

Education System on High Frequency Circuits using Information Technology

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Abstract

This paper deals with a high frequency(microwave) circuit simulator written in JAVA for the sake of a distance learning at undergraduate course. Through the World Wide Web browser, students can learn peculiar conceptions and behaviors of high frequency waves having the same order of wavelength as the circuit length. This simulator has also been contrived to have students' experience that some cascade matrices and the relationships among the cascade, impedance, and scattering matrix can design high frequency circuit.

Using these matrices, students can try to design some microwave devices such as filters with desired characteristics. Through this system, students would be able to learn the basic conception of high frequency signal and learn fundamental design method.

1. Introduction

Microwave has been used in many kinds of applications such as satellite or mobile communication, remote sensing, and many types of measurement systems. Due to the large information handling capability, high frequency technique such as microwave is useful for recent multimedia communication using large information including high quality images and audio signals. In addition, high-speed digital transmission needs the high frequency technique in recent computers and digital communication, where a high-speed digital signal has higher frequency spectra compared to the bit rate frequency and a wide frequency width.

Therefore, education on high frequency techniques has been one of the important fields in electrical engineering. On top of that, distance education has also been one of the hot topics in higher education among universities. Even in distance education, high frequency education is an important subject and then microwave simulators are needed instead of measuring instruments. However, it is not easy at present to use any commercial simulator through conventional system for students, because most of the simulators have been designed for

uses on a site and, in addition, we should take care of differences of platforms.

This paper deals with a high frequency circuit simulator written in JAVA[1] for the sake of a distance learning at undergraduate course. Through the World Wide Web browser, students can learn peculiar conceptions and behaviors of high frequency waves in a circuit being comparable in size with the wavelength. Teachers can let students use this system as their preparation for students' laboratory or for regular class by having access at any time from their home or a computer room in the university.

This simulator teaches the microwave network conception, i.e. students can design high frequency circuits or simulate their behavior using some cascade matrices, and also teaches the microwave network concept.

Using these matrices, students can try to design some microwave devices such as filters with desired characteristics. Through this system, students would be able to learn the basic conception of high frequency circuits and design method.

2. Microwave circuit using transmission line model.

In high frequency circuit with such as microwave frequency[2][3], students should consider the generalizations to circuit theory when effects are distributed rather than lumped, and also when circuits become comparable in size with wavelength so that retardation from one part of the circuit to another must be considered. Considering the distributed effects, students have to recognize that the fields contributing to circuit elements are always distributed in space as shown in fig.1 and the representation by a lumped element is valid only when the region is small in comparison with wavelength. The characteristics of this line is decided by both propagation characteristics $\gamma = \alpha + j\beta$ ($\alpha = 2\pi / \lambda_g$; λ_g is wavelength in the waveguide) and characteristic impedance Z_0 .

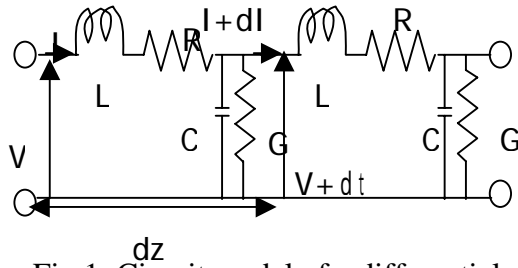


Fig.1: Circuit model of a differential length of a transmission line.

In this learning system, students have to be aware of the transmission line model as shown in fig.1. From this figure, the differential equations are derived as follows;

$$dV = -(R + j\omega L)Idz \quad (1)$$

$$dI = -(G + j\omega C)Vdz \quad (2)$$

The solutions of (1) and (2) are derived as follows;

$$V = V_i e^{-\gamma z} + V_r e^{\gamma z} \quad (3)$$

$$I = I_i e^{-\gamma z} + I_r e^{\gamma z} \\ = \frac{V_i}{Z_c} e^{-\gamma z} - \frac{V_r}{Z_c} e^{\gamma z} \quad (4)$$

$$Z_c = \sqrt{(R + j\omega L)/(G + j\omega C)}$$

In (3) and (4), V_r , V_i , I_r , and I_i are unknown coefficients, Z_c is characteristic impedance, $\gamma = \alpha + j\beta$ where α [Np/m] is attenuation constant and $\beta = 2\pi/\lambda$ [rad/m] is phase constant and expressed as

$$\gamma^2 = (R + j\omega L)(G + j\omega C), \quad (5)$$

where $\omega = 2\pi f$ is angular frequency.

