RF AND MICROWAVE ENGINEERING LABORATORY

EXPERIMENT-01

Measurement of Transmission Line Characteristics.

SUBJECT CODE: EC4P002

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❖ OBJECTIVES OF THE EXPERIMENT:

- Measure the characteristic impedance Z_0 of a coaxial transmission line.
- Measure the attenuation constant α of the coaxial transmission line.
- Measure the phase constant β of the coaxial transmission line.

➢ Measurement:

- Frequency: f (in MHz) = $\frac{1}{22}$ $(400 \times 22 + 1800)$ = 481.81 MHz
- Characteristic impedance Z_0 of a coaxial transmission line:

$$Z_{sc} = 980m\Omega - j42.59\Omega$$

$$Z_{oc} = 1.88\Omega + j56.35\Omega$$

$$Z_o = \sqrt{Z_{oc} \times Z_{sc}} = \left(\sqrt{2401.78 - j24.84}\right)\Omega = 49.01\angle - 0.296°\Omega$$

- Attenuation constant **α** of the coaxial transmission line:

$$l = 16.70cm$$

$$tanh(\gamma l) = \frac{Zsc}{Zoc} = A$$

$$A = 0.896\angle - 88.38°$$

$$\alpha = \frac{1}{2l}\left(ln\left|\frac{1+A}{1-A}\right|\right) = \frac{100}{2 \times 16.7} ln\left|\frac{1 + 0.896\angle - 88.38°}{1 - 0.896\angle - 88.38°}\right|$$

$$= \frac{100}{33.4} \times 0.028$$

$$\alpha = 0.084\ Np/m$$

- Phase constant **β** of the coaxial transmission line:

$$f_1 = \frac{1.117Ghz + 1.108GHz}{2} = 1.1125Ghz \approx 1112.5MHz$$

$$\boldsymbol{\beta = \frac{\pi f}{l(f_1 - f)} = \frac{\pi \times 481.81}{0.167(1112.5 - 481.81)}}$$

$$\boldsymbol{\beta = 14.382\ rad/m}$$

➢ **Derive the expression for β shown in the previous slide. Show your work clearly.**

$$\beta = \frac{2\pi}{\lambda}$$

We need to have a phase difference of π in the two frequencies so as to have the same impedance reading in open circuit/ short circuit mode. Let's assume the next observed frequency is f_1 and the original frequency is f. So, we have the phase difference as:

$$\Delta\phi = \pi = l\Delta\beta = l\left(\frac{2\pi}{\lambda_1} - \frac{2\pi}{\lambda}\right)$$

$$\pi = l\left(\frac{2\pi}{\lambda_1} - \frac{2\pi}{\lambda}\right)$$

$$\pi = l\left(\frac{2\pi f_1}{v} - \frac{2\pi f}{v}\right)$$

$$\boldsymbol{v = 2l(f_1 - f)}$$

Now using this result in the original equation:

$$\beta = \frac{2\pi}{\lambda} = \frac{2\pi f}{v} = \frac{2\pi f}{2l(f_1 - f)}$$

$$\boldsymbol{\beta = \frac{\pi f}{l(f_1 - f)}}$$

➢ What is the nature of the trace on the Smith chart in the VNA? What nature should it ideally be, and why is it different?

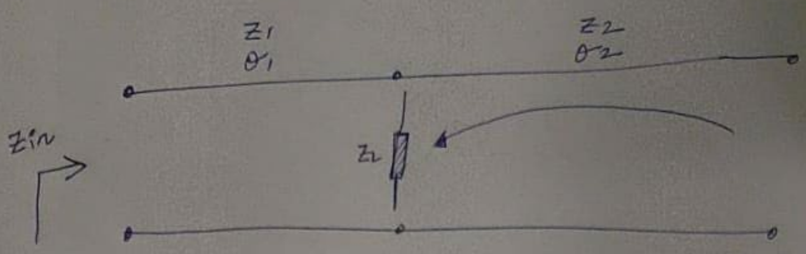
The nature of the trace was circular on the smith chart in the VNA. The ideal nature should be a dot on the short-circuit of open circuit side. We understand that a PERFECT OPEN has a reflection coefficient of one at an angle of zero degrees at all frequencies. There were two observations:

- For most of the part, the circular arc was along the edge of the smith chart, implying that the magnitude of the reflection coefficient remained close to unity along the circle.
- The angle was changing as it is obvious that the trace was a circular arc. This obviously implies that there were capacitances and inductances in a PERFECT OPEN or PERFECT CLOSE and which did depend on the frequency due to which there was change in the angles.
- What introduces these frequency dependent inductances and capacitances?

Although the calibration standards of a SOLT (short, open, load, thru) calibration kits are usually called opens and shorts, a more accurate name for almost all calibration standards would be offset open and offset short. Each calibration standard has a length of transmission line, after which the inner conductor is either left unconnected (an open standard) or shorted to the outer conductor (a short standard). This length of transmission line adds a delay, so the phases are no longer 0° and 180°. However, there are two other effects too.

- The open circuit has some capacitance between the inner and outer conductors. This causes a further delay
- The short has some inductance. This again causes further delay, although not as much as the capacitance of the open standard. The inductance can generally be ignored.

- **A transmission line is created by fusing end-to-end, two lossless coaxial cables of impedances Z_1 and Z_2, and electrical lengths θ_1 and θ_2. Obtain an expression for the characteristic impedance of this new fused transmission line.**



Looking from Z_1 side, as the fusion would not be symmetrical, lets find the overall impedance by the formula :

$$Z_0 = \sqrt{Z_{oc} Z_{sc}}$$

The (Z_2, θ_2) line can be transformed to Z_L in open ckt & short ckt as

$$Z_{L,sc} = jZ_2 \tan\theta_2 \qquad Z_{L,oc} = -jZ_2 \cot\theta_2$$

Now,

$$Z_{in,sc} = Z_1 \times \frac{(jZ_2 \tan\theta_2) + jZ_1 \tan\theta_1}{Z_1 + j(jZ_2 \tan\theta_2)\tan\theta_1}$$

similarly

$$Z_{in,oc} = Z_1 \frac{(-jZ_2 \cot\theta_2) + j\tan\theta_1 Z_1}{Z_1 + j(-jZ_2\cot\theta_2)\tan\theta_1}$$

$$\Rightarrow Z_0 = \sqrt{Z_{in,oc} \times Z_{in,sc}} = \sqrt{\frac{Z_1^2\, j(Z_2\tan\theta_2 + Z_1\tan\theta_1)\, j(Z_1\tan\theta_1 - Z_2\cot\theta_2)}{(Z_1 - Z_2\tan\theta_1\tan\theta_2)(Z_1 + Z_2\cot\theta_2\tan\theta_1)}}$$

$$= Z_1\sqrt{\frac{(Z_2\tan\theta_2 + Z_1\tan\theta_1)(Z_2\cot\theta_2 - Z_1\tan\theta_1)}{(Z_1 - Z_2\tan\theta_1\tan\theta_2)(Z_1 + Z_2\cot\theta_2\tan\theta_1)}}$$

➢ Give a brief explanation on your understanding of the experiment.

In this experiment, we have calculated the transmission line characteristics using supplied transmission line's open and short circuit impedance values. We can calculate the characteristic impedance and the attenuation coefficient **α** using the given mathematical relationship between the impedances. After that, we can calculate the phase constant **β** by observing the greater frequency **f_1** where we get the identical open and short circuit impedances.

➢ References:

- Why VNA calibration standards are arcs on a Smith Chart, not dots (kirkbymicrowave.co.uk)
- When we measure the OPEN or SHORT reflection on a VNA, why the results is in arcs, but not a dot, on a Smith Chart as most people expect? - Technical Support Knowledge Center Open (keysight.com)