(X) Loading of Lines

* For Distortionless line $RC = LG$ is the condition to be satisfied.
* For practical Txion line, $\frac{R}{G} >> \frac{L}{G}$, hence the signal is distorted.

∴ To satisfy the condition, it is necessary to reduce $\frac{R}{G}$ or to increase L/C.

* R can be decreased by increasing the area of cross section ie) diameter of the conductor. This increases the size/cost of the line.
* G can be increased by using poor insulators. that is easy & economical. G↑ the leakage of signal will increases thus received signal will become weak. that signal should be amplified at intermediate stage. This makes the design complicated.
* Hence this possibility is ruled out in practise
* ∴ it is necessary to increase $\frac{L}{C}$ ratio to achieve distortion less line.
* It is allowed to increase L (or) decrease C.
* if C is to be reduced, then the seperation b/w two lines are more.

* Thus the brackets will now carry less number of wires due to increased seperation.
* . The line will become very much costlier. hence this possibility also ruled out.
* . Only choice is increasing 'L'
  This opted in practice.

→ The process of increasing the inductance (L) of a line artificially ie) Lumped inductors were spaced at regular intervals along the line. This use to achieve distortionless line is called "Loading of Line"

Types of loading:

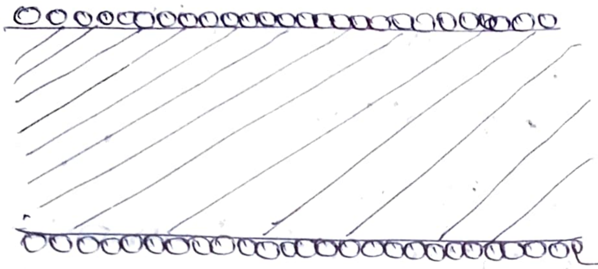
i) Continuous Loading: / Krarup loading / Heavy side:

In this type of loading, a type of iron or magnetic material such as permalloy (or) μ-metal having high permeability are wound round the conductor to be loaded.

* . If μ of the surrounding medium increase, thereby inductance (L) increases.
* This method increases the inductances upto 65 mH/km, but expensive in construction.
* Eddy current & hysteresis losses in magnetic material increase the primary constant (R).

*. Suppose if there is a small difference in mechanical treatment (or) pressure b/w the tape & conductor that cause large variations in primary constants.

*.



* Continuous loading used only in ocean cables where the problem of making water tight joints at loading points makes lumped loading difficult.

* <u>Adv:</u>

The α increases uniformly with increase in frequency.

<u>Propagation constant of continuous loaded cable</u>

* for continuous loaded cable it is assumed that $\boxed{G=0}$ & L is increased such that:

$$\boxed{\omega L >> R}$$

w.k.t

$$\underbrace{Z = R + j\omega L \;;\; Y = \cancel{G} + j\omega C}_{(1)} = j\omega C.$$

$$\gamma = \sqrt{ZY} = \sqrt{(R+j\omega L)(j\omega C)}$$

$$= \sqrt{\sqrt{R^2+\omega^2L^2}\,\lfloor \tan^{-1}\left(\frac{\omega L}{R}\right) \times \overset{\sqrt{\omega^2C^2}}{\omega C}\,\lfloor \pi/2}$$

$$= \sqrt{\omega^2 L \sqrt{1+\frac{R^2}{\omega^2 L}} \times \omega C \,\lfloor \frac{+\pi}{2} - \tan^{-1}\left(\frac{R}{\omega L}\right) + \pi/2}.$$

$$\gamma = \sqrt{\omega^2 LC \sqrt{1+\frac{R^2}{\omega^2L^2}}\,\lfloor \pi - \tan^{-1}(R/\omega L)} \quad \text{--- (2)}.$$