Using (3),(4), we can derive the cascade matrices [K] with the boundary conditions of $V=V_1$ and $I=I_1$ at $z=0$, and $V=V_2$ and $I=I_2$ at $z=l_z$ for the circuit length l_z as follows;

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = [K] \begin{bmatrix} V_2 \\ I_2 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix} \quad (6)$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cosh \gamma l_z & Z_c \sinh \gamma l_z \\ \frac{1}{Z_c} \sinh \gamma l_z & \cosh \gamma l_z \end{bmatrix}$$

In this learning system, we assumed microstrip line. The characteristic impedance Z_c of the microstrip is expressed with an experimental formulation[4] (see appendix A).

3. Microwave networks

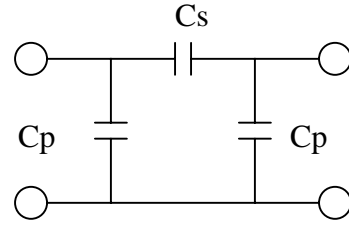


Fig.2 Equivalent circuit of microstrip gap.

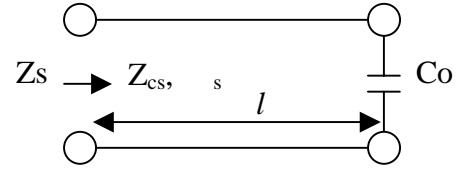
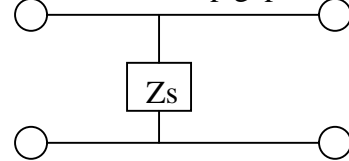


Fig.3 Equivalent circuit of microstrip stub

This system treats the concept of the microwave networks[2] of microstrip devices including a couple of parts such as gaps or stubs. Fig. 2 and fig.3 show the equivalent circuits from which we can derive the cascade matrices (see appendix B and C).

Using these cascade matrices, we can derive the impedance matrices [Z] and the scattering matrices [S] as follows;

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = [Z] \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} \\ = \frac{1}{C} \begin{bmatrix} A & |K| \\ 1 & D \end{bmatrix} \\ [S] = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} = \{[Z] + [I]\}^{-1} \{[Z] - [I]\}, \quad (7)$$

where [I] is the unit matrix. In this case, we assume a two port circuit on which, for example, the reflection power at the port 1 is described by S11 and the transmitted power from the port 1 to port 2 is described by S21. The cascade matrices [K] in (7) is made of products of several cascade matrices corresponding to each part of the device/circuit such as $[K] = [K_1][K_2] \dots$. The cascade matrices of $n \times n$, n port device with arbitrary structure can be described.

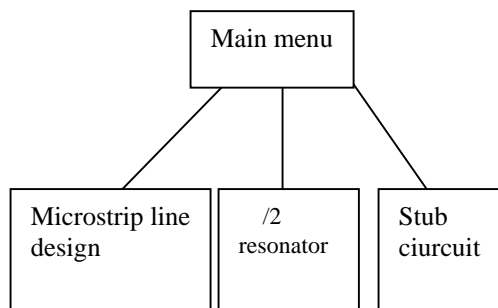


Fig.4 Tree structure of the simulator, where equivalent circuit and the cascade matrix of each circuit has been shown.

