Question:

What is a transmission line? When should transmission-line effects be considered, and when may they be ignored?

Answer:

Step 1

A transmission line is a conductor that is capable of transmitting energy from one point to another. A transmission line can be referred as a two-port network with each port having two sets of terminals.

Examples of a transmission line are coaxial cable, electric power lines and wiring.

Step 2

Whether to ignore the transmission line effects or to consider the, the decision is based on the length of the line (l) and the frequency of operation f.

For a frequency f, the wavelength is,

$$\lambda = \frac{c}{f}$$

The phase delay is given by,

$$\begin{aligned}
\phi_0 &= \frac{\omega l}{c} \\
&= \frac{2\pi f l}{c} \\
&= \frac{2\pi\left(\frac{c}{\lambda}\right)l}{c} \\
&= 2\pi\frac{l}{\lambda}
\end{aligned}$$

Step 3

If the ratio, $\frac{l}{\lambda}$ is very small (very less than 0.01), then the transmission line effects can be ignored.

If the ratio, $\frac{l}{\lambda}$ is somewhere equal or greater than 0.01, then the transmission line effects cannot be neglected. The time delay and the presence of reflected signals must be taken into consideration in such a case.

Therefore, the transmission lines effects are taken into consideration when $\frac{l}{\lambda} \geq 0.01$.

Question:

What is the difference between dispersive and nondispersive transmission lines? What is the practical significance of dispersion?

Answer:

Step 1

In a non-dispersive transmission line, there is no distortion of signals passing through it despite of its length.

Step 2

A dispersive line distorts the shape of the input pulses since there is propagation of different frequency components at different velocities.

The significance of dispersion is the degree of distortion is proportional to the dispersive line length.

Question:

What constitutes a TEM transmission line?

Answer:

Step 1

The transmission line is represented by a parallel-wire configuration, irrespective of its specific shape.

Each section of transmission line section is represented by equivalent circuit, and this representation is called as lumped circuit representation.

Hence, **the lumped circuit element in transmission line is used to represent each section by its equivalent circuit.**

Step 2

The TEM transmission lines lumped element section consist of following:

R', L', G', and C'

Here,

R': The combined resistance of both conductors per unit length, in Ω/m.

L': The combined inductance of both conductors per unit length, in $\mathrm{H/m}$.

G': The conductance of the insulation medium between the two conductors per unit length, in $\mathrm{S/m}$

C': The capacitance of the two conductors per unit length, in $\mathrm{F/m}$.

Therefore, **the transmission line parameters physical and electromagnetic properties are listed and explained above.**

Question:

What purpose does the lumped-element circuit model serve? How are the line parameters R', L', G' and C' related to the physical and electromagnetic constitutive properties of the transmission line?

Answer:

Step 1

The lumped-element circuit model is to analyze the transmission line by an equivalent circuit composed of its parameters such as resistance R', inductance L', conductance G', and capacitance C'.

The line elements R', L', G', C' reflects the physical properties of the currents and voltages on transmission line.

Step 2

The electromagnetic constitutive properties of the transmission line consist of two groups:

- μ_c and σ_c are the magnetic permeability and the electrical conductivity of the conductors.
- ε, μ and σ are the electrical permittivity, magnetic permeability and electrical conductivity of the insulation material separating them.

Step 3

The resistance R' directly proportional to the surface resistance, which depends on the material properties of the conductors μ_c and σ_c.

The line inductance L' and capacitance C' relates with electromagnetic constitutive properties as,

$$L'C' = \mu\varepsilon$$

The conductance G' and capacitance C' relates with electromagnetic constitutive properties as,

$$\frac{G'}{C'} = \frac{\sigma}{\varepsilon}$$

Question:

The attenuation α constant represents ohmic losses. In view of the model given in Fig. 2-6(c), what should R' and G' be in order to have no losses? Verify your expectation through the expression for α given by Eq. (2.25a).

