2.7 – Lossy Transmission Lines

Reading Assignment: ***pp. 79-82***

Recall that we have been **approximating** low-loss transmission lines as lossless ($R = G = 0$):

$$\alpha = 0 \qquad\qquad \beta = \omega\sqrt{LC}$$

But, **long** low-loss lines require a **better** approximation:

$$\alpha = \frac{1}{2}\left(\frac{R}{Z_0} + GZ_0\right) \qquad\qquad \beta = \omega\sqrt{LC}$$

Now, if we have **really long** transmission lines (e.g., long distance communications), we can apply **no** approximations at all:

$$\alpha = Re\{\gamma\} \qquad\qquad \beta = Im\{\gamma\}$$

For these **very** long transmission lines, we find that $\beta = Im\{\gamma\}$ is a **function** of signal **frequency** ω. This results in an extremely serious problem—signal **dispersion**.

HO: The Distortionless Line

The Distortionless Line

Recall that the **phase velocity** v_p (i.e., propagation velocity) of a wave in a transmission line is:

$$v_p = \frac{\omega}{\beta}$$

where:

$$\begin{aligned}\beta &= Im\{\gamma\} \\ &= Im\left\{\sqrt{(R + j\omega L)(G + j\omega C)}\right\}\end{aligned}$$

Thus, for a lossy line, the phase velocity v_p is a **function of frequency** ω (i.e., $v_p(\omega)$)—this is **bad**!

* Any signal that carries significant **information** must has some non-zero **bandwidth**. In other words, the signal energy (as well as the information it carries) is **spread** across many frequencies.

* If the different frequencies that comprise a signal travel at different velocities, that signal will arrive at the end of a transmission line **distorted**. We call this phenomenon signal **dispersion**.

Dispersion: A matter of distance

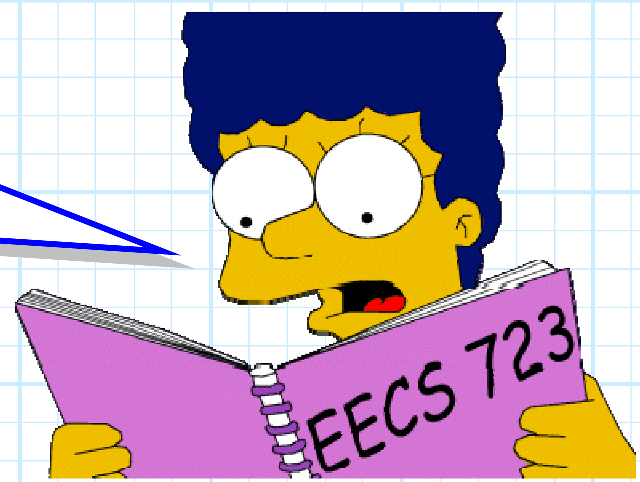
Recall for **lossless** lines, however, the phase velocity is **independent** of frequency—**no** dispersion will occur!

$$v_p = \frac{1}{\sqrt{LC}} \qquad [R = 0, G = 0]$$

Of course, a perfectly lossless line is impossible, but we find phase velocity is **approximately** constant if the line is low-loss.

Therefore, dispersion distortion on low-loss lines is **most often** not a problem.

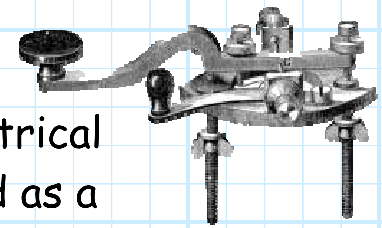
Q: You say *"**most** often"* *not a problem—that phrase seems to imply that dispersion sometimes **is** a problem!*

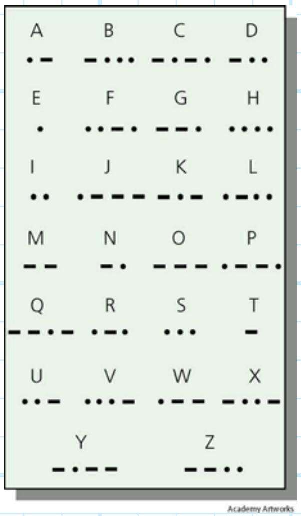


A: Even for low-loss transmission lines, dispersion can be a problem **if** the lines are **very** long—just a small difference in phase velocity can result in significant differences in propagation delay **if** the line is very long!

Purple monkey dishwasher

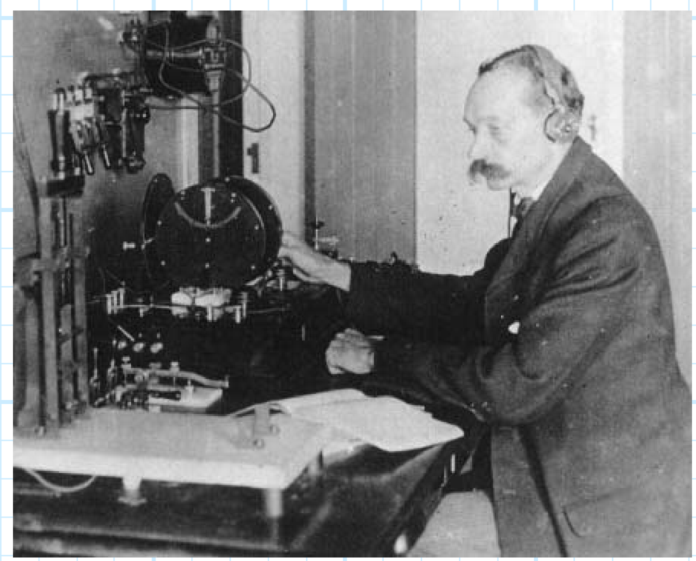
Modern examples of long transmission lines include phone lines and cable TV. However, the **original** long transmission line problem occurred with the **telegraph**, a device invented and implemented in the 19th century.