4. Simulation

In this simulator written in JAVA, students can learn several types of circuits described by the cascade matrices. This simulator offers a page for calculating the Z_c of the microstrip line and two types of circuits consisting of the gaps or a stub at the moment. Fig.4 shows the tree structure of the simulator where a web browser calls a JAVA applet written with complex variables from a HTML document. At first, students have to decide the width of the microstrip line w , the thickness h and permittivity of the substrate r , at the “design” page so that the characteristic impedance Z_c can be suitable value (mostly 50 ohm) at the page of “microstrip line design”.

4.1 Microstrip line with stub

Fig.5 is a microstrip line (main line) having a stub with l in length. At first, the stub has an open-ended termination. The width of both the main line and the stub are assumed to be same and should be decided to get the desired Z_c . The stub circuit at the web site is shown in fig.6, where there are two buttons for showing the equivalent circuit and matrix structure.

Fig.7 shows an example of S_{21} characteristics seen at the web site. Students input parameters such as stub length l , w , h , and r . After pushing the “Calculate”, students can see the S_{21} and frequencies at the minimums. Furthermore, students can learn the S_{21} characteristics for the case of short-ended stub by checking the check window.

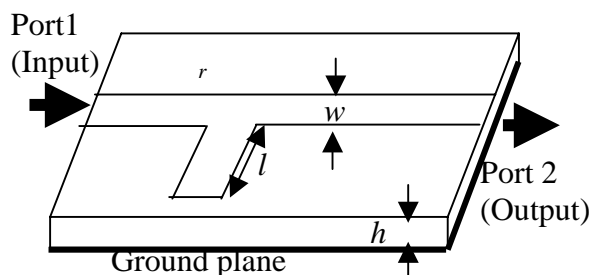


Fig.5 Microstrip line with stub.

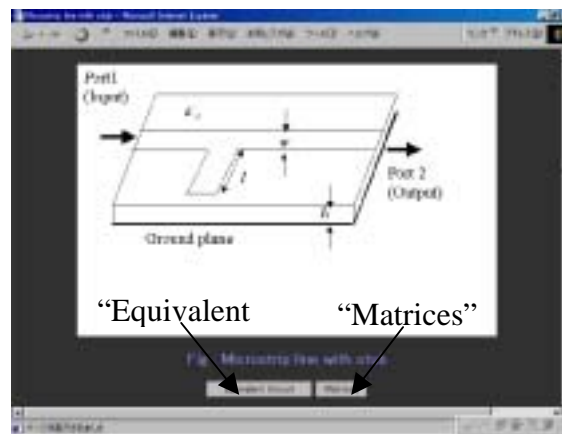


Fig.6 Figure of Microstrip line with stub.

Students are expected to notice the relationships between the effective wavelength λ_g and l . In the case of open-ended stub, when $|S_{21}|$ value is a minimum, l corresponds to $(2n-1)\lambda_{gm}/4$ (n :integer), where λ_{gm} is the wavelength of the frequencies at the minimums. In the case of short-ended stub, on the other, l corresponds to $n\lambda_{gm}/2$ when $|S_{21}|$ is at the minimum.

According to the S_{21} characteristics, students may come up with applications for filters. In addition, this simulator can also show both the phase characteristics and input impedance characteristics. From these characteristics, students may come up with other applications such as an impedance matching circuit or a phase shifter.

Students can also learn the equivalent circuit and microwave networks using cascade matrices after pushing the button of “Equivalent circuit” or “Matrices”. Fig.8 shows the equivalent circuit and matrices structure. The equivalent circuit and matrices are shown in other windows. This setup can be programmed using Java Script[5][6].

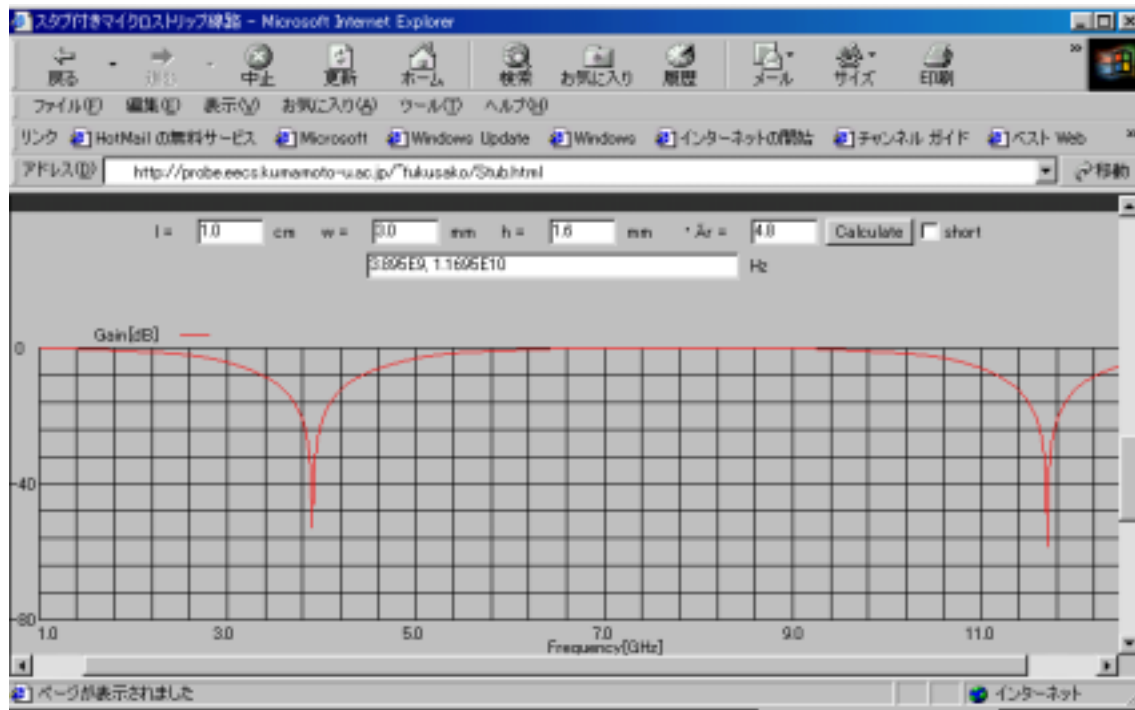


Fig7 S21 characteristics of the microstrip with stub on the web site.

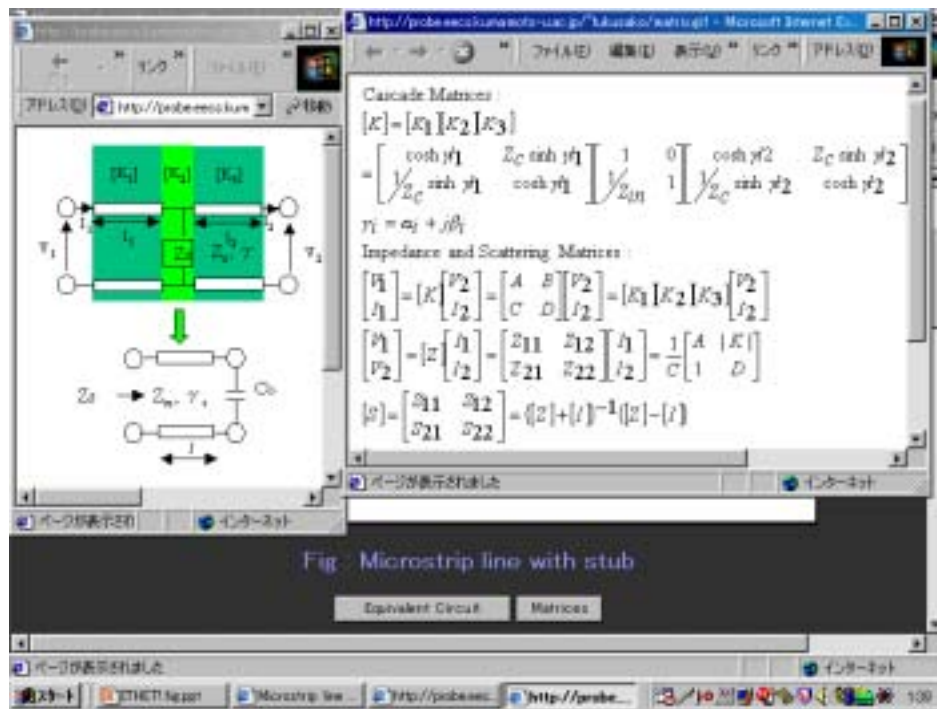


Fig.8 The equivalent circuit and matrices pages at the web site.

4.2 Half-wavelength microstrip resonator

Fig.9 shows the half-wavelength microstrip resonator with l_r in length, which is coupled with input and output ports through the gaps. Fig.10 shows the S_{21} characteristics of the resonator. Students input the parameters such as stub length l_r , w , h , and r . After pushing the "Calculate", this simulator will show the S_{21} and frequencies at the maximums. Students are expected to notice that these frequencies are resonance frequencies whose wavelength is $n \lambda_g/2$. On top of that, the Q value of the resonator is reduced as the n is increased. In also this page, students can learn the equivalent circuit or matrices structure of the resonator.

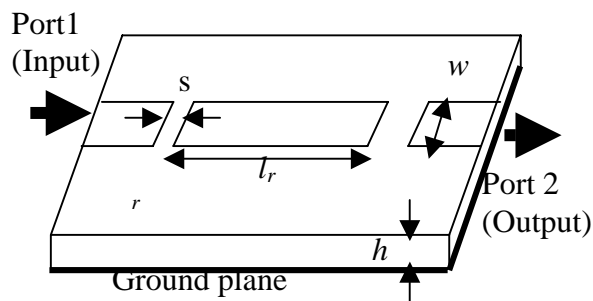


Fig.9 Half-wavelength microstrip resonator.

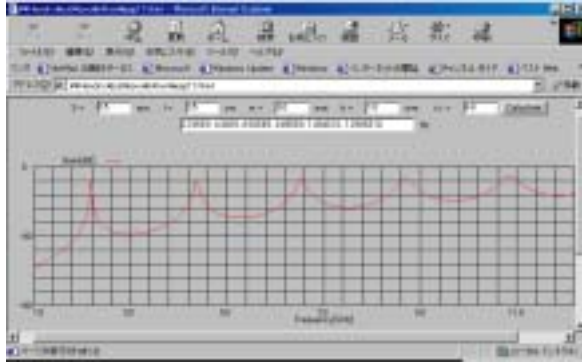


Fig.10 S_{21} characteristics of the half-wavelength resonator at the web site.

5. Discussions and conclusion

This simulation system for microwave circuit has been written in JAVA so that student can learn through internet. From this simulator, students can learn the microwave behavior in circuits being comparable in size and the microwave networks. The authors proposed two types of microwave circuits as examples. We can offer other type of circuits in addition those circuits. One aim of this system is encouragement of preparation on the student

laboratory. For example, students can design the microwave circuits for the laboratory at home or computer room, then they can fabricate the circuits and measure the characteristics in the laboratory room. At present this system has been assumed to use at the student laboratory in Kumamoto University for the design and fabrication[7]. At the same time, student can learn or confirm the transmission line theories, the microwave networks, and the microwave behavior on the circuits being comparable in size with the wavelength. This system is programmed with complex variables using our library, that is, it is easy to calculate the phase and complex impedance characteristics.

The computation time is an important problem on line because some students may have to pay communication charge by the hour when they use at home. In this simulator, only design formulas have been used so that computation time can be reduced compared to the MoM[8] (method of moment), FEM(Finite element method)[9] or FDTD (finite difference time domain) method[10]. Actually, there was not any problem on computation time when one of the authors used a PC with Windows98SE, Internet Explorer5, 500MHz Pentium III CPU, and 64MB memory.

As future problems, this system should be improved to treat any circuit with arbitrary form and more than two-port circuit. Any losses in the microstrip structure should also be considered[11]. Finally, this kind of system could contribute to publicity on the department through the Internet in addition to education.

6. References

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Appendix

A. Characteristics impedance of microstrip line

Characteristics impedance Z_c of microstrip line can be calculated using following equation[4];

$$Z_c = \frac{120}{\sqrt{2(\epsilon_r + 1)}} \left[\ln \left\{ \frac{4h}{w} + \sqrt{16 \left(\frac{w}{h} \right)^2 + 2} \right\} - \frac{\epsilon_r - 1}{2(\epsilon_r + 1)} \left\{ \ln \left(\frac{\pi}{2} \right) + \frac{\ln \left(\frac{4}{\pi} \right)}{\epsilon_r} \right\} \right] \quad (A)$$

which has 1 ~ 2% errors when $w/h < 3.3$, where w is the width of the line and h is the substrate thickness.

B. Parameters in the equivalent circuit of the gap in fig.2

$$C_s = 0.5hQ_1 \exp(-1.86s/h) \left\{ 1 + 4.19(1 - \exp(-0.785\sqrt{h/w})) \right\}$$

$$C_p = C_L(Q_2 + Q_3)/(1 + Q_2)$$

$$Q_1 = 0.04598(0.03 + \left(\frac{w}{h} \right)^{1.23})(0.272 + 0.07\epsilon_r)$$

$$Q_2 = 0.107 \left(\frac{w}{h} + 9 \right) \left(\frac{s}{h} \right)^{3.23}$$

$$+ 2.09 \left(\frac{s}{h} \right)^{1.05} (1.5 + 0.3 \frac{w}{h}) / (1 + 0.6 \frac{w}{h})$$

$$Q_3 = \exp(-0.5978) - 0.55$$

The cascade matrix of the gap is given by following equation;

$$A = 1 + \frac{Z_s}{Z_p}, \quad B = Z_s, \quad C = \frac{Z_s + 2Z_p}{Z_p^2}, \quad D = 1 + \frac{Z_s}{Z_p}$$

$$Z_s = \frac{1}{j\omega C_s}, \quad Z_p = \frac{1}{j\omega C_p}.$$

C. Parameters in the equivalent circuit of the stub in fig.3

$$Z_s = Z_c \frac{1 + Z_c Y_p \tanh \gamma l_s}{Z_c Y_p + \tanh \gamma l_s}, \quad Y_p = j\omega C_p,$$

C_p : Open - ended capacitance

C_p is given by following equations, which shows the edge effect at the open-ended termination[1]; This equation may have errors less than 2.5% when

$$C_p \cong \Delta l_L \sqrt{\epsilon_{eff}} / (Z_c c), \quad c : \text{velocity of light}$$

$$\Delta l_L = hPQR / S$$

$$P = 0.434907 \times \frac{(\epsilon_{eff}^{0.81} + 0.26)((w/h)^{0.8544} + 0.236)}{(\epsilon_{eff}^{0.81} + 0.819)((w/h)^{0.8544} + 0.87)}$$

$$Q = 1 + (0.5274 / \epsilon_{eff}^{0.9236}) \arctan(0.084(w/h)^{1.9413/T})$$

$$R = 1 - 0.218 \exp(-7.5w/h)$$

$$S = 1 + 0.377 \{ 6 - 5 \exp(0.036(1 - \epsilon_r)) \}$$

$$T = 1 + \frac{(w/h)^{0.371}}{2.358\epsilon_r + 1}.$$

$$0.01 \leq w/h \leq 100, \quad 1 \leq \epsilon_r \leq 50.$$

The ϵ_{eff} is the effective permittivity given as follows;

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + \frac{10h}{w} \right)^{-0.555},$$

then the propagation constant is given as follows;

$$\gamma = \alpha + j\beta$$

$$\beta = \frac{\omega}{c} \sqrt{\epsilon_{eff}}$$

$$\alpha = 0 \quad (\text{Lossless}).$$

The loss of microstrip line consists of dielectric loss, conductor loss, and radiation loss. However, in this simulator, any loss has been ignored. The attenuation constant has been discussed in detail at [11] which offers design formulas of the losses.