Investigation of FM Radio Reception in Sri Lanka

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Abstract *– A large number of state- and private FM radio channels are operating in Sri Lanka at present. A greater percentage of FM customers from Colombo and suburbs are the users of motor vehicles (both public- and private vehicle users). In villages, there are more house residents listening to radio. For household customers there exists the possibility of improving the reception qualities by improving the physical dimensions of the antenna elements whereas passengers of motor vehicles do not have that facility.*
Since a large number of FM channels occupy a relatively low bandwidth the antenna can be very much sensitive to frequency changes. Hence the frequency sensitivity of an antenna has also been investigated here. Therefore, both the household customer and the vehicle user should also be able to do required adjustments to the antenna with a prior knowledge about the consequences of any maladjustments.
The article investigates the various possibilities of optimization of FM reception for both house residents and vehicle users.
The results show that the vehicle antenna changes its directional properties beyond a certain length. At longer antenna lengths a split in the vertical radiation pattern takes place. This property can be made use in the reception of channels at higher elevation angles.
The analysis also show that the household antenna array improves the multi-directional reception ability for high end frequency channels.

Keywords*: Antenna, radio channel, FM reception*

Nomenclature

SLBC - Sri Lanka Broadcasting Corporation
FM - Frequency Modulation
AM - Amplitude Modulation
VHF – Very High Frequency
UHF – Ultra High Frequency

1 INTRODUCTION

Radio broadcasting in Sri Lanka can be categorized mainly into two areas: Radio broadcasting and Television broadcasting. Radio Ceylon started regular radio broadcasting in 1947 which was renamed as Ceylon broadcasting Corporation (CBC) in 1967 by the Ceylon broadcasting act No. 37 in 1966. Medium Wave frequency band (526 kHz – 1606 kHz) was mainly used with AM (Amplitude Modulation) as the modulating technique.

With the introduction of TV broadcasting in 1979 the demand for radio programmes dropped drastically. Gradually number of TV channels increased, and the domestic radio viewers dropped further. Domestic viewers became much more confined to remote villages where people have difficulties in watching TV due to various reasons.

SLBC continued with AM medium wave transmission until 1993. In 1993 SLBC switched to FM transmission (VHF lower band) from AM medium wave transmission.

With the increase of vehicles mainly in city areas of Sri Lanka, traffic congestion could be observed all over. As a mode of relaxation, the passengers of vehicles got more and more attracted to FM radio channels. More domestic FM users could be found in village areas compared to city area and suburbs.

With the increasing demand a large number of FM channels (both SLBC and private sector) have been introduced. Due to promotion schemes and various advertising campaigns by the private sector FM channels number of domestic FM listeners have been increased in city suburb areas and villages.

A good percentage of present TV channels are UHF channels, carrier frequencies become higher than 300 MHz. For FM transmission the average carrier frequency is around 100 MHz, thus wave length for FM transmission is approximately three times smaller than that of TV wave length. Therefore, the size of an ideal FM antenna (e.g. half wave dipole) becomes approximately 3 times larger than a TV antenna.

Another aspect to be considered in the design of a FM antenna is the frequency resolution of channels. FM sound quality is better than that of AM due to the fact that carrier frequency is less susceptible to channel noise compared to carrier amplitude. Due to large number of FM channels allocated in a relatively smaller bandwidth (87.8 MHz-107.5 MHz) the frequency resolution among carriers is relatively small. This can give rise to difficulties in tuning of FM channels. Proper selection of the antenna with appropriate dimensions can eliminate some of these difficulties and maintain a good sound quality.

As discussed previously there are two main categories of FM listeners. They are the domestic viewers and the passengers of motor vehicles.

Domestic viewers need an antenna installed at a higher elevation, in case the built-in antenna associated with the radio receiver shows poor performance. This is particularly true for remote areas. Once the antenna is installed it should be able to receive all possible FM transmissions covered in that area.

For passengers of motor vehicles situation is somewhat different. Since the antenna and the receiver change their positions with time, the signal reception by the antenna should be maintained satisfactorily irrespective of the location.

The antenna used in a motor vehicle is a *mono pole* type antenna whose length is normally adjustable.