Telegraphy was the essentially the **first** electrical engineering technology ever implemented, and as a result, led to the first ever **electrical engineers**!

Early telegraph "engineers" discovered that if they made their telegraph lines **too long**, the dots and dashes characterizing Morse code turned into a muddled, indecipherable **mess**. Although they did not realize it, they had fallen victim to the heinous effects of **dispersion**!

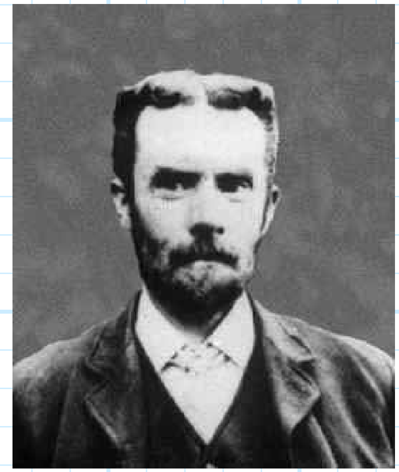


Thus, to send messages over long distances, they were forced to implement a series of intermediate "**repeater**" stations, wherein a human operator received and then **retransmitted** a message on to the next station. This **really** slowed things down!

Prevention, not correction!

Q: *Is there any way to* ***prevent*** *dispersion from occurring?*

A: You bet! **Oliver Heaviside** figured out how in the **19th** Century!



Heaviside found that a transmission line would be distortionless (i.e., no dispersion) **if** the line parameters exhibited the following **ratio**:

$$\frac{R}{L} = \frac{G}{C}$$

Let's see **why** this works. Note the complex propagation constant γ can be expressed as:

$$\begin{aligned}\gamma &= \sqrt{(R + j\omega L)(G + j\omega C)} \\ &= \sqrt{LC\,(R/L + j\omega)(G/C + j\omega)}\end{aligned}$$

Then **IF**:

$$\frac{R}{L} = \frac{G}{C}$$

we find:

$$\begin{aligned}\gamma &= \sqrt{LC\,(R/L + j\omega)(G/C + j\omega)} \\ &= \sqrt{LC\,(R/L + j\omega)(R/L + j\omega)} \\ &= (R/L + j\omega)\sqrt{LC} \\ &= R\sqrt{\frac{C}{L}} + j\,\omega\sqrt{LC}\end{aligned}$$

Thus:

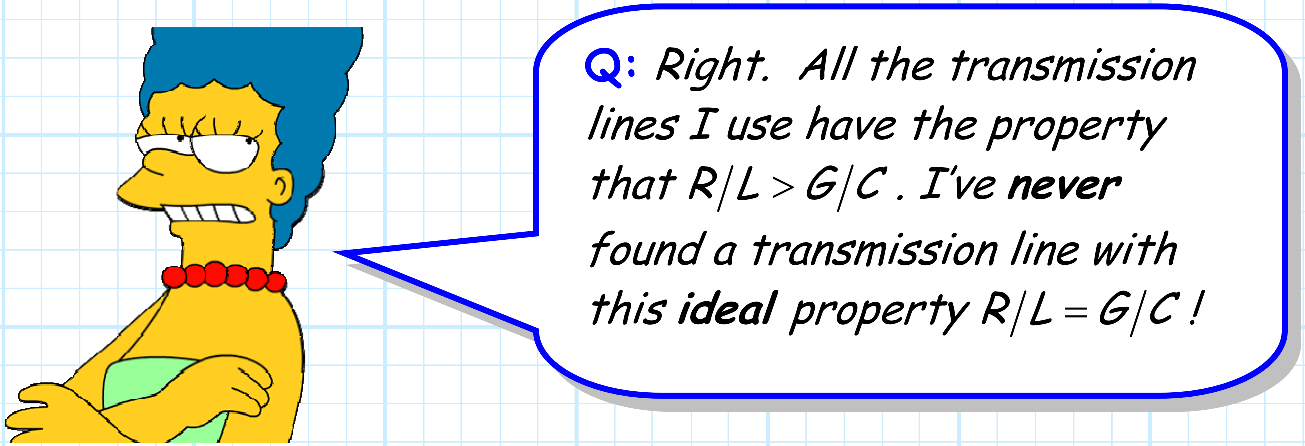
$$\alpha = Re\{\gamma\} = R\sqrt{\frac{C}{L}} \qquad\qquad \beta = Im\{\gamma\} = \omega\sqrt{LC}$$

The propagation **velocity** of the wave is thus:

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

The propagation velocity is **independent** of frequency! This lossy transmission line is **not** dispersive!

A Practical implementation



A: It is true that typically $R/L > G/C$. But, we can reduce the ratio R/L (until it is equal to G/C) by adding series **inductors** periodically along the transmission line.

This was **Heaviside's** solution—and it worked! **Long** distance transmission lines were made possible.

Q: *Why don't we increase G instead?*

A: