permeability $\mu = \mu_0 \mu_r$

Permittivity $\epsilon = \epsilon_0 \epsilon_r$

$$\beta = \frac{2\pi}{\lambda}.$$

Phase velocity $V_p = \frac{\omega}{\beta} = \frac{1}{\sqrt{\epsilon\mu}} = \lambda f = \frac{c}{\sqrt{\epsilon_r \mu_r}}$

$f = \frac{c}{\lambda}$ $\quad V_p = \frac{1}{\sqrt{\mu\epsilon}} = \frac{1}{\sqrt{\mu_0 \mu_r \epsilon_0 \epsilon_r}} = \frac{c}{\cancel{\sqrt{k}}}\ c = 3\times10^8 \text{ m/s}$

for freespace.

$\therefore \lambda = \frac{V_p}{f} = \frac{c}{f}$

for $f = 30\text{MHz}$, $\lambda = 10\text{m}$
$f = 300\text{MHz}$, $\lambda = 1\text{m}$
$f = 30\text{GHz}$, $\lambda = 1\text{cm}$.

As frequency increases, the wavelength reduces to dimensions comparable to the size of circuit boards or even individual discrete components.

Let us consider. $f = 1\text{MH}$
$\epsilon_r = 10$
$\mu_r = 1$

$$V_p = \frac{3\times10^8}{\sqrt{10\times1}} = \frac{3\times10^8}{3.16} = 0.949\times10^8 \text{ m/s} = 9.49\times10^7 \text{ m/s}$$

$$\lambda = \frac{V_p}{f} = \frac{9.49\times10^7}{1\times10^6} = 94.96 \text{ m}.$$