$\therefore \boxed{\omega L >> R}$

$$\gamma = \sqrt{\omega^2 LC \,\lfloor \pi - \tan^{-1}(R/\omega L)}$$

$$\gamma = \omega\sqrt{LC}\,\lfloor \frac{\pi}{2} - \frac{1}{2}\tan^{-1}(R/\omega L) \quad \text{--- (3)}.$$

here $\theta = \pi/2 - \frac{1}{2}\tan^{-1}(R/\omega L)$. — (4).

$$\cos\theta = \cos\left[\frac{\pi}{2} - \frac{1}{2}\tan^{-1}(R/\omega L)\right].$$

$$= \sin\left[\frac{1}{2}\tan^{-1}(R/\omega L)\right] \quad \left[\because \text{for smaller angle } \tan^{-1}\theta = \theta. \;\; \sin\theta = \theta.\right]$$

$$= \sin\left[\frac{1}{2}\frac{R}{\omega L}\right]$$

$$\boxed{\cos\theta = \frac{R}{2\omega L}.} \quad \text{--- (5)}$$

$$\sin\theta = \sin\left[\frac{\pi}{2} - \frac{1}{2}\overset{0}{\tan^{-1}\left(\frac{R}{\omega L}\right)}\right] \quad \because \omega L >> R.$$

$$\boxed{\sin\theta = \sin\pi/2 = 1.} \quad \text{--- (6)}.$$

from (3)

$$\gamma = \omega\sqrt{LC}\,\angle\theta = \omega\sqrt{LC}\,e^{j\theta}$$

$$= \omega\sqrt{LC}\left[\cos\theta + j\sin\theta\right]$$

$$\gamma = \omega\sqrt{LC}\left[\frac{R}{2\omega L} + j\right]$$

$$\alpha + j\beta = \frac{R}{2}\sqrt{\frac{C}{L}} + \omega\sqrt{LC}.$$

Comparing real & imaginary

$$\boxed{\alpha = \frac{R}{2}\sqrt{\frac{C}{L}}} \; ; \; \boxed{\beta = \omega\sqrt{LC}}$$

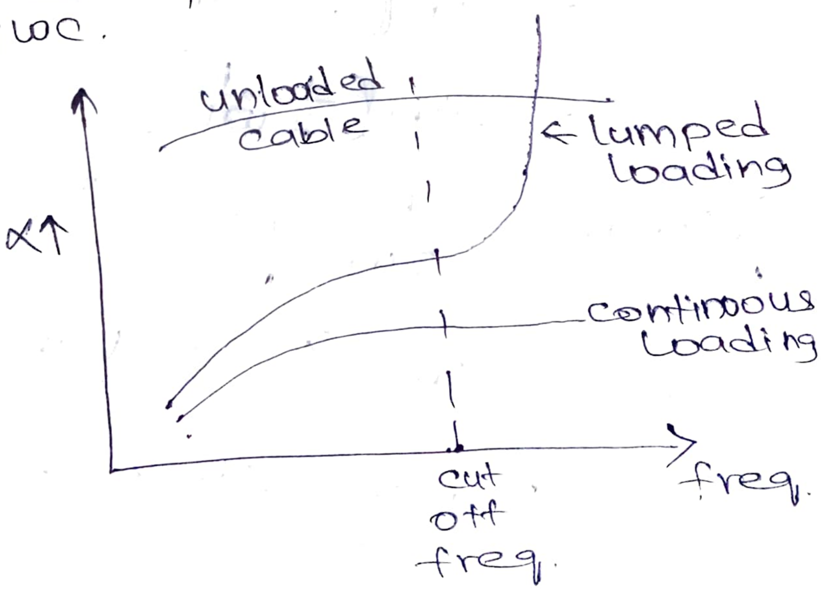
$$v_p = \frac{\omega}{\beta} = \frac{\cancel{\omega}}{\cancel{\omega}\sqrt{LC}} \quad \therefore \boxed{v_p = \frac{1}{\sqrt{LC}}}$$

under the assumption; $G=0$ & $\omega L >> R$, α & v_p both are independent of frequency & the loaded cable will be distortionless.

$$Z_0 = \sqrt{\frac{Z}{Y}} = \sqrt{\frac{R+j\omega L}{G+j\omega C}} \; ; \; \omega L >> R, \; G=0.$$

$$Z_0 = \sqrt{\frac{j\omega L}{j\omega C}}$$

$$\therefore \boxed{Z_0 = \sqrt{\frac{L}{C}}}$$



Advantage:

→ α is independent of frequency.

→ α is decreased by increasing L provided R is not increased.

→ Increase in L upto 100 mh/unit length is possible

Dis Adv:

→ Very Expensive.

→ Existing lines cannot be modified by this method, only replacement is possible.

→ Here it achieves only small increase in L/unit length.

ii) Lumped Loading:

*. In this type of loading, the inductors are introduced in lumps at uniform distance in the line. which is in the form of coils called Lumped loading.

*. The inductors are introduced in both the limbs to keep the line a balanced circuit.

*. It behaves as LPF.

*. It is more convenient than continuous loading provided that the frequency is limited to cut off frequency.

* The loading coils have certain resistance thus L↑ R also increases.

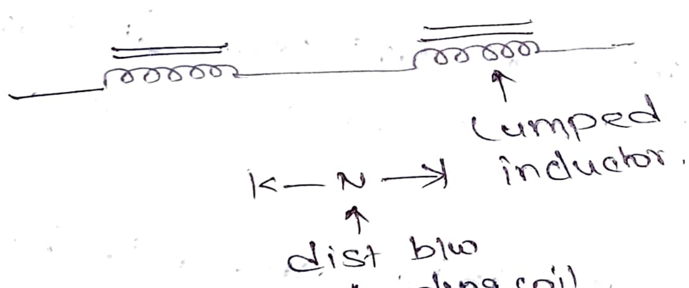
* If R↑ then hysteresis & eddy current losses in loading coil & hence distortion increases in line.

$$f_c = \frac{1}{\pi\sqrt{L_c C \times d}}$$

$L_c \rightarrow$ inductance of the loading coil & cable/km.

$C \rightarrow$ capacitance /km.

$d \rightarrow$ distance b/w two conductors.



Propagation constant of lumped loaded cable.

(or)

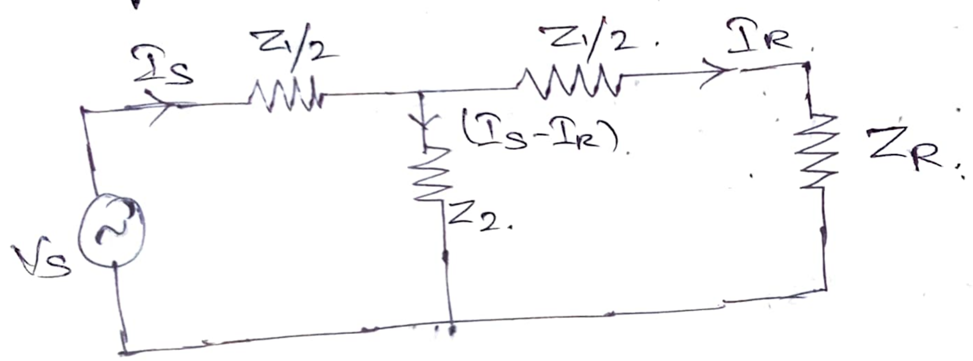
Campbell's formula.

* The performance of a line loaded at uniform intervals can be obtained by considering a symmetrical section of line from the center of

one loading coil to the center of the next, where the loading coil impedance is Z_c.

GA campbell developed a formula for propagation constant γ_L of loaded line interms of propagation constant of unloaded line & the secondary constant of unloaded line & impedance of loading coil Z_c.

Equivalent <u>T-N/w of unloaded line</u> as shown.



The equation voltage & current at any point in a line interms of sending end voltage & current (V_s & I_s) is given by.

$$V = V_s \cosh \gamma x - I_s Z_0 \sinh \gamma x.$$

$$I = I_s \cosh \gamma x - \frac{V_s}{Z_0} \sinh \gamma x.$$

$x \rightarrow$ distance measured from the sending end.

* At the receiving end ; $x = L$, $V = V_R$, $I = I_R$.

$$V_R = V_s \cosh \gamma L - I_s Z_0 \sinh \gamma L \quad — ①$$

$$I_R = I_s \cosh \gamma L - \frac{V_s}{Z_0} \sinh \gamma L. \quad — ②$$

Apply Kirchoff's KVL to equivalent T-n/w.

$$V_S = I_S \frac{Z_1}{2} + Z_2 (I_S - I_R).$$

$$V_S = I_S \left[\frac{Z_1}{2} + Z_2 \right] - I_R Z_2.$$

$$I_R Z_2 = I_S \left[\frac{Z_1}{2} + Z_2 \right] - V_S.$$

$$I_R = \frac{I_S}{Z_2} \left[\frac{Z_1}{2} + Z_2 \right] - \frac{V_S}{Z_2}.$$

$$I_R = I_S \left[\frac{Z_1}{2 Z_2} + 1 \right] - \frac{V_S}{Z_2} \quad — (3).$$

Comparing (2) & (3).

$$\frac{Z_1}{2 Z_2} + 1 = \cosh \gamma l.$$

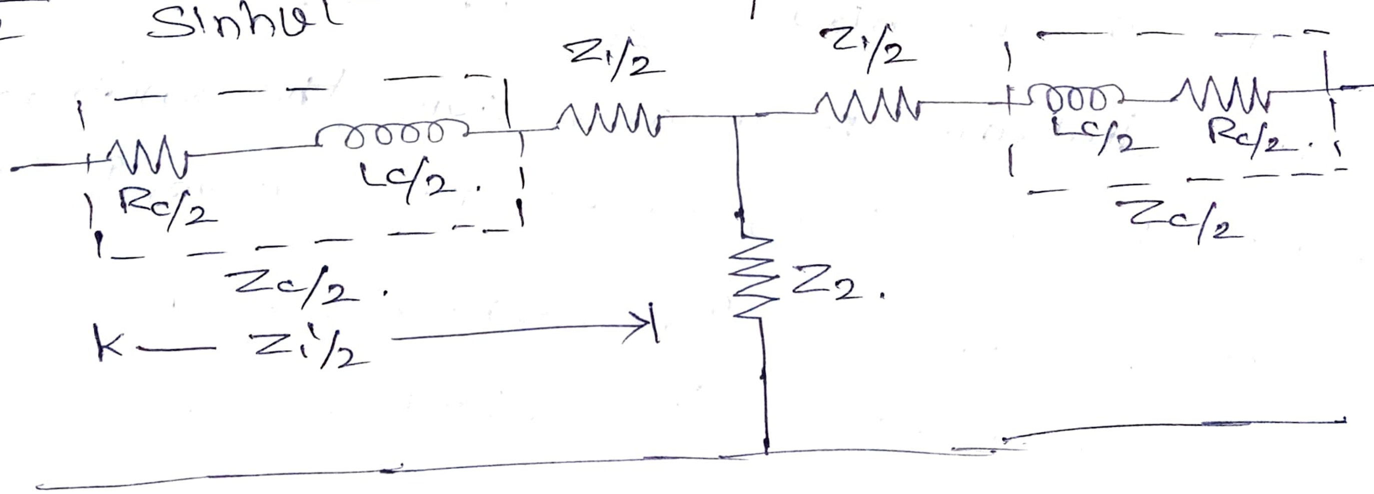
$$\frac{Z_1}{2 Z_2} = \cosh \gamma l - 1$$

$$\frac{Z_1}{2} = \frac{Z_0}{\sinh \gamma l} [\cosh \gamma l - 1].$$

||rly

$$\frac{1}{Z_2} = \frac{\sinh \gamma l}{Z_0}.$$

$$Z_2 = \frac{Z_0}{\sinh \gamma l}.$$



Z_1 & Z_2 are series & shunt arm impedance of unloaded line.

from fig; $\frac{Z_1'}{2} = \frac{Z_c}{2} + \frac{Z_1}{2} = \frac{Z_c}{2} + \frac{Z_0}{\sinh \gamma l}[\cosh \gamma l - 1]$

Equivalent T-n/w of loaded ~~& unloaded~~ line is represented.