Answer:

Step 1

The attenuation constant is given by

$$\begin{aligned}\alpha &= \Re e\{\gamma\} \\ &= \Re e\left(\sqrt{(R' + j\omega L')(G' + j\omega C')}\right)\end{aligned}$$

The transmission lines can be designed to exhibit low ohmic losses by selecting conductors with very high conductivities and dielectric materials with negligible conductivities. As a result the values of R' and G' assume very small values such that $R' \square\ \omega L'$ and $G' \square\ \omega C'$. From these conditions the value of R' and G' are set to $R' = G' \square\ 0$.

The attenuation constant yields for low ohmic losses is,

$$\alpha = \Re e\left(j\omega\sqrt{L'C'}\right)$$

Question:

How is the wavelength λ of the wave traveling on the transmission line related to the free-space wavelength λ0?

Answer:

Step 1

The phase velocity is given by the formula,

$$u_p = \frac{1}{\sqrt{\mu\varepsilon}}$$

The permittivity ε is often specified in terms of the relative permittivity ε_r defined as,

$$\varepsilon_r = \varepsilon/\varepsilon_0$$
$$\varepsilon = \varepsilon_r\varepsilon_0$$

Now substitute ε in u_p.

$$\begin{aligned} u_p &= \frac{1}{\sqrt{\mu_0\varepsilon_r\varepsilon_0}} \\ &= \frac{1}{\sqrt{\mu_0\varepsilon_0}}\cdot\frac{1}{\sqrt{\varepsilon_r}} \\ &= \frac{c}{\sqrt{\varepsilon_r}} \end{aligned}$$

Here, $c = \frac{1}{\sqrt{\mu_0\varepsilon_0}}$

If the insulating material between the conductors is air, then $\varepsilon_r = 1$

Substitute $\varepsilon_r = 1$ in u_p.

$$\begin{aligned} u_p &= \frac{c}{1} \\ &= c \end{aligned}$$

Step 2

The wave length is given by,

$$\lambda = \frac{u_p}{f}$$
$$= \frac{c}{f}\frac{1}{\sqrt{\varepsilon_r}}$$
$$= \frac{\lambda_0}{\sqrt{\varepsilon_r}}$$

Here, $\boldsymbol{\lambda_0 = c/f}$ is the wavelength in air corresponding to the frequency f.

Question:

When is a load matched to a transmission line? Why is it important?

Answer:

Step 1

When load impedance is equal to the characteristic impedance $(Z_L = Z_0)$ then load is matched to a transmission line.

Step 2

If load is not matched , then there are reflections in the transmission line and a standing wave is formed.

Question:

What is a standing-wave pattern? Why is its period $\lambda/2$ and not λ?

Answer:

Step 1

When there is a mismatch between the load impedance and the input impedance, the incident wave on the load is reflected back towards the source.

The incident and the reflected wave superimpose and form a stationary wave, this wave is called as standing wave.

Step 2

The incident wave or the reflected wave has a period of λ, it repeats for every λ in spatial variation.

The maximum value of the standing wave happens when incident interfere constructively.

The minimum value of the standing wave happens when incident interfere destructively.

Since the incident and reflected waves repeat for every λ, the interference occurs every $\frac{\lambda}{2}$.

The maxima or the minima repeat every $\frac{\lambda}{2}$.

The standing wave has these waves superimposed the resulting wave is reduced to a period of $\frac{\lambda}{2}$.

Question:

What is the separation between the location of a voltage maximum and the adjacent current maximum on the line?

Answer:

Step 1

The separation between the location of the voltage maximum and the adjacent current maximum on the line is $\frac{\lambda}{4}$, here λ is the wavelength .

The maximum value of the standing-wave pattern of $|\tilde{V}(d)|$ corresponds to the position on the line at which the incident and reflected waves are in-phase and therefore add constructively to give a value equal to $(1+|\Gamma|)|V_0^+| = 1.3V$.

Question:

What is the difference between the characteristic impedance Z0 and the input impedance Zin? When are they the same?

Answer:

Step 1

On a transmission line there is a standing wave that is two opposite travelling waves when the load is mismatched.

The characteristic impedance Z_0 of a transmission line is the ratio of the voltage and current of either of the travelling waves individually along the line at any point.

