Parameters Update Integration in EM Analysis of ATL and PTL in the FDM

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Abstract: The modeling of artificial and planar transmission lines for microwave communications is as critical as the premium set on the bandwidth of the line. Reflectionless networks are ideal for realizing the -3dB signal transmission margin. This paper proposes an electromagnetically (EM)-engineered measurement environment where the parameters of the frequency domain (FD) analysis of the ATL and PTL are adaptively and proactively updated for circuits characterization. This novelty promises immense enhancement in the channel characterization of TEM and dispersive transmission lines.

Keywords: ATL, FD, Microwave networks, PTL

1. Introduction

Transmission of information as an electromagnetic signal always occurs as a transverse electromagnetic (TEM) wave or as the combination of such waves as in a waveguide. [1][2]. With transmission lines, the metallic conductors confine the TEM wave to the vicinity of the dielectric surrounding the conductors; as a result, some aspects of the transmission are best treated in terms of the distributed circuit parameters of the line, while others require the wave properties of the line to be taken into account [1]. Energy travels along a transmission line in the form of an electromagnetic wave, the wave set up by the signal source being known as the incident (or forward) wave. Only when the load impedance at the receiving end is a reflectionless match for the line will all the energy be transferred to the load. If reflectionless matching is not achieved, energy will be reflected back along the line in the form of a reflected wave. The ratio of the maximum voltage to maximum current at any point on such a line is a constant, that is, independent of position; it is called the characteristic impedance, Z_o [1][2]. With a sinusoidal signal of angular frequency ω rad/sec, the characteristic impedance in terms of the primary constants is found to be [1][2]:

$$Z_o = \{(R+j\omega L)/(G+j\omega C)\}^{1/2}. \tag{1}$$

$$\begin{cases} \text{At low frequencies, } Z_o = \{R/G\}^{1/2} & R \gg \omega L, \text{ and } G \gg \omega C, \\ \text{At high frequencies, } Z_o = \{L/C\}^{1/2} & R \ll \omega L \text{ and } G \ll \omega C, \end{cases} \tag{2}$$

The phase shift coefficient (or radian/length) [1] is given by $\beta = 2\pi/\lambda$ (rad/m) (3)

Artificial transmission lines [1][2] comprise discrete lumped circuit elements representation of distributed constant lines. When the line is operating below a certain cut-off frequency, its nodal voltages represent discrete samples of the standing wave voltage on an equivalent uniform transmission line. An infinite number of elements would simulate a truly distributed network [2].

TEM transmission lines have both the electric and magnetic fields contained in a transverse plane perpendicular to the direction of propagation. Other lines, such as the planar transmission line, have some components of the electric and magnetic filed lines in the direction of propagation; these lines are often termed quasi-TEM lines. At low frequencies, the microstrip line is a quasi-TEM line and has propagation constant and characteristic impedance that vary with frequency. Thus, its phase velocity of propagation varies with frequency and the line is termed dispersive [1][3].

The phase velocities [3] of three practical scenarios are summarized thus:

(i) $\upsilon=1/(L_oC_o)^{1/2}=c$ (4)

where Lo and Co are the capacitance and inductance per unit length for an air-filled line and c is the speed of light in air.

(ii) $\upsilon =1/(\varepsilon_r L_oC_o)^{1/2}=c/\sqrt{\varepsilon_r}$ (5)

where ε_r is the relative dielectric constant of the dielectric material (but not magnetic-medium) of the TEM TL

(iii) $\upsilon=1/(\varepsilon_{reff} L_oC_o)^{1/2}=c/\sqrt{\varepsilon_{reff}}$ (6)

where ε_{reff} is the effective dielectric constant of the non-TEM TL; it accounts for the part of the electric energy that is confined among the various materials with different dielectrics.

2. EM-Engineered Measurement Model

The frequency domain measurement (FDM) is very insufficient to model TEM and non-TEM lines at microwave frequencies. This shortcoming can be obviated by having an embedded electromagnetically-engineered measurement environment on the measuring equipment platform. Tuning parameters and facilities for setting TL optimisation goals should be incorporated in the program module. In this way, the FD parameters are simulated and updated in apriori and then measurements taken would reflect ideal TL values. The various line cases are summarized below.

2.1 Terminating Conditions of the Lossless ATL

In practice, scenarios where lossless transmission lines with particular terminations whose lengths reveal useful properties arise [1][2].

The total voltage on the line is $V(z)=V_o^+(e^{-j\beta z}+e^{j\beta z})$ (7)

The input impedance, Z_{in}, of a transmission line is given by [2]:

$Z_{in} = Z_o\{Z_L+jZ_o\tan(\beta l)\}/\{Z_o+jZ_L\tan(\beta l)\}$ (8)

where Z_L= load impedance (Ω), Z_o =characteristic impedance of the ATL (Ω) and l is the length of the ATL (m).

The ratio of the amplitude of the reflected voltage wave to the amplitude of the incident voltage wave at the load is called the voltage reflection coefficient, Γ, and is given by [1][2]:

$\Gamma = V_o^- / V_o^+ = \{Z_L - Z_o\}/\{Z_L + Z_o\}$ (9)

The voltage standing wave ratio, s, is given by [2]:

$S = |V|_{max}/|V|_{min} = \{1+|\Gamma|\}/\{1-|\Gamma|\}$ (10)

where V_{max} and V_{min} are the maximum and minimum voltages along the ATL respectively. Equation (10) provides a measure of the mismatch between the load and the transmission line. Also, the following holds [2]:

when $R<Z_o$, $Z_o=s.R$ and when $R>Z_o$, $Z_o=R/s$ (11)

2.1.1 Short-Circuited Line (Z_L=0)

In the case of the short circuited lossless line [2], the input impedance is purely reactive (inductive) and is given by:

$Z_{in}= jZotan(\beta l)$ (12)

$\Gamma= -1$ and $V(z) =-2jV_o^+\sin(\beta z)$. This is shown in figure 1.

