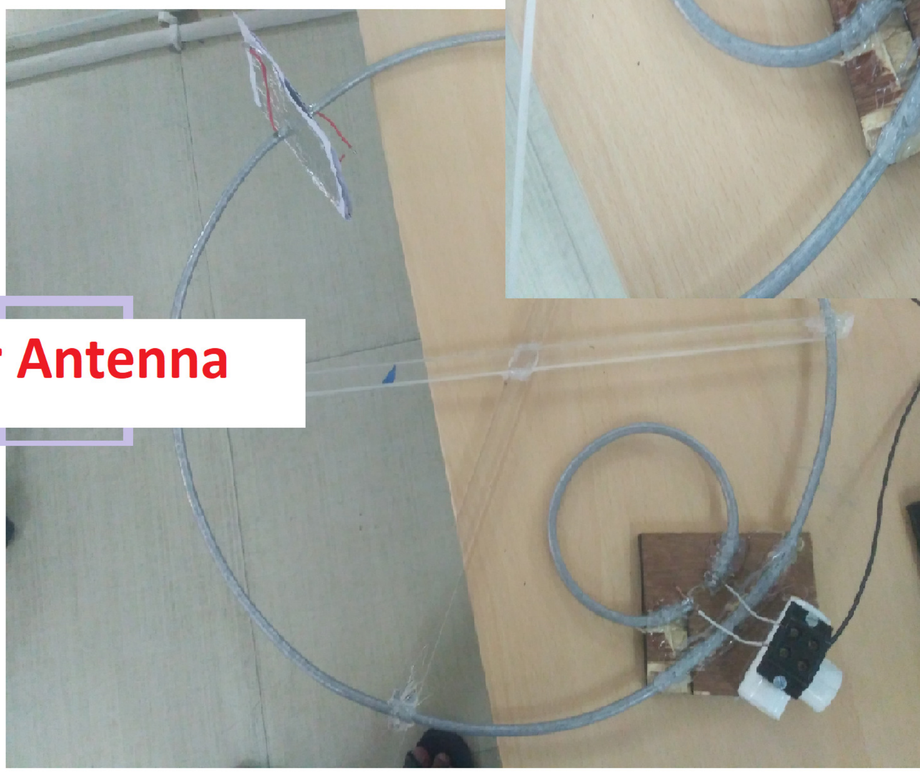
Antenna Design



Circular Antenna

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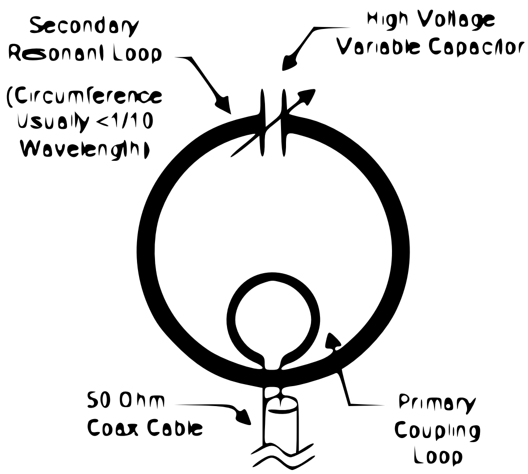
1. Introduction

A loop antenna is a type of a radio antenna, which consists of a loop (circular electrical conductor) usually fed by a balanced source or feeding a balanced load.The large self-resonant loop antenna has a circumference close to one wavelength of the operating frequency and so is resonant at that frequency.



This category also includes smaller loops 5% to 30% of a wavelength in circumference, which use a capacitor to make them resonant.These antennas are used for both transmission and reception.

2. Components Used

The following components are used in the project:-
Aluminium rod of diameter approximately 1 cm, coax cable,
Aluminium foil, plywood of square shape (15cm X 15cm), two acrylic stick of length about 0.5m, copper wire

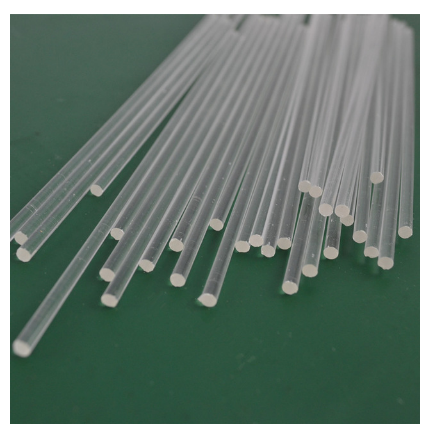
*1) **Aluminium rod**:* Antenna loop is made using the aluminium rod in circular form.

