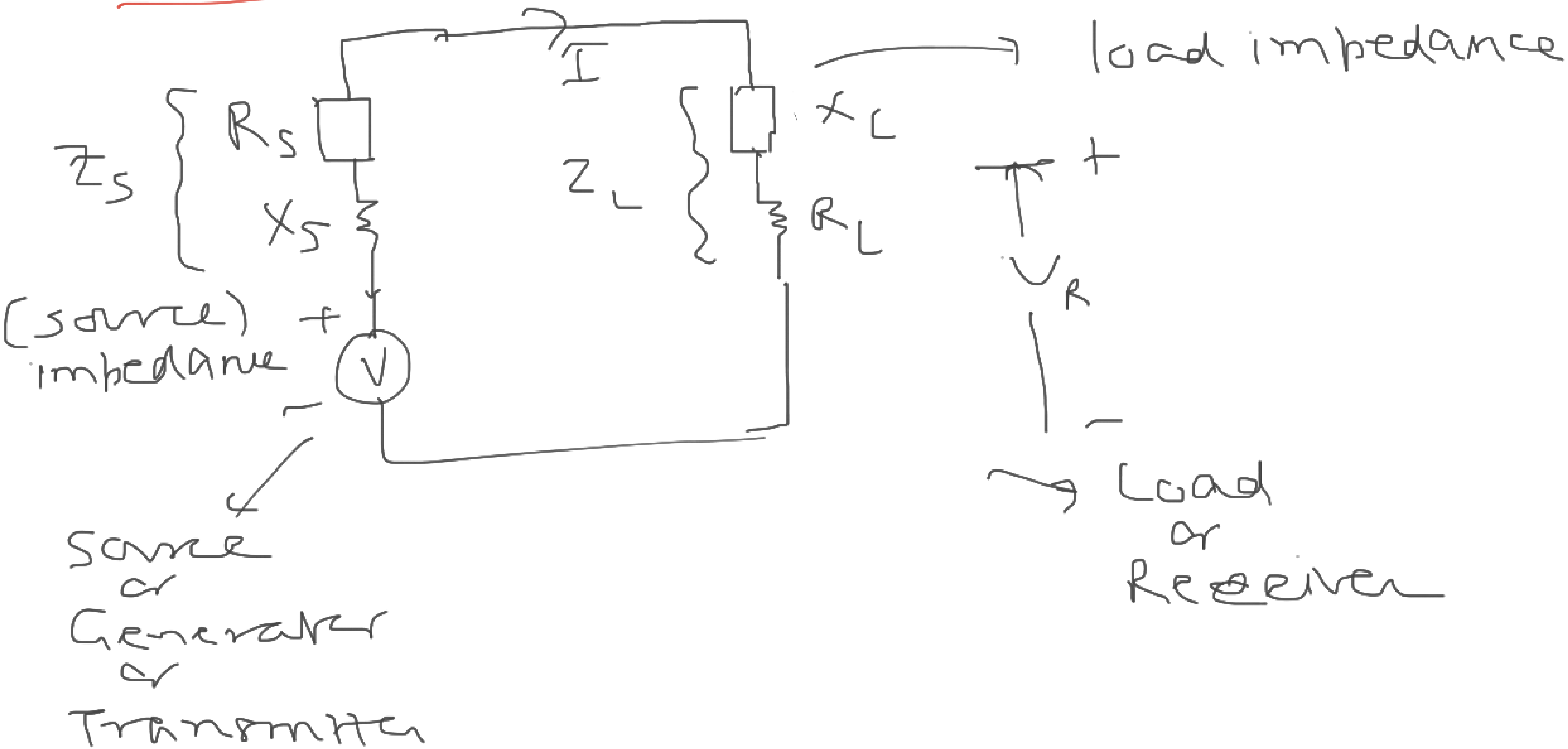
09/04/2021

Maximum Power Transfer in RF Circuit Design



When a signal source is required to deliver power to a load, power transfer should be maximum.