$\lambda = 94.9 \text{ m}.$

$\frac{\omega}{\beta} = \lambda f$

$\lambda = \frac{\omega}{\beta f} = \frac{2\pi \cancel{f}}{\beta \cancel{f}}$

$= \frac{2\pi}{\beta}$ - phase constant

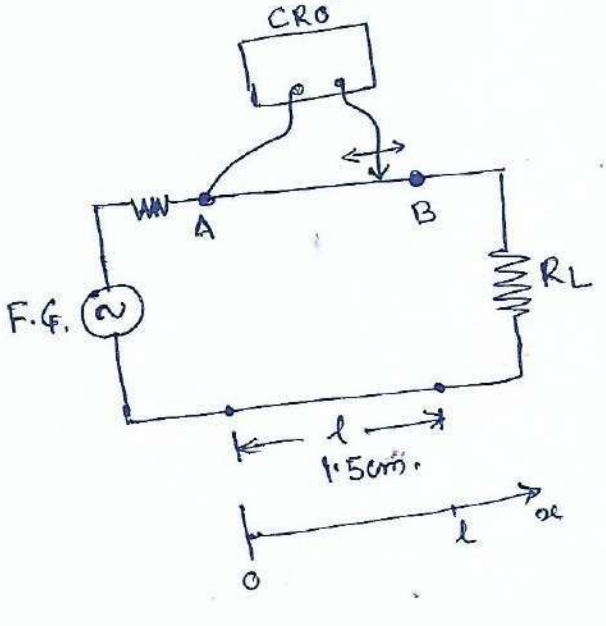
Now $l = 1.5\text{cm}.$

$f = 10\text{GHz}$

$V_p = \cancel{\frac{3\times10^8}{\sqrt{10}}}\ 0.949\times10^8 \text{ m/s}$

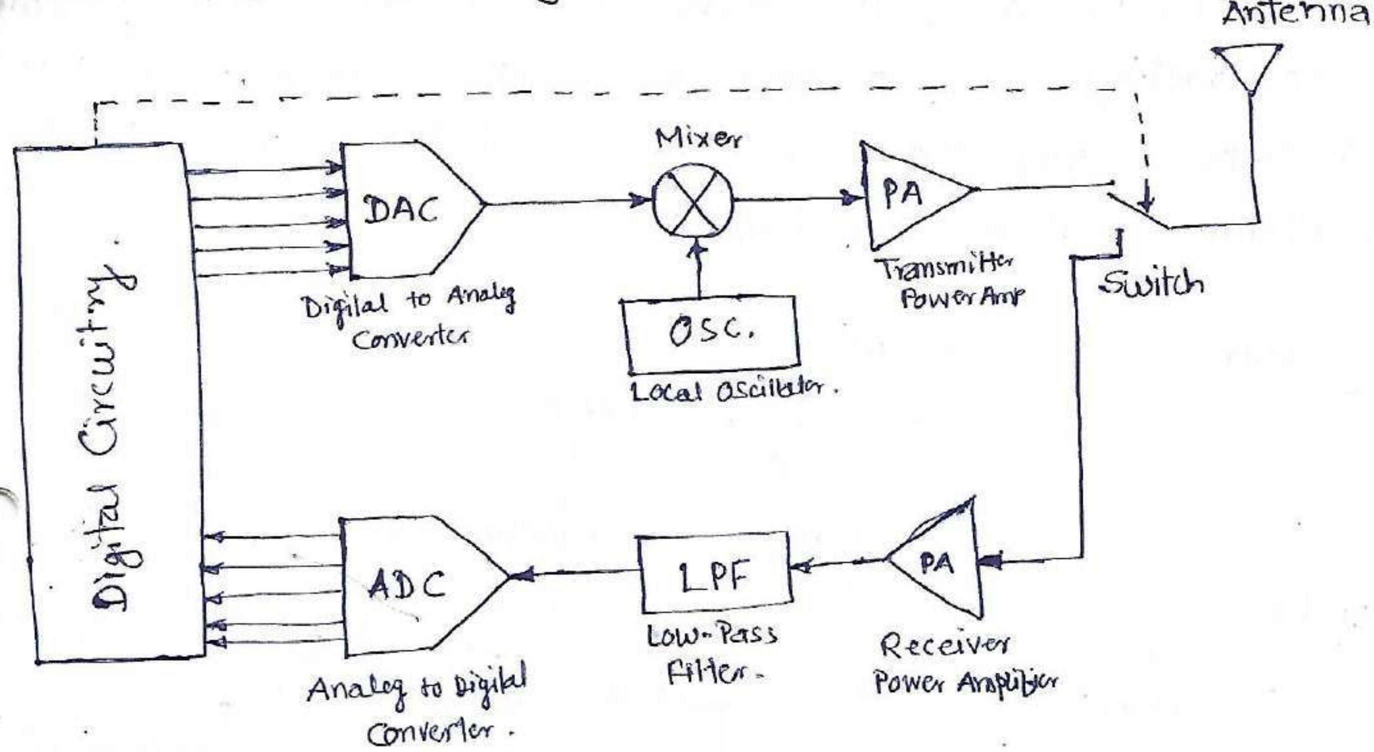
$$\lambda = \frac{0.949\times10^8}{10\times10^9} = \frac{0.949\times10^8}{10^{10}\ 100} = \frac{0.949}{100} \text{ m}$$

$\lambda = 0.949\text{cm}$



Comm. RF IC Design/High Frequency Engg.

Block diagram of a generic RF system.



Behavior of Various passive Components at High RF

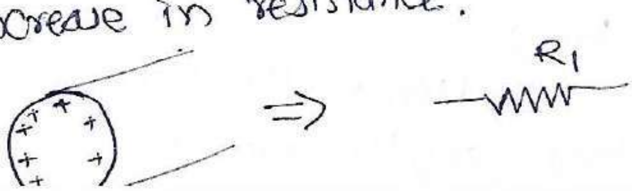
1) Wire - A wire is the simplest element to study having zero resistance, which makes it appear as a short circuit at DC & low AC frequencies. But at high RF/MW frequencies it becomes a very complex element & deserves special attention.

Skin effect in a wire - As freq. increases, the electrical signals propagate less & less in the inside of the conductor. The current density increases near the outside perimeter of the wire & causes a higher impedance to be seen by the signal as shown in fig.

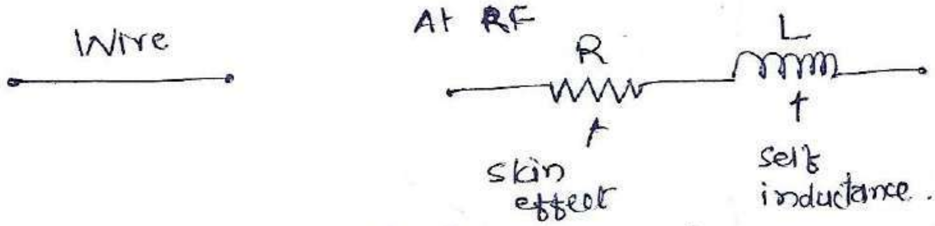
This is because the resistance of wire is given by

$$R = \frac{\rho L}{A}$$

& if effective cross-sectional area (A) decreases, this leads to an increase in resistance.



Wire Inductance - In the medium surrounding any current carrying conductor, there exists a magnetic field. If the current (I) is AC, this magnetic field is alternately expa & contracting. This produces an induced voltage in the wire, that opposes any change in the current flow. This opposition to change is called self-inductance.



2. Resistor -

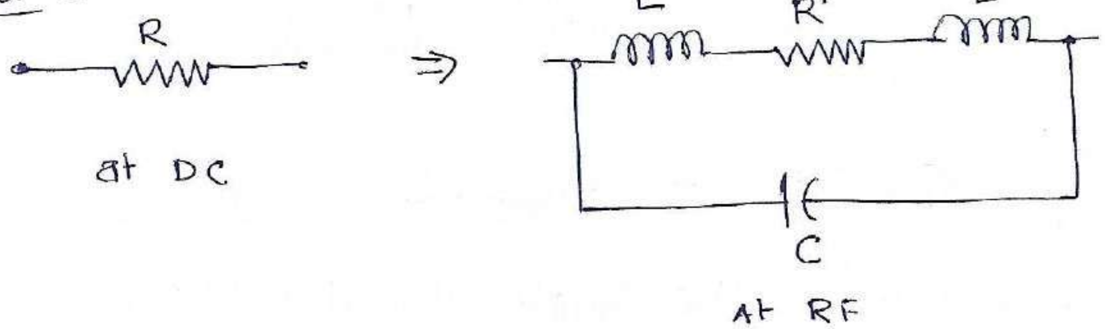
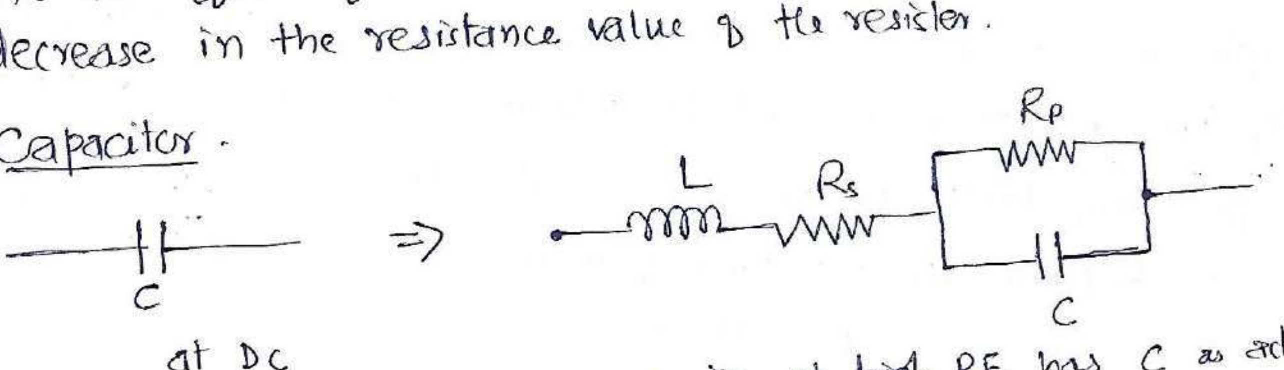
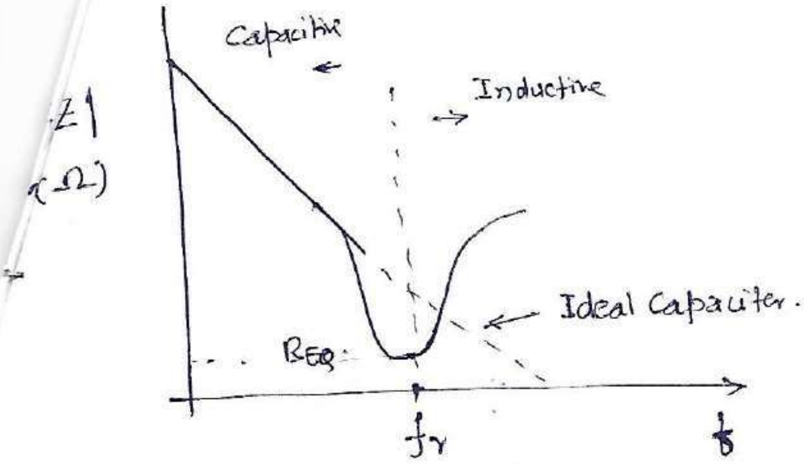


Fig. shows a simple resistor at DC. As frequency increases, the lead wire inductance (L), increased resister value (R'>R) due to skin effect & parasitic capacitance becomes predominent, as shown in fig(b). The net effect of all these parasitic elements on the average, is a decrease in the resistance value of the resistor.

3. Capacitor.



The equivalent circuit of capacitor at high RF has C as actual capacitor, L is lead inductance, R_s is the series resistance & R_p is the insulation resistance. Hence the behavior of capacitor at high RF becomes very complex due to series RLC ckt.

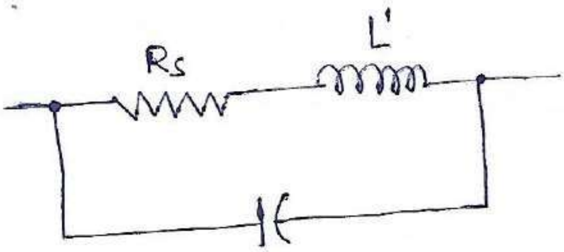


1. for $f < f_r$ – In this region as frequency increases, the lead inductance's reactance goes up gradually, cancelling the capacitors reactance & thus causing resonance (f_r)

2. $f > f_r$ – In this region the capacitor acts like inductor & is no longer performing its intended function.

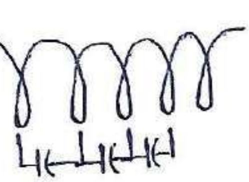
4. Inductor –

At DC.

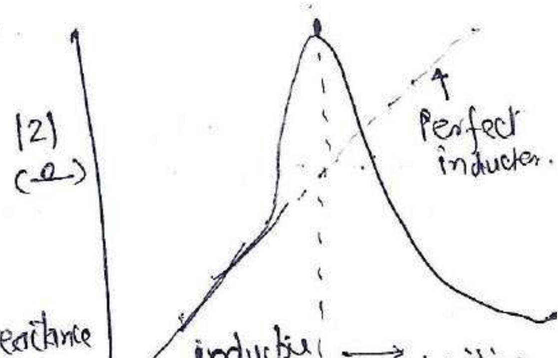


C_d. At high RF

The equivalent circuit of inductor at high RF is shown in fig which shows R_s as series inductance of inductor, L is value of inductance of inductor & C_d is distributed capacitance due to windings or turns of the inductor as shown below.



C_d.