*2) **coax cable**:* Signal from PiFM is feed through this in antenna.

*3) **Aluminium foil**:* Tuning capacitor is made using this.

*4) **plywood of square shape**:* Large and small loop is fixed by making grooves in it.

*5) **acrylic stick**:* It helps in supporting the antenna in a plane.



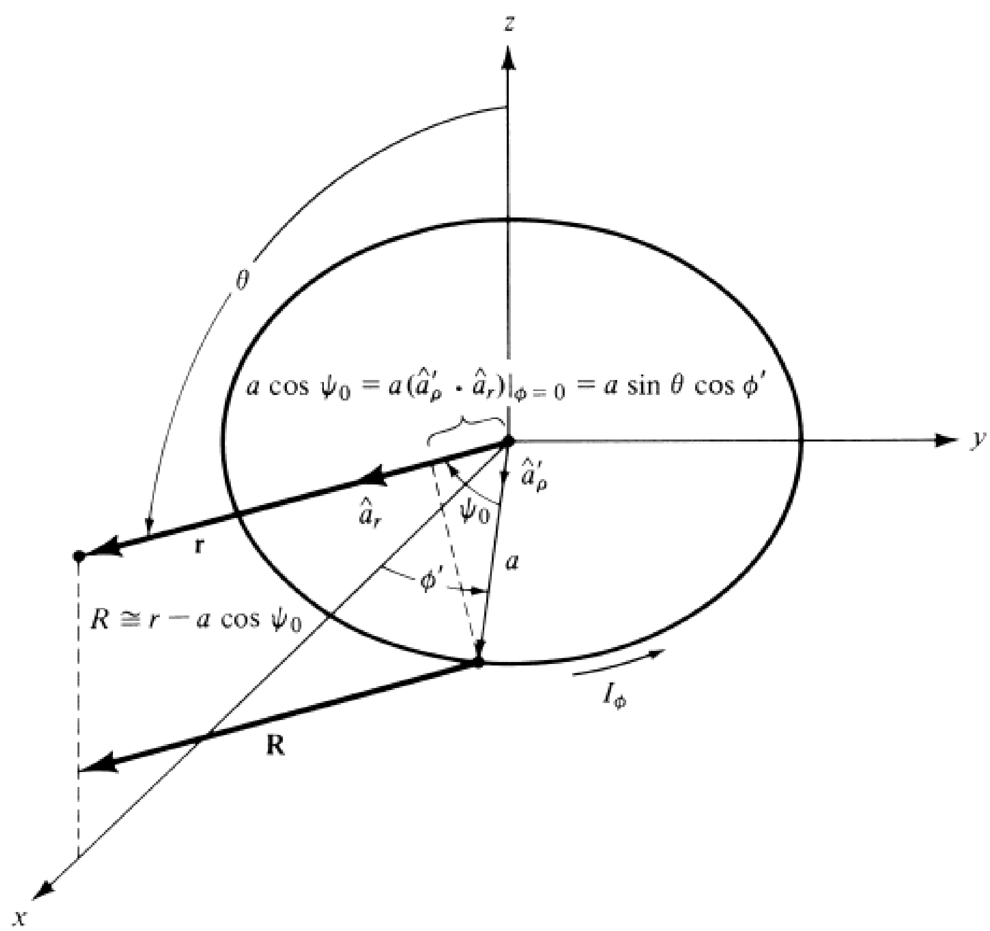
*6) **copper wire**:* It is used for connection between the coax cable junction switch and coupling loop

3. Characteristics of Circular Antenna

- Power Density
- Radiation Pattern
- Directivity
- Efficiency

*A. **Parameters***

*1) **Radiated Electric and Magnetic Field**:* The field in the far field region is calculated using the following diagram.



