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Ac Steady State Analysis of Transmission Line

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Abstract: In this paper, LT spice has been used to simulate the lumped equivalent circuit of transmission line. The transmission line has been analyzed using alternating current by linear sweep, short circuit and open circuit experiments. In order to verify the results, the electromagnetic wave phase velocity and transmission line characteristic impedance have been calculated, and compared with the theoretical value.

1. Introduction

A transmission line is a linear structure that transmits electromagnetic energy or electromagnetic signals by guiding electromagnetic waves. In general, because of their length, transmission lines cannot be considered lumped. Therefore, segmented circuits composed of lumped devices are used to simulate transmission lines. [1]

2. Theoretical analysis

Lumped circuit is an almost ideal circuit model, in which the response of each component and the transmission medium to the power supply excitation is simultaneous. The signal transmission can be considered as instantaneous.

The electromagnetic signal and electromagnetic energy are transmitted in the form of electromagnetic wave in the circuit and the maximum propagation speed of electromagnetic wave is limited speed of light. However the propagation speed of electromagnetic wave is less than the speed of light in the actual circuit, so the phase of each component may be different in the circuit. However, the phase difference in the circuit can be ignored, and the circuit can be considered as a lumped circuit when the wavelength of the electromagnetic wave in the circuit is much larger than the line of the circuit itself.

Obviously, the transmission line does not meet the above conditions due to its low working frequency and long length. [2]This experiment used a simulated transmission line formed of 12 identical (lumped) L-C sections, when analyzing the ac steady state of the transmission line. The arrangement of the line is shown in figure 1. The circuit simulates a transmission line with insulation having a relative permittivity Ɛr (relative dielectric constant) of 2.25. RG=50Ω, R1=200 Ω and R2 is variable. The load can be changed by terminating the line with resistances or short or open circuits or even resistive and complex loads. The experiment simulates a low loss line with per meter quantities: L = 0.7mH, C = 6.8nF, R = 1Ω and G = 2.0e -6 S.

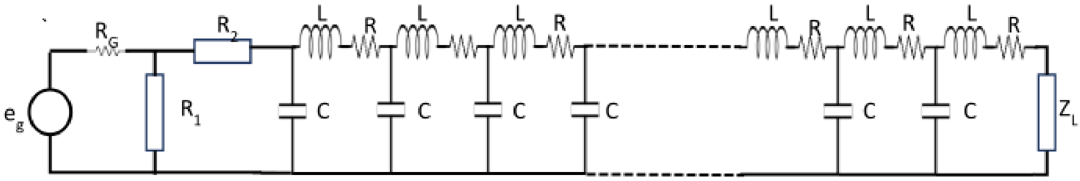

Fig. 1 Transmission line equivalent circuit

3. Alternating Current Steady State Experiment

Sinusoidal excitation is required in this experiment and ac small signal analysis is selected in LT spice. Set the generator eg to 10V. For this part the transmission line should be matched at the source end by adjusting R2.

The characteristic impedance

$$Z0=\sqrt{\frac{L}{C}}=320\Omega$$

And,

$$Zs=Z0=320\,\Omega$$

$$R1//Rg=40\,\Omega$$

So,

$$R2=Zs-R1//Rg=280\,\Omega$$

With the source and load matched, do a linear sweep of the frequency between5kHz and 150 kHz using about 400 points. Plot the load voltage and the source voltage and subtract (V load - V source) them using the cursor arithmetic as shown in Fig 2.

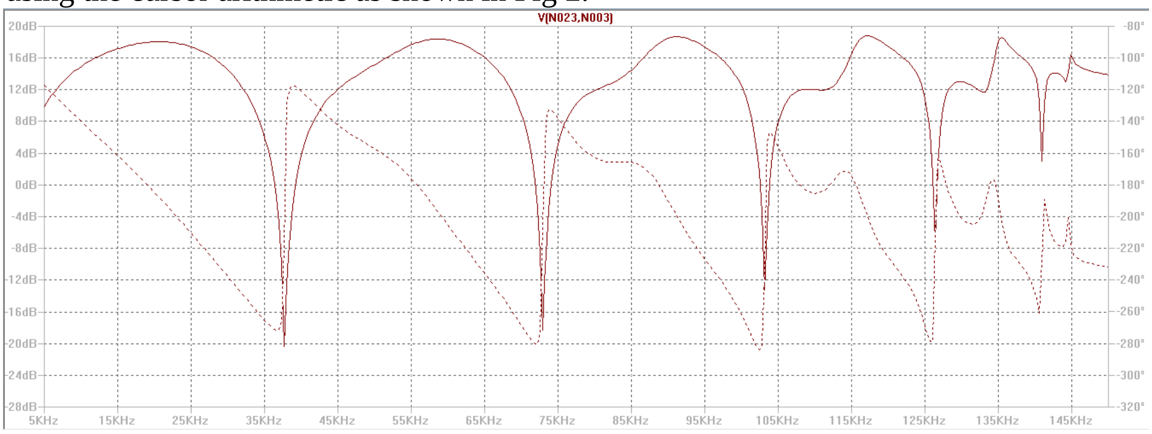

Fig. 2 The voltage difference

In figure 2, the solid line is the voltage amplitude and the dotted line is the phase. Take points where the phase of differential voltage is a multiple of 180 degrees, and record the frequency of the horizontal axis of these points.

β is the propagation coefficient. Vp is the phase velocity. Make a table of the frequencies when the phase of this difference voltage is a multiple of 180 degrees ($n\pi$) as shown in Table 1.

Table 1 Corresponding parameters

φ	f(Hz)	ω (rad/s)	β
π	19221	120084.24	0.00060
2 π	37846.9	237797.83	0.00119
3 π	55656.1	351582.55	0.00175
4 π	75066.3	477938.66	0.00236
5 π	88802.8	557964.45	0.00279
6 π	103315	655430.48	0.00324
7 π	107911	678024.81	0.00412
8 π	111908	703138.70	0.00479
9 π	115655	726681.80	0.00550
10 π	126645	795734.00	0.00598
11 π	128019	804367.10	0.00664
12 π	133889	841249.40	0.00731

From the table, the scatter diagram of ω - β can be make.

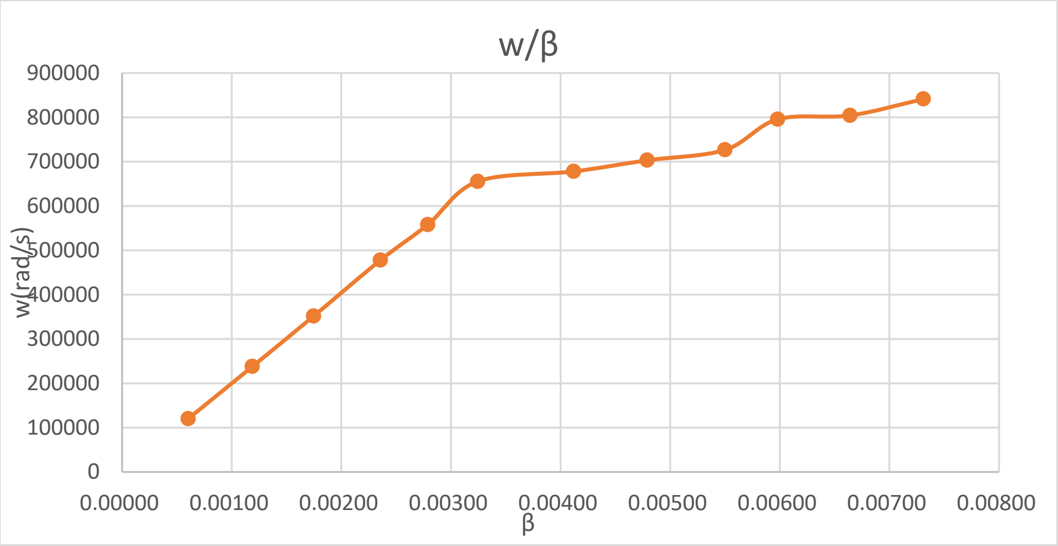

Fig.3 ω - β scatter plot

Take the straight part of Fig 3 and calculate the slope. The slope is Vp and the slope is equal to 2.004×108.The theory of Ɛr is equal to2.25, so

$$V_p = \frac{c}{\sqrt{\varepsilon_r}} = 2\times10^8 m/s$$

It can be seen that the actual value is close to the theoretical value.

Let's say that the transmission line is only 5/8 times the wavelength of the electromagnetic wave, so

$$\lambda = \frac{8}{5} l = 8352m$$

$$f = \frac{v_p}{\lambda} = 23.99kHz$$

Therefore, the power frequency is set as 23.94 kHz and the amplitude is still 10V.Set the load end as open circuit and selects the list function of LT spice. At this time Spice will then give the voltages and current at every node. Record the source voltage Vso and overall partial voltage between transmission line and load end Vd. Similarly, the load end is set as short circuit and record the same data. The input impedance and characteristic impedance are

$$Z_{in}^{o/c} = \frac{V_d R}{V_{so} - V_d}$$

$$Z_{in}^{s/c} = \frac{V_d R}{V_{so} - V_d}$$

$$Z_0 = \sqrt{Z_{in}^{s/c} \times Z_{in}^{o/c}}$$

After calculation, we can get Z0=352Ω.The impedance obtained from experiments is close to the theoretical impedance.

Reference

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