Step 2

The input impedance Z_{in} is the impedance which can see through the input terminals of the transmission line.

Step 3

For the matched transmission line, output impedance Z_0 is equal to the load impedance Z_L.

For the half wave length transmission line, the input impedance Z_{in} is equal to the load impedance Z_L, provided the load impedance is equal to the characteristic impedance Z_0, the input impedance is equal to the characteristic impedance Z_0.

Thus, the input impedance Z_{in} is equal to the output impedance Z_0 for the half wave length matched transmission line.

Question:

What is a quarter-wave transformer? How can it be used?

Answer:

Step 1

The quarter-wave transformer is a transmission line in which length of the line is $l = \lambda/4$. This is also called as quarter wave line.

The quarter wave transformer technique is used to match a transmission line to a load with a complex impedance.

Question:

A lossless transmission line of length l is terminated hi a short circuit. If l < λ/4, is the input impedance inductive or capacitive?

Answer:

Step 1

Write the expression for the input impedance of the transmission line.

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

Substitute $\frac{2\pi}{\lambda}$ for β.

$$Z_{in} = Z_o \frac{\left(Z_L + jZ_o \tan\left(\frac{2\pi}{\lambda}\right)l\right)}{\left(Z_o + jZ_L \tan\left(\frac{2\pi}{\lambda}\right)l\right)}$$

Step 2

Substitute 0 for Z_L, the load is a short circuit.

$$Z_{in} = Z_o \frac{\left(0 + jZ_o \tan\left(\frac{2\pi}{\lambda}\right)l\right)}{\left(Z_o + j(0)\tan\left(\frac{2\pi}{\lambda}\right)l\right)}$$
$$= jZ_o \tan\left(\frac{2\pi}{\lambda}\right)l$$

$$l < \frac{\lambda}{4}$$
$$\Rightarrow \beta l < \frac{2\pi}{\lambda}\left(\frac{\lambda}{4}\right)$$

If $\Rightarrow \beta l < \frac{\pi}{2}$

Step 3

The characteristic impedance of a lossless transmission line is real and it is a resistance only.

The value of $\tan\left(\left(\frac{2\pi}{\lambda}\right)l\right)$ is positive and finite, when $\beta l < \frac{\pi}{2}$.

Thus, the value of the input impedance of the transmission line of length, $l < \frac{\lambda}{4}$ is,

$Z_{in} = jaZ_o$; a is a constant related to $\tan\left(\left(\frac{2\pi}{\lambda}\right)l\right)$, when $\beta l < \frac{\pi}{2}$.

The input impedance is positive and it is in the form of $j\omega L$.

Thus, the input impedance is of inductive nature.

Question:

What is the input impedance of an infinitely long line?

Answer:

Step 1

The input impedance of an infinitely long line is equal to its characteristic impedance Z_0 as long as $\alpha \neq 0$.

Question:

If the input impedance of a lossless line is inductive when terminated in a short circuit, will it be inductive or capacitive when the line is terminated in an open circuit?

Answer:

Step 1

It is given that, if the input impedance of a loss less transmission line is inductive when terminated in a short circuit.

The input impedance of the load less transmission line terminated in an open circuit is given by,

$$Z_{in}^{oc} = -jZ_0 \cot \beta l$$

Thus, the negative sign indicates that the circuit is lagging means input impedance is capacitive.

Question:

According to Eq., the instantaneous value of the reflected power depends on the phase of the reflection coefficient θr, but the average reflected power given by Eq. does not. Explain.

$$P^r(d,t) = -|\Gamma|^2 \frac{|V_0^+|^2}{2Z_0}[1+\cos(2\omega t - 2\beta d$$
$$+ 2\phi^+ + 2\theta_r)].$$

$$P^r_{av} = -|\Gamma|^2 \frac{|V_0^+|^2}{2Z_0} = -|\Gamma|^2 P^i_{av}.$$

Answer:

Step 1

The instantaneous value of the reflected power depends on the phase of the reflection coefficient θ_r, but the average reflected power does not depend on the refection coefficient since the time-averaged values of sinusoids do not depend on phase. That is when a time-average of a sine or cosine is taken; the value will be zero, which eliminated the phase term.

Question:

What is the average power delivered by a lossless transmission line to a reactive load?

Answer:

Step 1

The average power delivered by a lossless transmission line with a reactive load is,

$$\frac{|V_0^+|^2}{2Z_0}\left[1-|\Gamma|^2\right]$$

Where,

Amplitude of the incident wave is V_0^+,

Characteristic impedance is Z_0, and

Reflection coefficient is Γ.

Question:

What fraction of the incident power is delivered to a matched load?

Answer:

Step 1

All of the incident power is delivered to a matched load.

Question:

Verify that

$$\frac{1}{T}\int_0^T \cos^2\left(\frac{2\pi t}{T}+\beta d+\phi\right)dt=\frac{1}{2},$$

regardless of the values of d and ϕ, so long as neither is a function of t.

Answer:

Step 1

Write the expression of the integral equation.

$$\frac{1}{T}\int_0^T \cos^2\left(\frac{2\pi t}{T}+\beta d+\phi\right)dt$$

Observe that d,ϕ are independent of the t and are constants.

Determine the value of the integral.

$$\begin{aligned}\frac{1}{T}\int_0^T \cos^2\left(\frac{2\pi t}{T}+\beta d+\phi\right)dt&=\frac{1}{T}\int_0^T\left(\frac{1+\cos\left(2\left(\frac{2\pi t}{T}+\beta d+\phi\right)\right)}{2}\right)dt\\&=\frac{1}{T}\int_0^T\left(\frac{1}{2}\right)dt+\frac{1}{T}\int_0^T\left(\frac{\cos\left(\frac{4\pi t}{T}+2\beta d+2\phi\right)}{2}\right)dt\\&=\frac{1}{2T}[t]_0^T+\frac{1}{2T}\int_0^T\left(\cos\left(\frac{4\pi t}{T}+2\beta d+2\phi\right)\right)dt\end{aligned}$$

Step 2

Consider the second term $\frac{1}{2T}\int_0^T\left(\cos\left(\frac{4\pi t}{T}+2\beta d+2\phi\right)\right)dt$.

$\cos\left(\frac{4\pi t}{T}+2\beta d+2\phi\right)$ is the cosine signal in the above integral.

Compare the cosine in the above integral with standard cosine signal, $\cos(\omega t+x)$.

$$\omega=\frac{4\pi}{T}$$
$$\frac{2\pi}{T_0}=\frac{4\pi}{T}$$
$$T_0=\frac{T}{2}$$

The cosine is periodic with a fundamental period of $\frac{T}{2}$, the integral is over a period of T, an integral multiple of $\frac{T}{2}$.

Step 3

Integration of a sine and cosine over its fundamental period and an integral multiple of fundamental period is equal to zero as the positive half cycles and negative half cycles are equal and cancel out.

Thus, the second part of the integral is '0'.

$$\frac{1}{2T}\int_0^T\left(\cos\left(\frac{4\pi t}{T}+2\beta d+2\phi\right)\right)dt=0$$

The resulting expression is,

$$\begin{aligned}\frac{1}{T}\int_0^T\cos^2\left(\frac{2\pi t}{T}+\beta d+\phi\right)dt&=\frac{1}{2T}[t]_0^T+0\\&=\frac{1}{2T}[T-0]\\&=\frac{1}{2}\end{aligned}$$

Thus, the value of integral is $\boxed{\frac{1}{T}\int_0^T\cos^2\left(\frac{2\pi t}{T}+\beta d+\phi\right)dt=\frac{1}{2}}$.

Hence proved.

Question:

The outer perimeter of the Smith chart represents what value of $|\Gamma|$? Which point on the Smith chart represents a matched load?

Answer:

Step 1

The Smith chart is a graphical tool used to analyze and design transmission line circuits. The outer perimeter of the Smith chart represents $|\Gamma|=1$. Here Γ is the reflection coefficient. The origin of the Smith chart represents a matched load.

Question:

What is an SWR circle? What quantities are constant for all points on an SWR circle?

Answer:

Step 1

An SWR circle is a circle on a Smith chart with constant radius. The reflection coefficient, $|\Gamma|$ is constant for all values on the SWR circle. Since the standing wave ratio, S depends on the reflection coefficient; the standing wave ratio is also constant on the SWR circle of Smith chart.

Question:

What line length corresponds to one complete rotation around the Smith chart? Why?

Answer:

Step 1

A complete rotation around the Smith chart corresponds to $l = \frac{\lambda}{2}$ because we must have a phase change of 2π in Γ which gives

$$
\begin{aligned}
2\beta d &= 2\left(\frac{2\pi}{\lambda}\right)d \\
&= 2\left(\frac{2\pi}{\lambda}\right)\left(\frac{\lambda}{2}\right) \\
&= 2\pi
\end{aligned}
$$

Here,

Γ is voltage reflection coefficient,

λ is wave length,

β is phase constant and

d is distance from the load.

Question:

Which points on the SWR circle correspond to locations of voltage maxima and minima on the line and why?

Answer:

Step 1

The zero phase angle point on the SWR circle of a Smith chart corresponds to the location of the voltage maxima because the constant-magnitude voltage is completely real and positive and the phase angle π point corresponds to the location of the voltage minima because the constant-magnitude voltage is only real and negative.

Question:

Given a normalized impedance zL, how do you use the Smith chart to find the corresponding normalized admittance yL = 1/zL ?

Answer:

Step 1

It is given the normalized impedance value z_L. The normalized admittance value y_L can be found using Smith chart by moving to the opposite side of the point representing the normalized impedance on the constant-SWR circle and taking the value at the point as the normalized admittance.

Step 2

The normalized admittance is the mirror image of the normalized Impedance. Hence, by moving in that direction we can find the value of normalized admittance.

Question:

To match an arbitrary load impedance to a lossless transmission line through a matching network, what is the required minimum number of degrees of freedom that the network should provide?

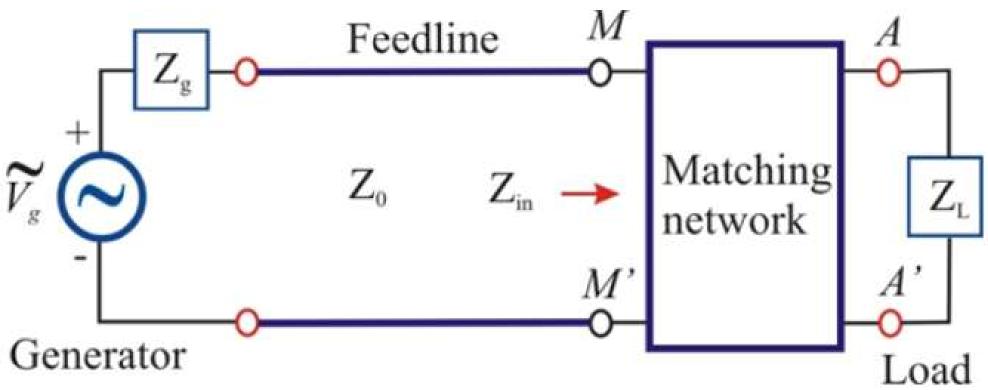
Answer:

Step 1

The transmission line is said to be matched to the load when it's characteristic impedance

$Z_0 = Z_L$, in which case waves traveling on the line towards the load are not reflected back to the source.

The impedance-matching network is



Step 2

The purpose of the matching network is to eliminate reflections at terminals MM' for waves incident from the source. Even though multiple reflections may occur between AA' and MM', only a forward traveling wave exists on the feedline.

The function of a matching network is to transform the load impedance Z_L such that the input impedance Z_{in} looking into the network is equal to Z_0 of the transmission line.

Within the matching network, reflections can occur at both terminals (AA' and MM') creating a standing-wave pattern, but the net result (of all of the multiple reflections within the matching network) is that the wave incident from the source experiences no reflection when it reaches terminals MM'. This is achieved by designing the matching network to exhibit impedance equal to Z_0 at MM' when looking into the network from the transmission line side. If the network is lossless, then all the power going into it will end up in the load. Matching networks may consist of lumped elements (to minimize ohmic losses only capacitors and inductors are used) or of sections of transmission lines with appropriate lengths and terminations.