It comes-

$$E_r \simeq E_\theta = 0$$

$$E_\phi \simeq \frac{ak\eta I_0 e^{-jkr}}{2r} J_1(ka\sin\theta)$$

$$H_r \simeq H_\phi = 0$$

$$H_\theta \simeq -\frac{E_\phi}{\eta} = -\frac{akI_0 e^{-jkr}}{2r} J_1(ka\sin\theta)$$

where, The Bessel function of the first kind and order n is defined by the infinite series

$$J_n(z) = \sum_{m=0}^{\infty} \frac{(-1)^m (z/2)^{n+2m}}{m!(m+n)!}$$

*2) **Power Density**:* The time-average power density is formed. That is,

$$\mathbf{W}_{\text{av}} = \frac{1}{2}\text{Re}[\mathbf{E} \times \mathbf{H}^*] = \frac{1}{2}\text{Re}[\hat{\mathbf{a}}_\phi E_\phi \times \hat{\mathbf{a}}_\theta H_\theta^*] = \hat{\mathbf{a}}_r \frac{1}{2\eta}|E_\phi|^2$$

which can be written as

$$\mathbf{W}_{\text{av}} = \hat{\mathbf{a}}_r W_r = \hat{\mathbf{a}}_r \frac{(a\omega\mu)^2 |I_0|^2}{8\eta r^2} J_1{}^2(ka\sin\theta)$$

with the radiation intensity given by

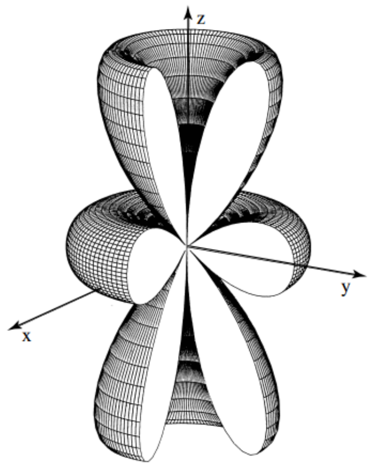
$$U = r^2 W_r = \frac{(a\omega\mu)^2 |I_0|^2}{8\eta} J_1{}^2(ka\sin\theta)$$

*3) **Radiation Resistance**:* This gives the radiation resistance of the single turn loop

$$R_r = \eta \frac{8}{3}\pi^3 \left(\frac{A}{\lambda^2}\right)^2$$

*4) **Radiation Pattern**:* The radation pattern is given by the following equation

$$\frac{(a\omega\mu)^2 |I_0|^2}{8\eta} J_1{}^2(ka\sin\theta)$$



The maximum radiation intensity occurs when ka sin = 1.84 so that

$$U|_{\max} = \frac{(a\omega\mu)^2|I_0|^2}{8\eta} J_1{}^2(ka\sin\theta)|_{ka\sin\theta=1.84} = \frac{(a\omega\mu)^2|I_0|^2}{8\eta}(0.582)^2$$

*5) **Directivity**:*

$$R_r = \frac{2P_{\text{rad}}}{|I_0|^2} = \frac{2\pi(a\omega\mu)^2}{4\eta(ka)} = \eta\left(\frac{\pi}{2}\right)ka = 60\pi^2(ka) = 60\pi^2\left(\frac{C}{\lambda}\right)$$

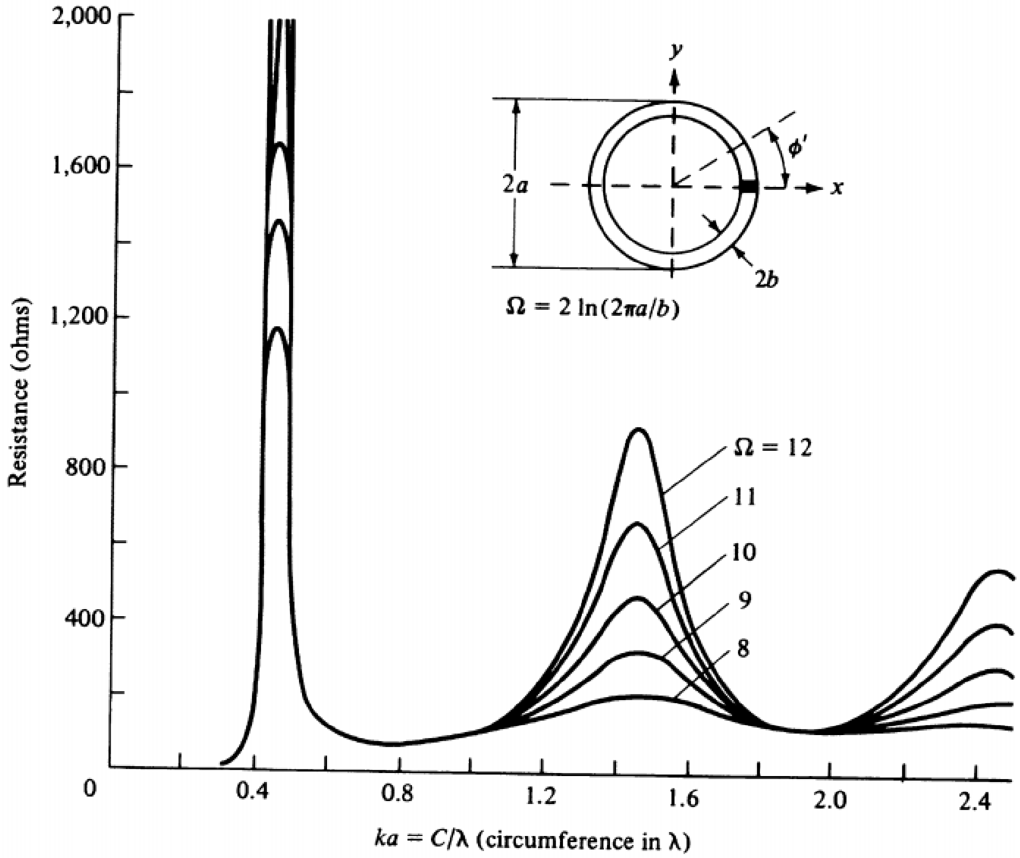
$$D_0 = 4\pi\frac{U_{\max}}{P_{\text{rad}}} = 4\pi\frac{ka(0.582)^2}{2\pi} = 2ka(0.582)^2 = 0.677\left(\frac{C}{\lambda}\right)$$