Average power delivered to load R_L is

$$P_L = V_R \cdot I \qquad \left[\because V_R = I \cdot R_L\right]$$

$$= [I \cdot R_L] \cdot I$$

$$\Rightarrow P_L = \underbrace{\frac{V}{\sqrt{(R_S+R_L)^2+(X_S+X_L)^2}}}_{=I} \cdot R_L \cdot \underbrace{\frac{V}{\sqrt{(R_S+R_L)^2+(X_S+X_L)^2}}}_{=I}$$

$$\Rightarrow P_L = \frac{V^2 R_L}{(R_S+R_L)^2+(X_S+X_L)^2}$$

$$\boxed{P_L = \frac{V^2 R_L}{(R_S+R_L)^2 + (X_S+X_L)^2}} \quad \text{——} \ (1)$$

Looking first at effect of X_L on P_L

it will be seen that in (1) by making

$\boxed{X_L = -X_S}$, P_L will be maximum given by

A

$$P_L = \frac{V^2 R_L}{(R_S+R_L)^2}$$

R_L can now be varied to maximise the expression (1) for P_L, & maximum value is obtained by taking $\frac{dP_L}{dR_L} = 0$

From ①, $\frac{dP_L}{dR_L} = V^2\left[R_L \frac{d}{dR_L}\{(R_s+R_L)^{-2}\} + \{R_s+R_L\}^{-2} \cancel{\frac{dR_L}{dR_L}} \right]$

$$= V^2\left[R_L (-2)(R_s+R_L)^{-3} + (R_s+R_L)^{-2} \right]$$

$$= V^2\left[\frac{-2R_L}{(R_s+R_L)^3} + \frac{1}{(R_s+R_L)^2} \right]$$

$$= V^2\left[\frac{-2R_L + (R_s+R_L)}{(R_s+R_L)^3} \right]$$

$$\frac{dP_L}{dR_L} = \frac{V^2\left[(R_s+R_L) - 2R_L\right]}{(R_s+R_L)^3}$$

$$\Rightarrow \frac{dP_L}{dR_L} = \frac{V^2\left[(R_s+R_L)-2R_L\right]}{(R_s+R_L)^2} = 0$$

from which

$$R_s = R_L \quad \text{(B)}$$

From (A) & (B) condition, maximum power transfer will take place when

$$\boxed{R_L + jX_L = R_s - jX_s}$$

$$Z_L = Z_s^*$$

(conjugate matching of impedances)

If $R_s = R_L$, $X_s = X_L$ ie,

$$R_L + jX_L = R_s + jX_s$$

maximum power transfer will not take place

but reflection less matching

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}, \quad Z_L = Z_0 \text{ [no reflection } \therefore \Gamma = 0 \text{]}$$

CONJUGATE MATCHING

Chip Resistors

[illegible]

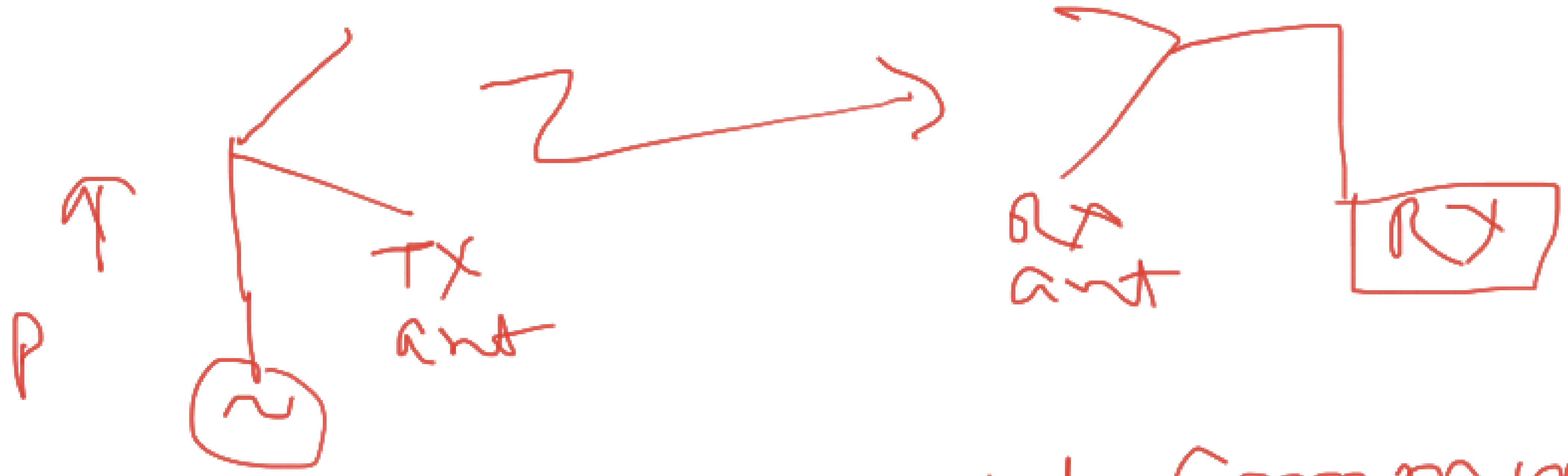
Size code	Length L (mils)	Width W (mils)
0402	40	20
0603	60	30
0805	80	50
1206	120	60
1212	120	180