2.1.2 Open Circuit Line (Z_L=∞)

Here [2], $Z_{in} = -jZ_o\cot(\beta z)$, $\Gamma=1$ and $V(z)=2V_o^+\cos(\beta z)$ (13)

The above macroscopic treatment of the line can be extended to planar transmission lines with appropriate boundary conditions.

3. Results

The insufficiency of the traditional FDM approach has been unfolded via a comparative time domain measurement (TDM) model. An ATL of about 3750m length was used for this experiment in both approaches.

Table 1 shows the open and short circuits measurements taken to determine the length of the ATL in the FD. The line resonanted at 41.35KHz and 41.10KHz in the S/C and O/P cases respectively. The resulting voltage distribution for the two terminating cases is shown in figure 1.

TABLE 1. DETERMINATION OF LENGTH OF ATL USING FDM.

CONDITION	FREQUENCY, f (KHz)	PERIOD, T (μs)	WAVELENGTH, λ (m)	LENGTH, l=λ/2 (m)
O/C	41.35	24	7250	3625
S/C	41.10	24	7294	3647

$T=1/f$; $\lambda=(2.998\times10^8)/f$

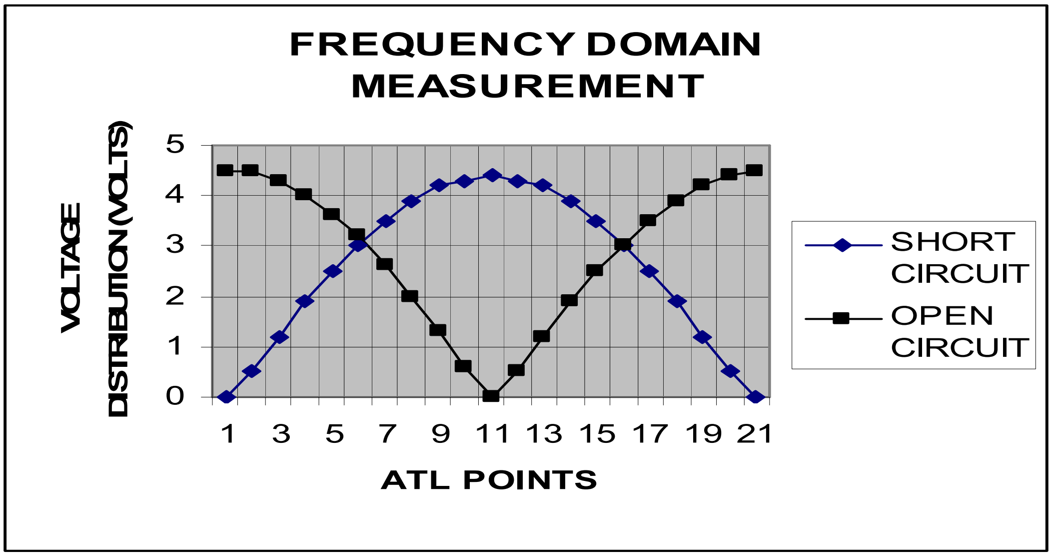

Fig. 1. A plot of short circuit and open circuit Voltage Distributions for a 21-point ATL.

Table 2 shows the determination of the characteristic impedance, Z_o and the VSWR of the ATL using three resistors (A, B and C) as terminating loads.

TABLE 2. Determination of Z_o and Voltage Standing Wave Ratio (VSWR) using FDM.

RESISTANCE (Ω)		V_{max} (V)	V_{min} (V)	VSWR ($=V_{max}/V_{min}$)	R<Z_o	R>Z_o	Z_o (Ω)
					Z_{o1}(Ω)	Z_{o2}(Ω)	
R_A	99.83	2.81	1.66	1.69	168.70	59.00	168.70
R_B	43.70	3.40	0.91	3.74	163.40	11.70	163.40
R_C	555.90	3.35	1.05	3.19	1777.00	174.30	174.30

Table 3 shows the time delay recorded in the TD analysis. For the open and short circuits cases, the approximate time delay value was 25μs. Being a step input (pulse signal), the length of the ATL was determined directly assuming the wave traveled along the line at the speed of light.

TABLE 3. Time Delay and Length of ATL using TDM.

CONDITION	TIME DELAY, τ (μs)	LENGTH, $l = (\tau \times 2.998 \times 10^8)/2$ (m)
O/C	24.80	3717.52
S/C	24.70	3702.53

The above results reveal the superiority of the time domain measurement over the frequency domain approach. The TDM yielded an average 3,710m ATL length and characteristic impedance of 173Ω as opposed to the FDM's 3,636m and 170 Ω respectively.

Again, the TDM is inherently handicapped relative to the length of the ATL used for the experiment. These anomalies are therefore attributed to the open nature of the measurement platform which is obviously lacking the EM-engineered environment to address line and measurement constraints in real-time.

4. Conclusion

This paper has revealed the shortcomings of the frequency domain measurement of non-dispersive transmission lines and by extension, non-TEM lines. Fundamental in this presentation is the need for an EM-engineered measurement platform to be incorporated into measuring equipment where insitu data reception, simulation, optimisation and measurement can be adaptively and proactively effected in a closed loop scenario.

This proposed model promises to enhance timely transmission lines modeling, design, fabrication and /or manufacture. Thus, accurate lines characterization will be ensured and cheap microwave devices will be produced with attendant reliability.

References

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