Step 3

The matching network, which is intended to match a load impedance $Z_L = R_L + jX_L$ to a loss less transmission line with characteristic impedance Z_0, may be inserted either in series (between the load and the feedline) or in parallel. In either case, the network has to transform the real part of the load impedance from R_L (at the load) to Z_0 at MM' and transform the reactive part from X_L (at the load) to zero at MM'. To achieve these two transformations, the matching network must have at least two degrees of freedom (that is, two adjustable parameters).

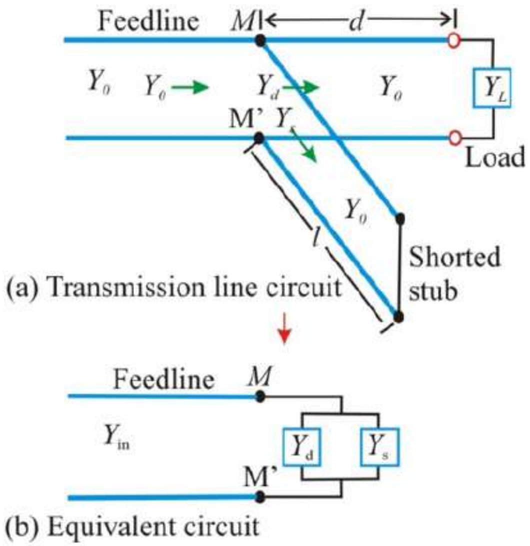
Question:

In the case of the single-stub matching network, what are the two degrees of freedom?

Answer:

Step 1

The single-stub matching network is



Step 2

The single-stub matching network consists of two transmission line sections, one of length d connecting the load to the feed line at MM' and another of length l connected in parallel with the other two lines at MM'. This second line is called a stub and it is usually terminated in either a short or open circuit and hence its input impedance and admittance are purely reactive. The stub shown in the figure has a short-circuit termination.

The required two degrees of freedom are provided by the length l of the stub and the distance d, from the load to the stub position

Chapter 2 Problem 26CQ

When a transmission line is matched to a load through a single-stub matching network, no waves will be reflected toward the generator. What happens to the waves reflected by the load and by the shorted stub when they arrive at terminals MM' in Fig.?