$$L(\mu H) = \frac{0.394\, r^2 N^2}{9r + 10l}$$

r = radius of turn (cm)

N = no. of turns

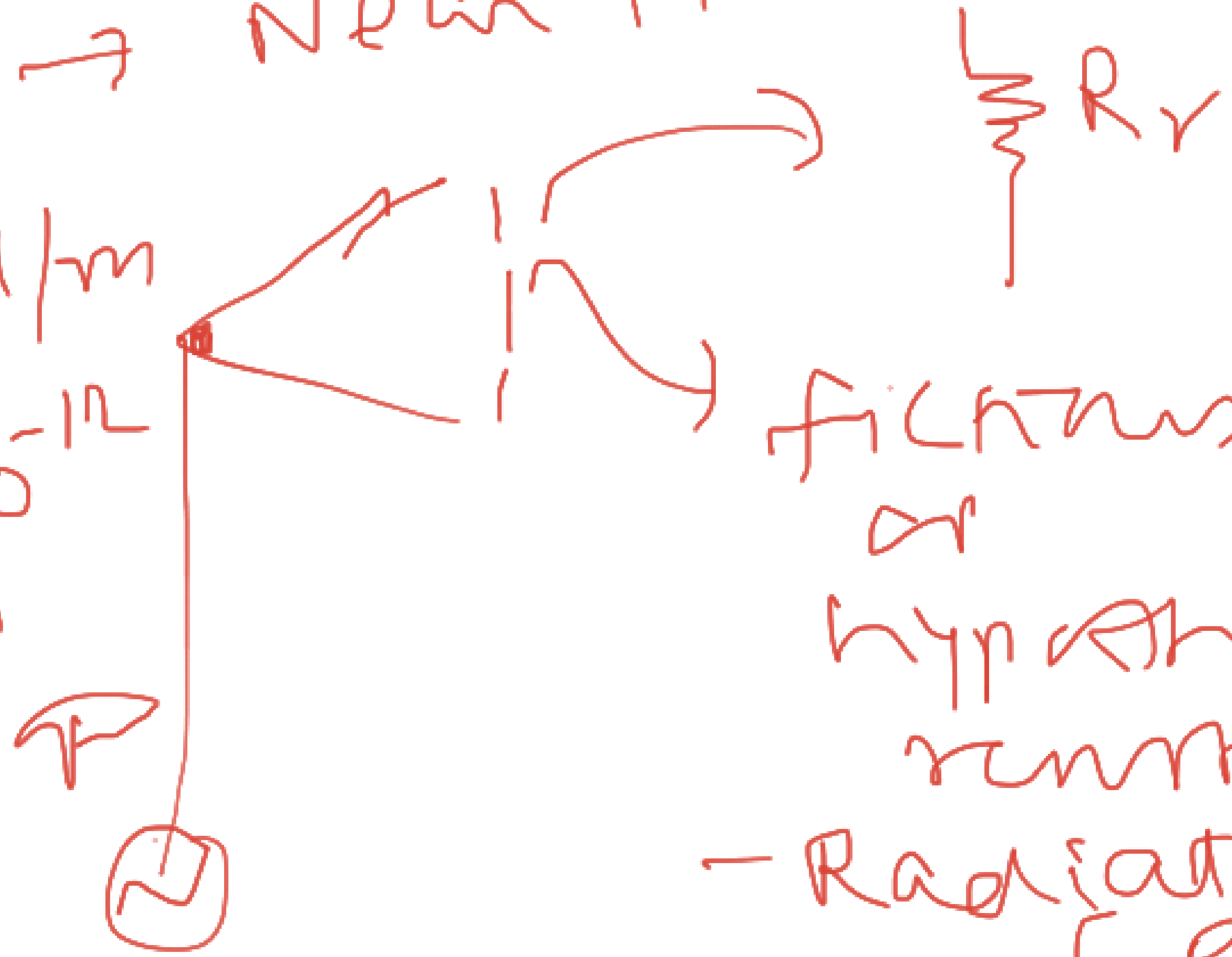
l = coil length (cm)



NFC → Near Field Communication

$\mu_0 = 4\pi \times 10^{-7}$ H/m

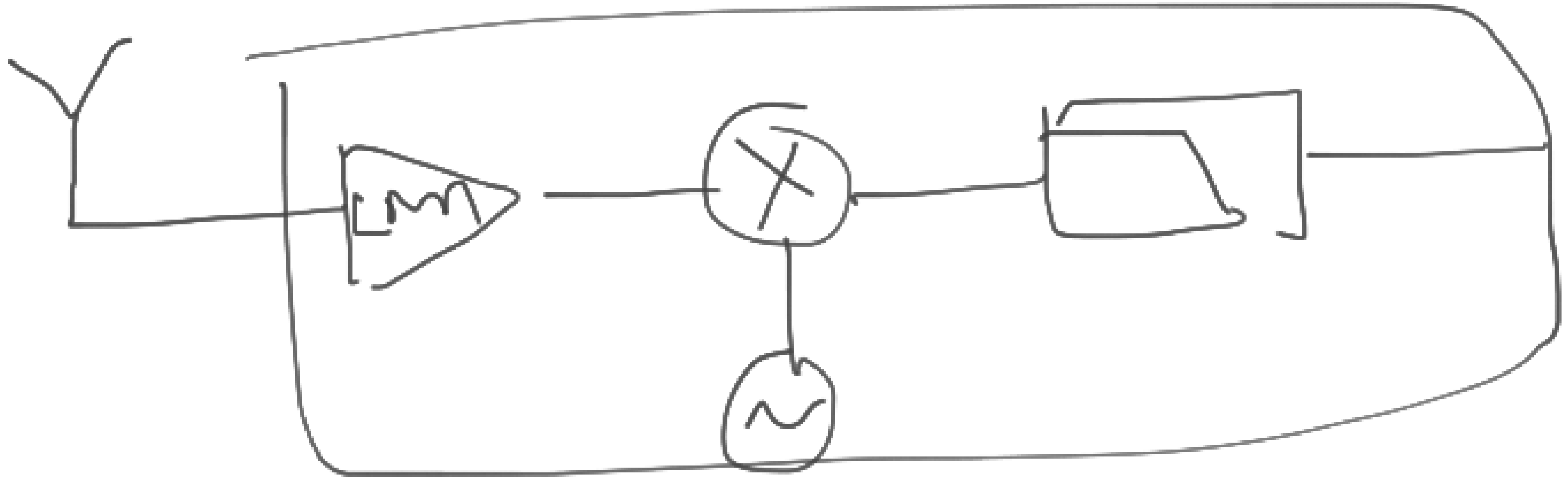
$\epsilon_0 = 8.854 \times 10^{-12}$ F/m



