalent circuit model

3 SINGLE FACTOR ANALYSIS SIGNAL INSERTION LOSSES OF RF CABLE

This paper studies the RF coaxial cable (Fig. 3) is surrounded by an axis formed between the inner and outer conductors of the two-conductor system, according to isolated by an insulating material between the inner and outer conductors, then entire cable from the outermost layer of protection. In this structure, due to the presence of the outer conductor can be shield the influence of external electromagnetic environment of their transmitted signals, but also can reduce the external radiation of electromagnetic energy cable by itself, so that the signal only can be transmitted within the cable from one end to another. Geometric parameters of the simulation model are shown in Table 1. The inner and outer conductors are silver plated copper conductor, insulation and jackets are poly-tetra-fluorine–ethylene (PTFE). Finite element analysis of material properties at room temperature are shown in Table 2, where in the metal festivity, thermal conductivity and thermal conductivity of the insulating material, the dielectric constant is variable with respect to temperature, while the dielectric constant of the insulating material is variable with signal frequency.

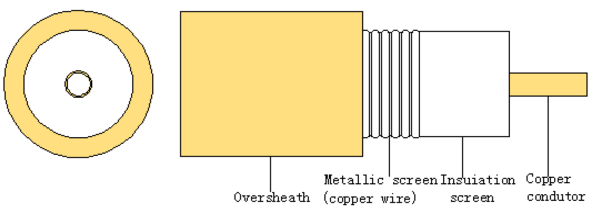

Figure.3. Simulation model of RF cable

Table1. Loss parameter level table of RF cable signal

Factors	Insulation thickness $H(mm)$	Ambient temperature $T(℃)$	Signal frequency $f(\times 10^9 Hz)$
1	0.48	20	1
2	1.035	80	9
3	1.53	150	18

Table 2. Material properties in 20 ℃

Material properties	Inner conductor / shield	Insulation / jacket
Resistivity $/\Omega\cdot m$	1.724e-8	-
Thermal Conductivity $/W(\mathrm{m}\cdot\mathrm{K})^{-1}$	420	0.005
Specific heat coefficient $/J(kg\cdot\mathrm{K})^{-1}$	386	1.05
Relative permeability	1	1
Density $/(kg/\mathrm{m}^3)$	8900	2200
Relative permittivity $/F\cdot m^{-1}$	1	2.1

3.1 *Signal frequency effect signal transmission characteristics of RF cable*

Keeping other parameters unchanged, here choose the experiment signal frequency range from 1GHz to 18GHz, the insulating layer have a thickness of 1.053mm RF cable insertion loss S_{21}, Fig 4 is the simulation results of terminal response with different frequency.

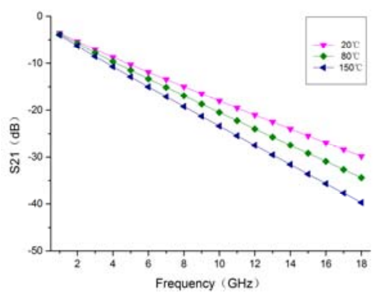

Figure 4. Signal attenuation varies with frequency

Fig 4 shows that the same type of RF cable insertion loss with increasing signal frequency increases when a certain frequency through the RF cable, RF cable will have a skin effect between the inner and outer conductor, and the more signal frequency increases, the more skin depth shallow, the effective resistance of the conductor is also growing, the signal on conductor loss is growing too. For the insulating layer media, with the increasing signal frequency, the dielectric constant is increasing as follow, so the dielectric loss will increase.

3.2 *Ambient temperature is impact on RF cable signal transmission characteristics*

Keeping other parameters unchanged, only change the RF cable where the ambient temperature, set temperature range is 20℃-150℃, the insulating layer having a thickness of 1.053mm RF cable insertion loss S_{21}, Fig 5 is the simulation results of terminal response with different ambient temperature.

