

Lecture 11: Dispersion. Stripline and Other Planar Waveguides.

Perhaps the biggest reason the TEM mode is preferred over TE or TM modes for propagating communication signals is that ideally it is **not dispersive**. That is, the phase velocity of a TEM wave is not a function of frequency [$v_p \neq g(\omega)$] provided the material properties of the waveguide are not functions of frequency.

To see this, recall for a TEM wave that $\beta = \omega\sqrt{LC}$. Therefore,

$$v_p = \frac{\omega}{\beta} = \frac{1}{\sqrt{LC}}$$

which is not a function of frequency, as conjectured, provided neither L nor C are functions of frequency.

However, for either TE or TM modes, v_p **is** a function of frequency regardless of the material properties of the waveguide.

Take the rectangular waveguide as an example. In the last lecture, we found that with $e^{-j\beta z}$ propagation

$$\beta = \beta_{mn} = \sqrt{k^2 - k_{c,mn}^2} \quad \text{and} \quad k_{c,mn}^2 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2$$

where $m, n = 0, 1, 2, \dots$ ($m = n \neq 0$) for TE modes, while $m, n = 1, 2, \dots$ for TM modes.

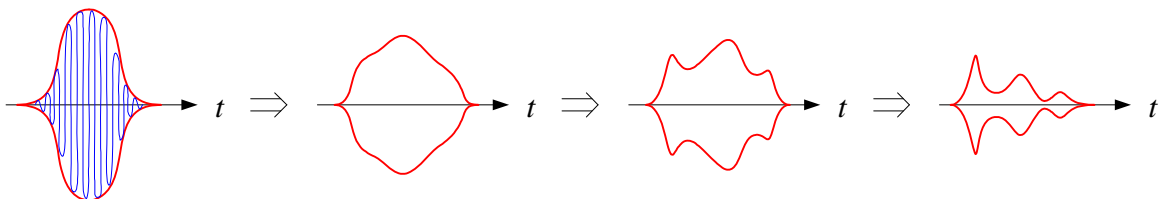
For a CW signal carried by one of these modes, the phase velocity is

$$v_{p,mn} = \frac{\omega}{\sqrt{\omega^2 \mu \epsilon - k_{c,mn}^2}}$$

which is clearly a function of frequency. Consequently, we have confirmed that **TE and TM modes** in a rectangular waveguide **are dispersive**.

One special case is $m = n = 0$. Since $k_{c,00} = 0$, then $v_p \neq g(f)$ which means this is not a dispersive mode. However, the $m = n = 0$ mode is the TEM mode, which cannot exist in a hollow conductor waveguide.

The problem with (temporally) dispersive modes is that they can severely **distort signals** that have been modulated onto them as the carrier. As the signal propagates down the waveguide:



In communications, such distortion is often unacceptable. Therefore, the TEM mode is the one commonly used in microwave engineering. (For high power applications, hollow waveguides made be required; hence, one would need to somehow work around the distortion.)

Since we prefer to work with the TEM mode of wave propagation, it is important that we use waveguides in our microwave circuits that will support **TEM or “quasi-TEM” modes**. Examples of such structures are:

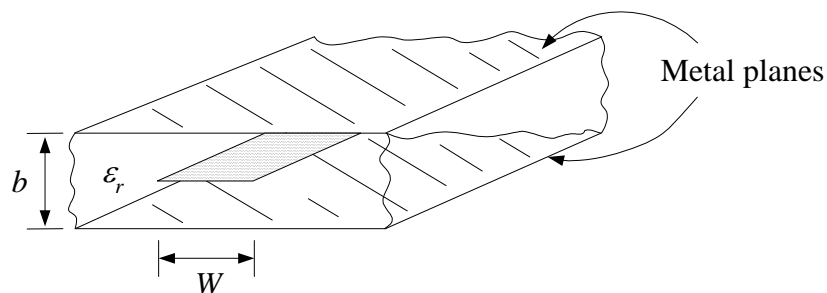
- Microstrip and covered microstrip
- Stripline
- Slotline
- Coplanar waveguide.

In this course, we will work primarily with microstrip. Actually, in the lab we will exclusively use microstrip.

Before delving into microstrip, however, let's quickly overview some of these other TEM waveguides, beginning with stripline.

Stripline

Stripline is a popular, planar geometry for microwave circuits. As shown in Fig. 3.22:



Stripline has one or more interior strip conductors immersed in a dielectric with ground planes above and below.

Stripline can support the TEM mode exclusively provided that $b \lesssim \lambda/4$ where $\lambda = \lambda_0 / \sqrt{\epsilon_r}$. At higher frequencies, TE and TM modes may also propagate, which leads to signal distortion and other undesirable effects. This is called an “**over-moded**” waveguide.

We’ll assume that the (carrier) frequency is “low” enough that $b \lesssim \lambda/4$ and only the TEM mode propagates. As with any TEM mode, in a stripline with $\mu = \mu_0$:

$$\bullet \quad v_p = \frac{1}{\sqrt{LC}} = \frac{c_0}{\sqrt{\epsilon_r}} \quad (3.176),(1)$$

$$\bullet \quad \beta = \frac{\omega}{v_p} = k_0 \sqrt{\epsilon_r} \quad (3.177),(2)$$

$$\bullet \quad Z_0 = \sqrt{\frac{L}{C}} = \frac{\sqrt{LC}}{C} = \frac{1}{v_p C} \quad (3.178),(3)$$

Once ϵ_r is known, we can straightaway determine v_p , β , and Z_0 since none of these quantities depend on frequency for a TEM mode.

