Lossy T-lines; Velocity & Dispersion

Let's think now about the velocity of propagation in the lossy line.

From before, we know \[ \beta = \frac{\varphi}{\lambda} = \frac{w}{V_p} \], so

\[ V_p = \frac{w}{\beta} \]; but for a lossy line, \[ \beta = \text{Im} \left\{ \sqrt{(2+jl) (6+jAC)} \right\} \]; remembering that

\[ R = \sqrt{2+jl} (6+jAC) \]

\[ Z = \alpha + j\beta \]

Then \( V_p \) is dependent on frequency... is this a problem? Yes!

Signals that carry any information must occupy some bandwidth. FM broadcast (stereo) occupies a bandwidth of about 100 kHz. AM broadcast signals are about 6 kHz in width. These are analog modulation schemes. What about digital signals?

A high-speed digital serial channel has time on the order of 10's of ps. Many high frequency components make up the edges. What if each frequency travels at a different velocity?

Note: Dispersion is a form of distortion. The waveform shape is changed. Attenuation is not considered a form of distortion. Attenuation changes amplitude but not shape.
Lossy T-lines; Velocity + Dispersion

When each frequency making up an edge travels at a different speed, the waveform edges get “smeared” over time and space. Dispersion!

Transmitted signal @ ≤ 5 GHz: A very high-speed digital signal.

Received signal after traveling down a lossy transmission line with loss. Created with a pseudo-random bit stream of 100’s of cycles,

(electronics.stackexchange.com)

Lossy lines can strongly effect high-speed digital signals.

What about lower frequencies/longer lines?
Lossy T-lines; Velocity & Dispersion

The first transatlantic telegraph cables had problems with dispersion. Data rates (Morse code) were very low but the loss was great.

The first message (99 words) from Queen Victoria to President Buchanan took 16 hours to transmit.

Dispersion caused an overlapping between adjacent dots and dashes making them indistinguishable. This is called intersymbol interference (ISI).

Oliver Heaviside (1850-1925) determined that if the parameters for a transmission line were such that \[ \frac{L}{Z} = \frac{C}{Z} \], the line would exhibit a velocity of propagation that was independent of frequency.

Let's see how this works...
Lossy T-lines; Velocity + Dispersion

From before, we know,

\[ \gamma = \sqrt{(R+i\omega L)(\frac{R}{C}+j\omega C)} \]

Let's rearrange this equation so that we can do a substitution easily:

\[ \gamma = \sqrt{LC (\frac{R}{L}+j\omega)(\frac{R}{C}+j\omega)} \]

\[ = \sqrt{\frac{R}{L}+j\omega} \sqrt{\frac{R}{C}+j\omega} \]

\[ = \sqrt{\frac{R}{L}+j\omega} \sqrt{\frac{R}{C}+j\omega} \]

\[ = \frac{R}{L} \sqrt{\frac{R}{C}} + j\omega \sqrt{\frac{R}{C}} \]

So, \( \beta = \omega \sqrt{LC} \)

Thus if \( V_p = \frac{\omega}{\beta} \) then \( V_p = \frac{\omega}{\omega \sqrt{LC}} = \frac{1}{\sqrt{LC}} \) as a lossless line and is independent of frequency. Thank goodness for Heaviside!
Lossy T-lines; Velocity & Dispersion

For typical T-lines, we find that \( \frac{G}{L} \ll \frac{B}{L} \).

- Modern dielectrics are really good; thus "G" is very small \((\approx 10^{-5})\).
- R is usually copper, the next to best conductor.

What to do?
- Decrease R?, increase G?, decrease L?, increase L?
- Drawbacks, physical considerations?

Solutions:
- Increased conductor spacing
- Put insulator with iron dust
- Distribute inductors
- Magnetic coating on conductor
- Repeat...

See: wikipedia.org/wiki/heavyside-condition