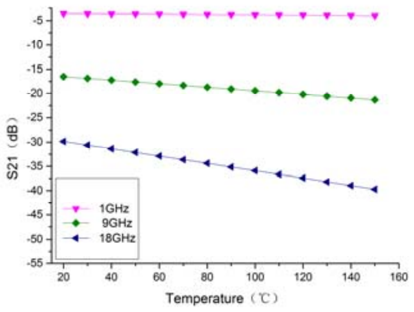

Figure5. Signal attenuation variation with temperature

Fig 5 show that the inner and outer conductors of the RF cable resistance increases when ambient temperature rise. At the same time, when ambient temperature rise, the dielectric constant of the insulating layer with the ambient temperature also increases, resulting in an increase in dielectric loss. In addition, Fig 4 shows the signal frequency in 1GHz, the signal attenuation is less impact on temperature; as the signal frequency increases to 18GHz, the signal attenuation is growing during the recent influence of ambient temperature.

4 MULTIPLE FACTORS ANALYSIS SIGNAL INSERTION LOSSES OF RF CABLE

Using orthogonal design parameter combinations RF cable structure design, ambient temperature and signal frequency to ensure that a minimum number of parameter combinations to get all the information of the selected parameters on radio frequency cable signal transmission characteristics. Then using the finite element method, finite element analysis of signal transmission characteristics in the above-mentioned combination of RF cable parameters and other conditions of the cable, and then get the degree of influence of each parameter on the RF cable signal transmission characteristics, and finally obtain the required combination of parameters.

4.1 *Orthogonal test design*

In the multivariate experiments, when a comprehensive test, the number of tests and experimental treatment will rapid growth with the factors and the number of cells increasing, it is impossible to test all of the arrangements in the first treatment. By orthogonal table to pick out parts of a strong representation of treatment combinations to do the test can be a good solution to the full implementation of multivariate test in many times and the problem is difficult to control the condition. In the orthogonal table, including factors and levels, the presence of factors will affect the test results, and each level is represented by a combination of different factors. According to RF cable signal loss, select the three key factors affecting the RF cable signals: an insulating thickness H, the ambient temperature T, the signal frequency f. Three factors and three levels were selected to show in Table 1. According to the principles of orthogonal experiment design parameters derived factor level quadrature signal loss RF cable as shown in Table 3.

Table 3.Level orthogonal table and simulation results of RF cable signal loss

Number	$H(mm)$	T(℃)	$f(\times10^9 Hz)$	Simulation results $S_{21}(dB)$
1	1(0.48)	1(20)	1(1)	-6.349
2	1(0.48)	2(80)	2(9)	-23.735
3	1(0.48)	3(150)	3(18)	-45.853
4	2(1.035)	1(20)	2(9)	-16.506
5	2(1.035)	2(80)	3(18)	-34.377
6	2(1.035)	3(150)	1(1)	-3.995
7	3(1.53)	1(20)	3(18)	-27.671
8	3(1.53)	2(80)	1(1)	-2.918
9	3(1.53)	3(150)	2(9)	-19.747

Table 3 Shows that a total of nine different level combination of parameters insertion loss of RF cable signal, the corresponding RF cable build nine three-dimensional simulation model based on these nine kinds of RF cable parameters combination, after set 9 different insertion loss in computer simulation, as shown the last below in Table 3. As apparent from Table 3, the thickness of the insulating layer is 0.48mm, ambient temperature is 150 ℃and the signal frequency is 18GHz, the maximum attenuation of the RF signal cable is -45.853dB, so as the number 3 of parameter combinations in table. Similarly, the insulating layer thickness is 1.53mm, ambient temperature is

80 ℃and the signal frequency of 1GHz, the RF cable signal attenuation minimum for -2.918dB, namely the number 8 of parameter combinations in table.

4.2 *Range analysis of signal insertion loss of RF cable*

The signal transmission characteristics S_{21} obtained by orthogonal experiment table 3. Range analysis of insertion loss RF cable obtained results shown in Table 4.

Table 4.Range analysis results of signal transmission characteristics S_{21} of RF cable

Result	Insulation thickness $H(mm)$	Ambient temperature T(℃)	Signal frequency $f(\times 10^9 Hz)$
T_{i1}	-75.937	-50.526	-13.262
T_{i2}	-54.878	-61.03	-59.988
T_{i3}	-50.336	-69.595	-107.901
K_{i1}	-25.312	-16.842	-4.421
K_{i2}	-18.293	-20.343	-19.996
K_{i3}	-16.779	-23.198	-35.967
R_i	8.533	6.356	31.546
Order	2	3	1

From Table 4, the factors on the RF cable signal transmission characteristics S_{21} of the range in order of signal frequency $f(Hz)$> insulation thickness $H(mm)$> ambient temperature T(℃), that is the signal frequency on the RF cable signal transmission characteristics S_{21} in maximum, followed by an insulating layer thickness, the ambient temperature on the least impact. AS analysis results shown, RF cable signal frequency is huge impact on signal transmission characteristics, when the trial of the RF cable environment, in order to ensure the integrity of the radio frequency signal transmission cable, the frequency of their trial environment is extremely important.

4.3 *Variance analysis of signal insertion loss of RF cable*

From the preceding analysis shows that the use of visual range analysis can quickly affect the various factors according to size of the sort, but the accuracy of the results and analysis of variance for tight phase is lack. In addition, significant analysis factors also need to be determined by analysis of variance.

In this study, orthogonal each column is not saturated, there is a blank line, which can be regarded as the error term corresponding factor analysis of variance which is necessary to avoid the error terms obtained by experiment is repeated estimates the amount. Signal transmission characteristics S_{21} of the test results variance analysis table as shown in Table 5.

Table 5. Signal attenuation analysis of variance table

Variance source	Sum of squares	Freedom	Estimator of variance	F	$F_{0.01}$	$F_{0.05}$	Significance
Insulation thickness $H(mm)$	124.3914	2	62.1957	7.6502	99.0	19.0	Non-significant
Ambient temperature T(℃)	60.8138	2	30.4069	3.7401	99.0	19.0	Non-significant
Signal frequency $f(\times 109Hz)$	1492.8348	2	746.4174	91.8114	99.0	19.0	Significant
Error Q_E	16.2598	2	8.1299				
Sum Q_T	1694.2998	8					

The table 5 and table 4 shows the signal frequency values F for significant factors between $F_{0.01}$ and $F_{0.05}$ in three factors affect the RF cable signal transmission characteristics S_{21}. And the value F of the ambient temperature and the thickness of the insulation is less than $F_{0.05}$ is a non-significant factor.

These analytic results show that the factors affecting the RF cable signal transmission characteristics of the signal frequency is the largest and also significant. The other two factors RF cable signal transmission characteristics less affected, and Non-significant. With the further illustrates that the biggest affect factor in the radio frequency signal transmission cable for signal transmission characteristics.

5 CONCLUSIONS

The following conclusions can be found according to experiment:

Size of the RF cable, the temperature of the environment and the frequency of the transmitted signal will have an impact on its insertion loss S_{21}. In other conditions remain unchanged, only changing one factor, the RF cable insertion loss is decrease with increasing insulation layer thickness, in other words with the increase of the RF cable insulation thickness, RF cable signal attenuation smaller. RF cable insertion loss increases as the ambient temperature and signal frequency increases, the greater attenuation of the RF signal cable.

By orthogonal test design, range analysis showed that the effect of RF cable insertion loss factor in the order of: the signal frequency the greatest impact, followed by an insulating layer thickness of the RF cable, and finally the ambient temperature. And get in the insulating layer having a thickness of 1.53mm, ambient temperature is 80 ℃and the signal frequency is 1GHz, RF cable signal attenuation minimum for -2.918dB.

REFERENCES

Bao. G, Chen. Z and Wu .H. "Adaptive finite-element method for diffraction gratings(J)," JOSA A, Vol. 22, No. 6, PP.1106-1114, 2005.

D. J. Fernandes, W. L. A. Neves and J. C. A. Vasconcelos, "Coupling capacitor voltage transformer:A model for electromagnetic transient studies(J)," Electric Power Systems Research, Vol.22, No.2, PP.125-134, 2007.

L. K. Kenneth and I. P. Karen. "Cable transient voltages due to microphonics(J)," Journal of Electrostatics, Vol. 65, No. 12, PP.723-727, 2007.

M. Marzinotto and C. Mazzetti. "Overvoltage attenuation in power cable lines-A simplified estimation method(J)," Electric Power Systems Research, Vol. 80, No. 5, PP. 506-513, 2010.

R. Vaughan, et al., “The electromechanical design of a molded interconnect device for use inside an RF coaxial cable(J),” Analog Devices Integr Microsyst Lab Rochester, NY, USA, Tech. Rep, 2010.

Zhang. J, Chen. Q. P, and Shi. J. “Transient analysis for multi-conductor transmission lines based on FDTD method(J),” Applied Mechanics and Materials, 2014, PP. 1207-1212.