$Z_c \to$ impedance of loading coil.

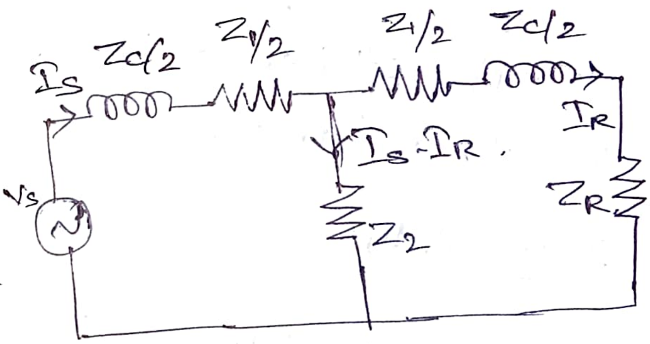
$d \to$ distance b/w centre of two coils.

$Z_1, Z_2 \to$ impedance of unloaded line.

∴ The receiving current I_R in terms of V_s, I_s of loaded line is.

$$I_R = I_s \cosh \gamma l - \frac{V_s}{Z_0} \sinh \gamma l \quad \text{---} (4).$$

Apply KVL.



$$V_s = I_s\left[\frac{Z_c}{2} + \frac{Z_1}{2}\right] + [I_s - I_R]Z_2.$$

$$V_s = I_s\left[\frac{Z_c}{2} + \frac{Z_1}{2} + Z_2\right] - I_R Z_2$$

$$I_R Z_2 = I_s\left[\frac{Z_c}{2} + \frac{Z_1}{2} + Z_2\right] - V_s$$

$$I_R = \frac{I_s}{Z_2}\left[\frac{Z_c}{2} + \frac{Z_1}{2} + Z_2\right] - \frac{V_s}{Z_2}.$$

$$I_R = I_s\left[\frac{Z_c}{2Z_2} + \frac{Z_1}{2Z_2} + 1\right] - \frac{V_s}{Z_2}. \quad \text{---} (5).$$

Comparing (4) & (5) we get.

$$\frac{Z_c}{2Z_2} + \frac{Z_1}{2Z_2} + 1 = \cosh \gamma_L d.$$

$$\frac{1}{Z_2} = \frac{\sinh \gamma l}{Z_0}.$$

$$\boxed{Z_2 = \frac{Z_0}{\sinh \gamma l}}.$$

$$1+\frac{Z_1+Z_c}{2Z_2}=\cosh\gamma_i d=1+\frac{\frac{Z_1+Z_c}{2}}{Z_2}=1+\frac{Z_1'}{2Z_2}$$

sub Z_2 & Z_c, Z_1, of unloaded

$$\cosh\gamma_i d=1+\frac{\frac{\cancel{Z_0}(\cosh\gamma d-1)}{\sinh\gamma d}}{\cancel{Z_0}/\sinh\gamma d}+\frac{Z_c}{2Z_0/\sinh\gamma d}$$

$$\cosh\gamma_i d=\cancel{1}+\cosh\gamma d-\cancel{1}+\frac{Z_c\sinh\gamma d}{2Z_0}$$

$$\boxed{\cosh\gamma_i d=\cosh\gamma d+\frac{Z_c\sinh\gamma d}{2Z_0}}$$

* This equ: makes the calculation of loading coil effects in reducing attenuation & distortion in the line.

Dis Adv:

- → for a cable, Z_2 is essentially capacitive.
- → LPF = cable capacitance + lumped inductance.
- → $f < f_c$ → Attenuation is reduced.
- → $f > f_c$ ⇒ Attenuation rises.

Adv:

* cost is less.
* existing lines can be modified.
* Inductance is not increased with a limited value.