$$A_{em} = \frac{\lambda^2}{4\pi}D_0 = \frac{\lambda^2}{4\pi}\left[0.677\left(\frac{C}{\lambda}\right)\right] = 5.39\times10^{-2}\lambda C$$

where C(circumference) $= 2\pi a$ and $\eta \simeq 120\pi$.

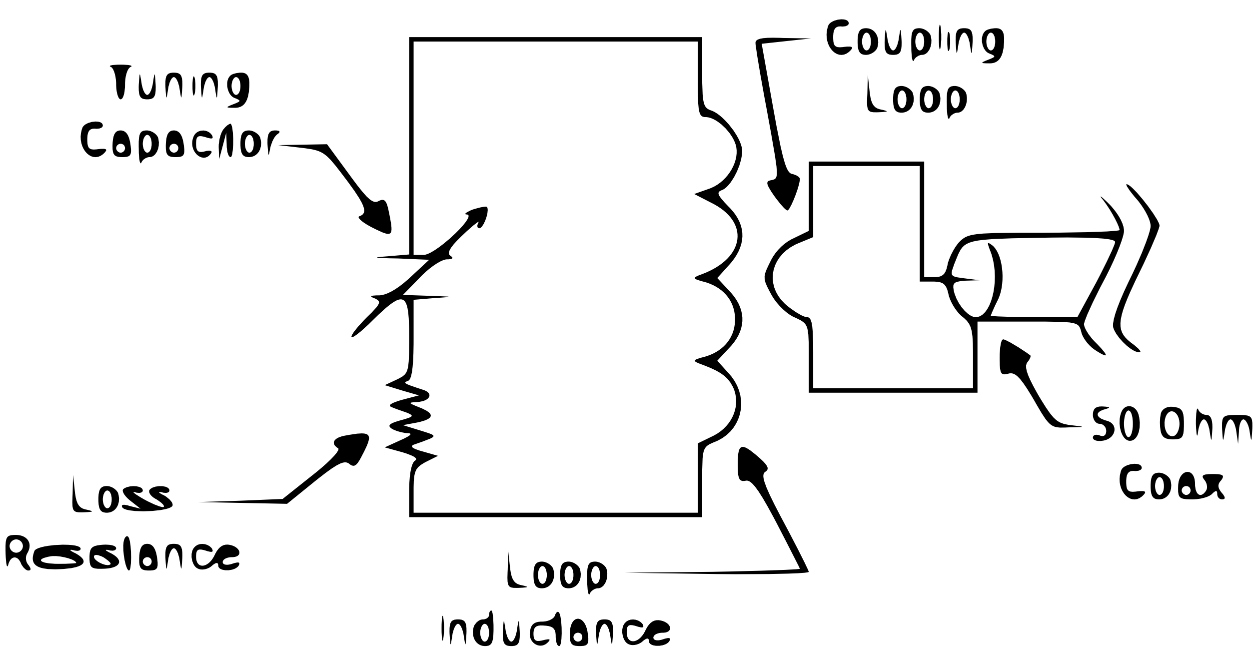
*B. **Graph***

*1) **Resistance vs Circumference**:* When the circumference of the loop approaches , the maximum of the radiation pattern shifts exactly along the loops normal. Then, the input resistance of the antenna is also good . The maximum directivity occurs when C 1.4 but then the input impedance is too large.