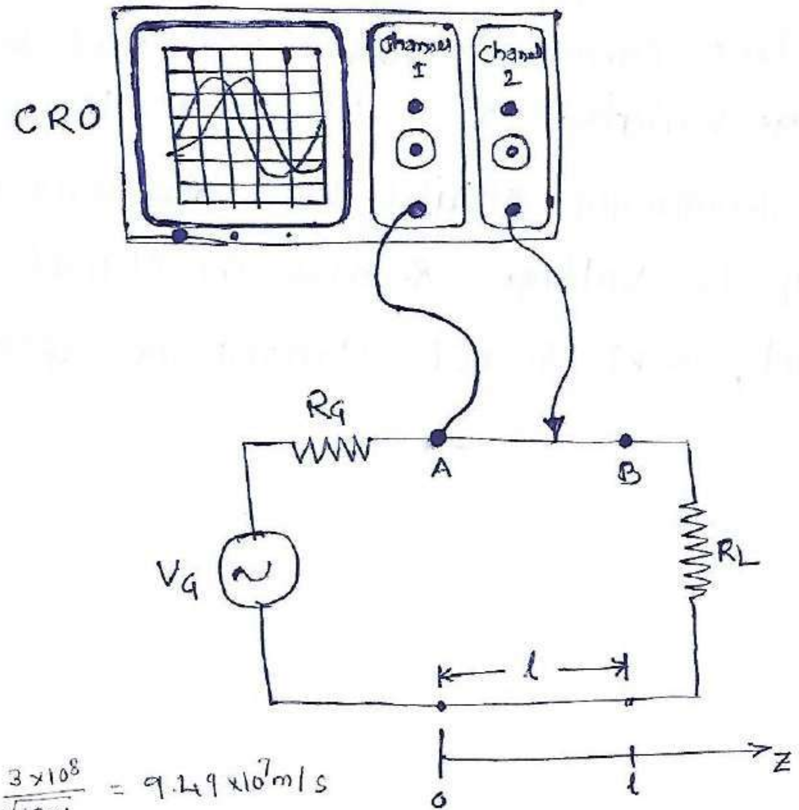


1. for $f < f_r$, In this region, the inductor's reactance ($X_L = \omega L$) increases as freq. is increased.

2. $f > f_r$, in this region the inductor behaves like capacitor & as freq. is increased the reactance decreases.

KVL & KCL NOT applicable at High RF

Let us Consider a simple electric circuit consisting of load resistor R_L & Sinusoidal voltage V_G with internal resistance R_G connected to the load by means of 1.5 cm long copper wires.



$$V_p = \frac{\omega}{\beta} = \lambda f = \frac{1}{\sqrt{\epsilon \mu}} = \frac{c}{\sqrt{\epsilon_r \mu_r}}$$

If $\epsilon_r = 10$, $\mu_r = 1$

$$\therefore V_p = \frac{3\times 10^8}{\sqrt{10\times 1}} = 9.49\times 10^7 \, m/s$$

$$\lambda = \frac{V_p}{f} = \frac{9.49\times 10^7}{1\times 10^6} = 94.86 \, m$$

We further assumed that those wires are aligned along the Z-axis & their resistance is negligible.

If the generater is set to a freq. of 1 MHz, the wavelength 'λ' will be 94.86 m. A 1.5 cm long wire connecting source with load will experience spatial vo ltage variations on such a minute Scale that they are insignificant.

When freq is increased to 10 GHz, the situation become dramatically different. In this case the wavelength reduces to $\lambda = V_p/10^{10}$ m $= 0.949$ cm & thus is approximately two-thirds the length of the wire. Consequently, if voltage measurements are now conducted along 1.5 cm wire, locations becomes very important in determining the phase reference of signal. This fact would readily be observed if an oscilloscope ... to measure the voltage at the beginning (location A), at the end (location B) or somewhere along the wire, where distance A-B is 1·5 cm. measured along the z-axis.

We are now faced with dilemma. A simple ckt. shown in fig. can be analyzed with Kirchoffs Volt. law (KVL)

$$\sum_{i=1}^{N} V_i = 0$$

when line connecting source with load does not possess a spatial voltage variation, as in the case in low-freq. circuits. When the frequency attains such high values that spatial behavior of the voltage & also the current, has to be taken into account, KVL & KCL cannot be applied directly.

—x—