fictitious or hypothetical resistance

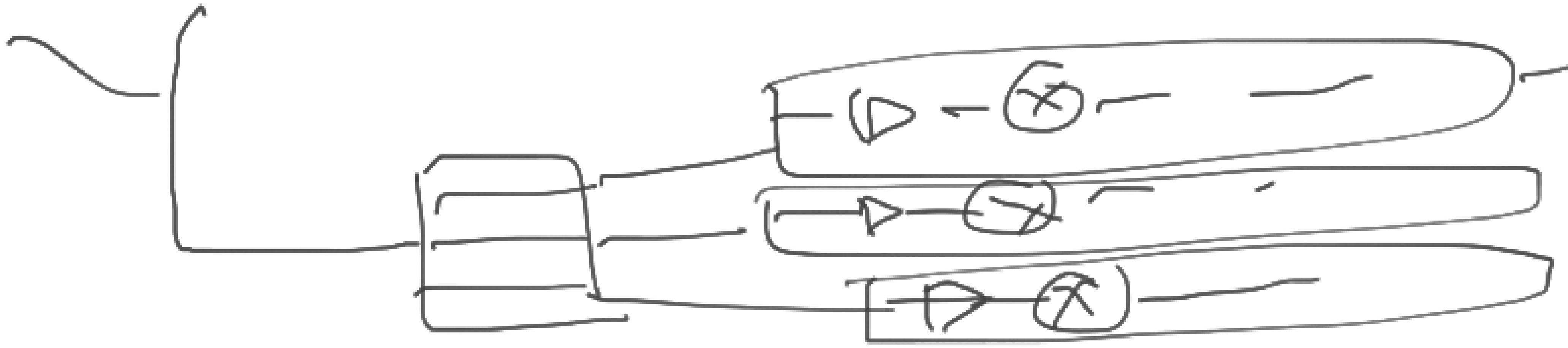
- Radiation resistance (R_r)

$= \text{impedance of free space} = \sqrt{\dfrac{\mu_0}{\epsilon_0}} = Z_0 = 120\pi$ or $377\,\Omega$



IF →

(Range)



R (range)

θ (Longitude)

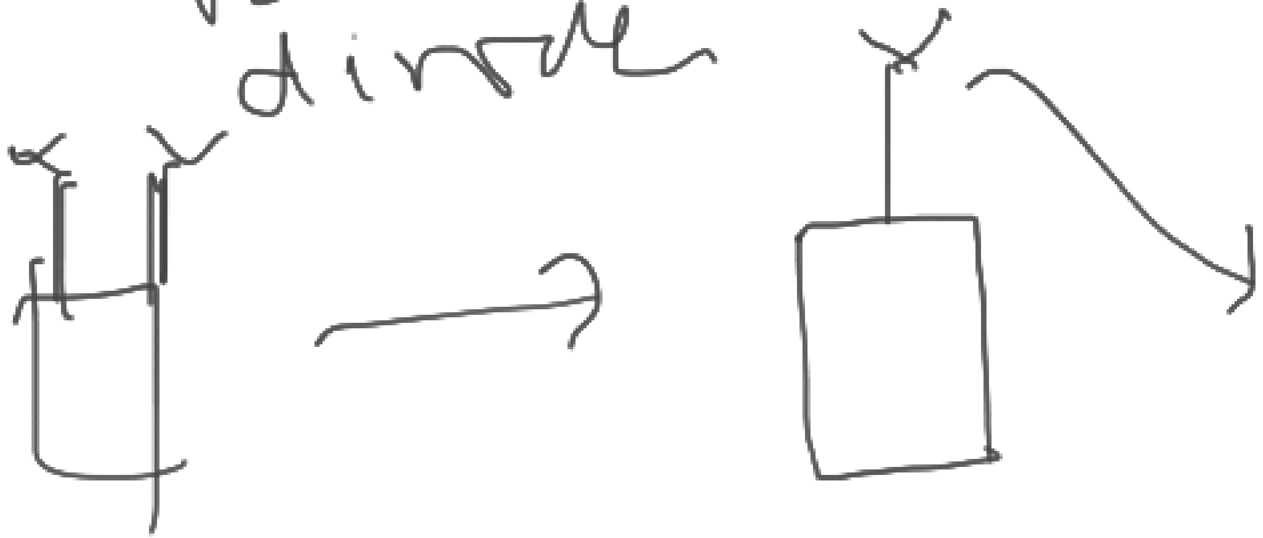
φ (Latitude)

Azimuth or

or Elevation

1 2 3

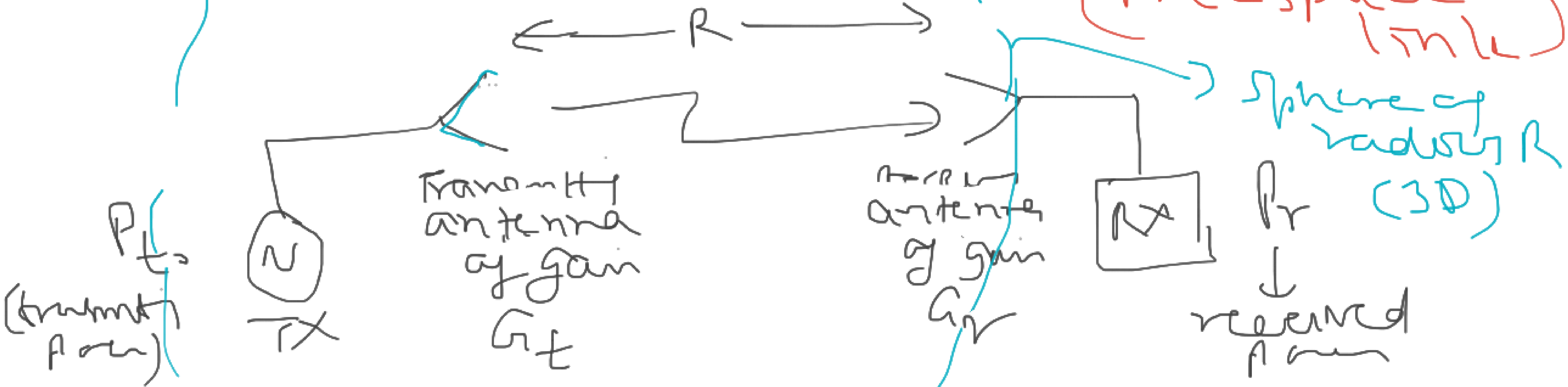
Pann
direction



Dublexer

→ Embedded antenna

LOS link (Line of Sight) or RF link (Free space link)



If gain = 1 (0 dB), then antenna will radiate uniformly in all direction

↳ omnidirectional antenna (ideal or perfect antenna)

or isotropic antenna

Surface area of sphere of radius R is

$$A = 4\pi R^2$$

But as sphere expands (ie, as R increases), power density, ie, amount of power delivered by sphere of surface area A decreases & is given by

$$S_{av} = \frac{P_t}{A} = \frac{P_t}{4\pi R^2} \quad \left(\frac{W}{m^2}\right)$$

average power density

If G_t is gain of transmitting antenna, then in sum

$$S_{av} = \frac{P_t}{4\pi R^2} \cdot G_t \qquad \left(\frac{W}{m^2}\right)$$

This power density is incident on receiving antenna of gain G_r

$$G_r = \frac{4\pi A_e}{\lambda^2} \qquad \text{(dimensionless)}$$

where λ is operating wavelength $\left(= \frac{c}{f}\right)$

A_e = effective aperture area of antenna

$$\Rightarrow A_e = \frac{G_r \lambda^2}{4\pi}$$

Received power is given by

$$P_r = A_e \cdot S_{av} \quad \left(\cancel{m^2} \cdot \frac{W}{\cancel{m^2}}\right)$$

$$= S_{av} \cdot A_e$$

$$= \frac{P_t G_t}{4\pi R^2} \cdot \frac{G_r \lambda^2}{4\pi}$$

Free space condition

$$\boxed{P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2}$$

(W)

$$\boxed{P_r \propto \frac{1}{R^2}}$$