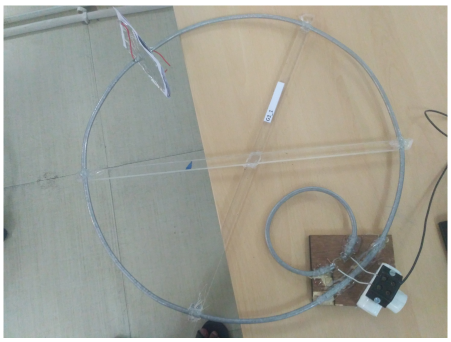
4. Electrical Model of Antenna

The equivalent circuit of the loop antenna is show in the following figure.



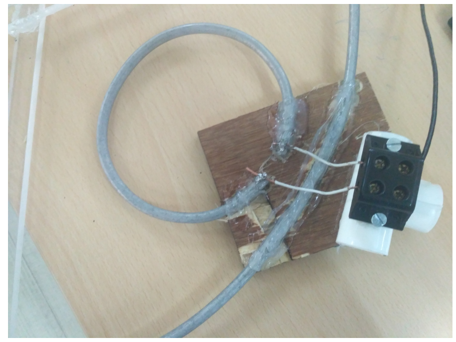
5. Design Procedure

Frequency of transmission is 103.3MHz.
It gives the λ equals approx. 3m
The circumference of the bigger loop is half of λ which equals 1.5m

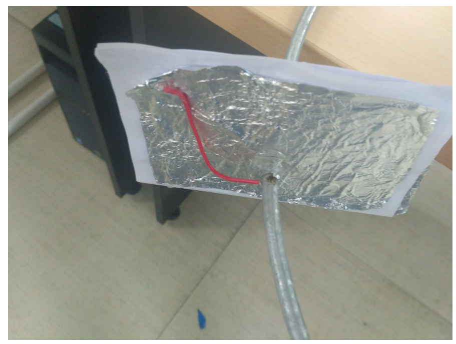


The circumference of the coupling loop is one-fifth of the bigger loop which gives 0.3m.
The purpose of coupling loop is to magnetically induce current in the bigger loop for transmission of signal.

Now place the smaller loop diameterically opposite to the capacitor close to bigger loop. There should be a gap between bigger and smaller loop.
Caution: Bigger and smaller loop must not touch each other.



Feed the signal from PiFM using the coax cable to the one end of coupling loop and the other wire of coax to other end of smaller loop.



GPIO pin 4 transmits the signal. One layer of coax is connected to GND of RaspberryPi.

6. Measurement

A. *Resistance of Al rod*

The resistance of the bigger loop is 2.5 Ω measured using multimeter.

B. *Inductance*

The inductance is also measured using a resiatance of known value and current source. It comes approx. 2.35 X 10^{-8} H.

C. *Capacitance*

The frequency of the transmission is 103.3 MHz. Using the following equation , the value of capacitor comes 0.101 nF.

$$f = \frac{1}{2\Pi\sqrt{LC}}$$

D. Power provided by PiFM

Maximum current drawn from GPIO 4 is 50mA at voltage 3.3V. So power transmitted by the PiFM is 165mW. It is calculated using the equation

$$Power = currentXvoltage$$

7. Installation

The loop antenna is placed away from metallic body for better performance. It is kept at a very high place . The axis of the loop is horizontal for better range.

8. Tradeoffs

Small loop antennas have very low value of radiation resistance. This results into power loss as heat due to flow of current with high levels. Hence large loop antennas are preferred over smaller ones. Larger loop is expensive.

9. Problem Faced

- It was very difficult to resonant the antenna using the capacitor which is made using the aluminium foil.

10. Future Scope of Work

- Variable air capacitor can be used in place of capacitor to tune to other transmission frequency.

11. References

- Antenna Theory:Analysis and Design by Constantine Balanis
- A Magnetic Loop Antenna for Short-wave Listening (SWL)
- StackExchange
- Wikipedia