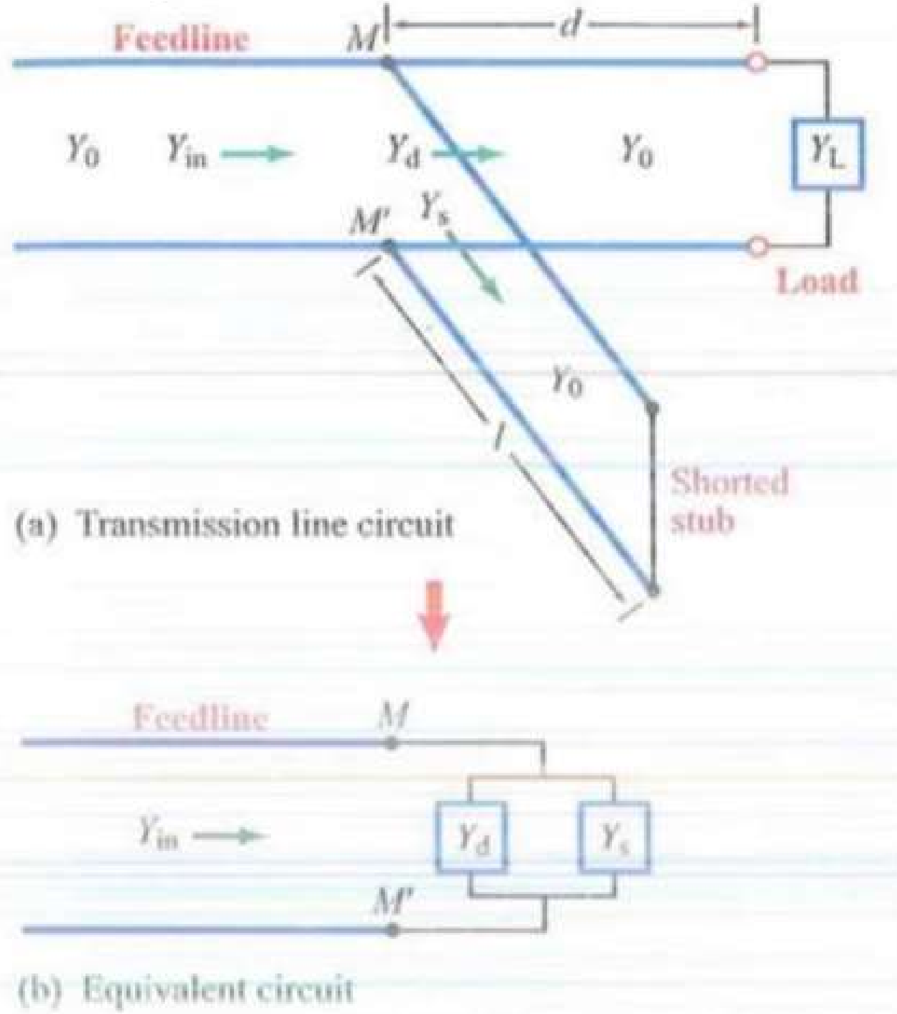
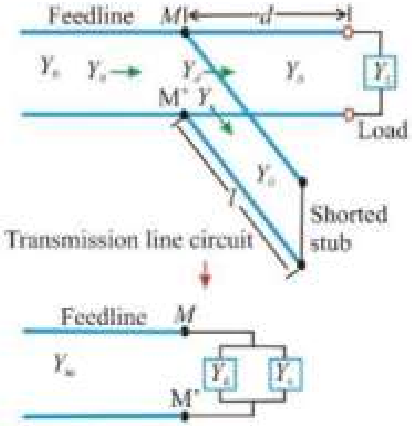


Figure 2-38: Single-stub matching network.



(a) Transmission line circuit

(b) Equivalent circuit

Because at MM' the stub is added in parallel to the line (which is why it is called a shunt stub), it is easier to work with admittances than with impedances. The matching procedure consists of two steps. In the first step, the distance d is selected so as to transform the load admittance $Y_L = \frac{1}{Z_L}$ into an admittance of the form $Y_d = Y_0 + jB$, when looking towards the load at MM'. Then, in the second step, the length l of the stub line is selected so that its input admittance Y_s at MM' is equal to $-jB$. The parallel sum of the two admittances at MM' yields Y_0 the characteristic admittance of the line.

Question:

What is transient analysis used for?

Answer:

Step 1

Thus far, our treatment of wave propagation on transmission lines has focused on the analysis of single-frequency, time-harmonic signals under steady-state conditions. The

impedance-matching and Smith chart techniques we developed, while useful for a wide range of applications, are inappropriate for dealing with digital or wideband signals that exist in digital chips, circuits, and computer networks. For such signals, we need to examine the transient transmission line response instead.

The transient response of a voltage pulse on a transmission line is a time record of its back and forth travel between the sending and receiving ends of the line, taking into account all the multiple reflections (echoes) at both ends.

Question:

The transient analysis presented in this section was for a step voltage. How does one use it for analyzing the response to a pulse?

Answer:

Step 1

The transient analysis on transmission lines for a step voltage can be used for analyzing the response of a rectangular pulse $V(t)$ of duration τ by treating the pulse as the sum of two step functions of opposite polarities displaced by a distance τ relative to each other.

Question:

What is the difference between the bounce diagram for voltage and the bounce diagram for current?

Answer:

Step 1

Transient analysis of pulses on transmission lines can be performed using a bounce-diagram graphical technique that tracks reflections at both the load and generator ends of the transmission line.

The bounce diagram for voltage and that for current works on the same principle except r the reversal of the signs of Γ_L and Γ_g at the top of the bounce diagram

sherlock