“Forward” Stripline Design

We will need to design stripline with a specific Z_0 . **How do we determine C** (the p.u.l. capacitance) required in (3) to accomplish this? Unfortunately, there is no simple, exact analytical solution for stripline (or microstrip, for that matter).

Other the other hand, extremely accurate **numerical solutions** can be found using a number of techniques including the method of moments and the finite element method, among others.

By curve fitting to these numerical solutions, it can be shown that for a stripline:

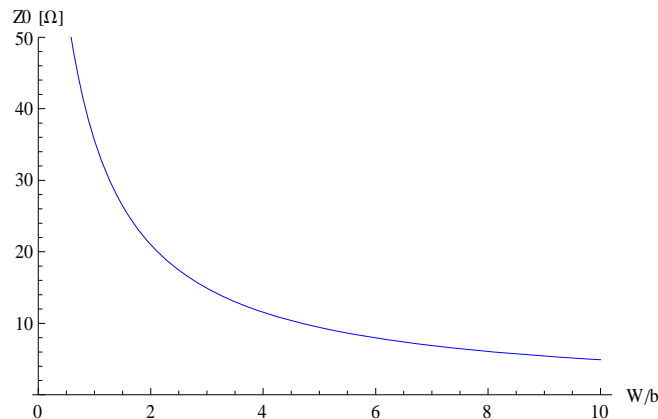
$$Z_0 \approx \frac{30\pi}{\sqrt{\epsilon_r}} \frac{b}{W_e + 0.441b} \quad [\Omega] \quad (3.179a),(4)$$

where W_e is called an “effective strip width” given by

$$\frac{W_e}{b} = \frac{W}{b} - \begin{cases} 0 & \frac{W}{b} \geq 0.35 \\ \left(0.35 - \frac{W}{b}\right)^2 & \frac{W}{b} < 0.35 \end{cases} \quad (3.179b),(5)$$

Equation (4) is quite accurate, to 1% or so.

As an example, if we stack two Rogers RO4003C laminates, then $b = 2 \cdot 0.032" = 1.626$ mm and $\epsilon_r = 3.38$. Using (4):



Notice that as W/b increases, Z_0 decreases.

With $b = 1.626$ mm, then to obtain $Z_0 = 50 \Omega \Rightarrow W/b = 0.58$ from this plot. Therefore, $W = 0.58 \cdot b = 0.943$ mm.

“Reverse” Stripline Design

One can also determine the “inverse” of (4) so that W/b can be determined once ϵ_r and the required Z_0 are specified:

$$\frac{W}{b} = \begin{cases} x & Z_0 \sqrt{\epsilon_r} \leq 120 \\ 0.85 - \sqrt{0.6 - x} & Z_0 \sqrt{\epsilon_r} > 120 \end{cases} \quad (3.180a),(5)$$

where $x = \frac{30\pi}{Z_0 \sqrt{\epsilon_r}} - 0.441$. (3.180b)

For example, with $\epsilon_r = 3.38$ and $Z_0 = 50 \Omega$, $50\sqrt{3.38} = 91.92$. From the upper solution in (5) we find that

$$\frac{W}{b} = \frac{30\pi}{50\sqrt{3.38}} - 0.441 = 0.5843$$

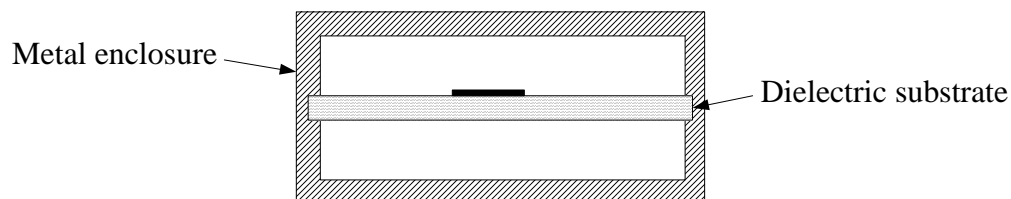
This is very close to the graphical solution we just obtained.

The text describes an approximate electrostatic solution for Z_0 on pp. 144-147. Surprisingly, that numerical solution is presumably **less accurate** than (4), so we will not discuss it. [It assumes a **constant charge density** on the strip conductor as in (3.188), which cannot be true because of the so called “edge effect,” as we’ll see in Lecture 13.]

Other Planar Waveguides

Besides stripline and microstrip, there are a few other **popular planar waveguides**:

1. Slotline – Fig 3.33,
2. Coplanar waveguide – Fig 3.34,
3. Covered microstrip – Fig 3.35,
4. Suspended stripline:



A nice comparison of the electromagnetic and physical characteristics of coaxial cable, hollow waveguides, stripline, and microstrip is given in **Table 3.6**.