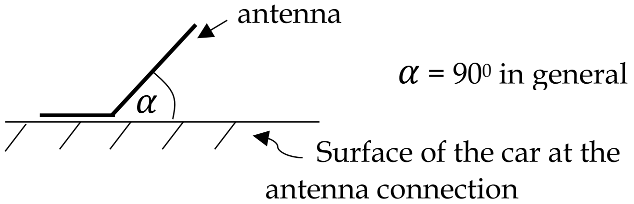


Figure 1: Vehicle antenna

In the case of a domestic user the receiver is provided with a similar type of adjustable monopole antenna.

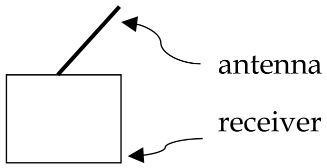


Figure 2: Domestic receiver

The built-in antenna of the receiver does not exhibit good performance for most of the remote places. Therefore, a separate dipole antenna (with/without additional elements) has to be installed at a higher elevation. Since the type of polarization used in FM transmission is vertical polarization, always the antenna (and the additional elements) should be kept vertical.

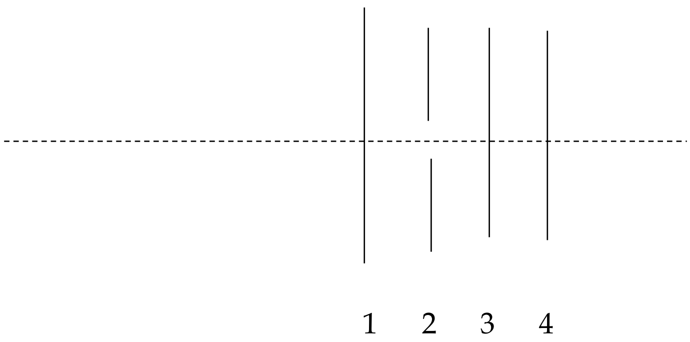


Figure 3: 4-element domestic antenna

Various researchers have investigated the directional gain optimization problem for an array in the past (Cheng, et al., 1991 and Jason, et al., 2001). Research work has already been carried out to find optimum parameters of a Yagi array for the reception of multiple UHF TV channels (Perera, 2017).

The main objective of this research work is to investigate the performance of a domestic F.M antenna array and a mono-pole vehicle antenna under restricted conditions. It has been investigated here, how an antenna array designed for a particular frequency channel responds to high-end and low-end FM channels. Also, the impact of the antenna length on the directional properties of a vehicle antenna has been investigated in this paper.

2 THEORETICAL BACKGROUND

2.1 The mono-pole antenna

The mono-pole antenna used in a motor vehicle makes an image monopole using the metallic surface of the vehicle (surface on which the antenna is installed).

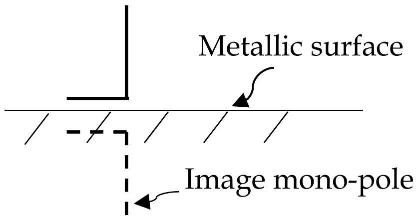


Figure 4: Formation of a virtual dipole antenna

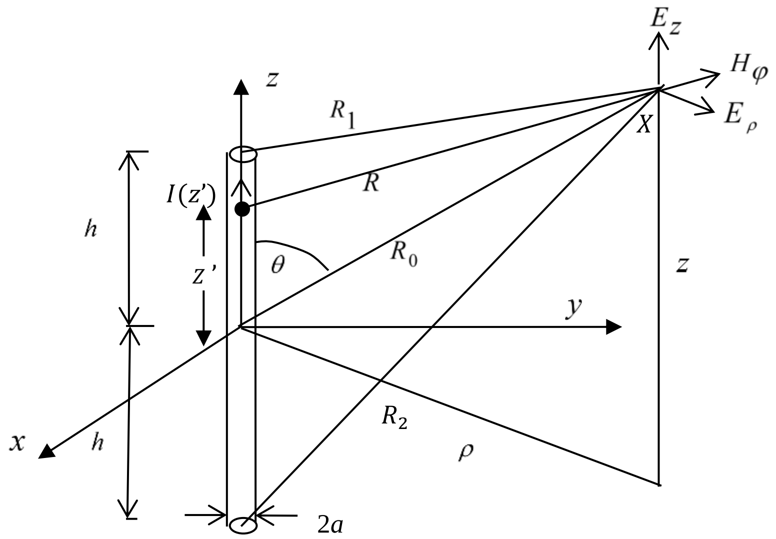
The antenna and the image together make a dipole antenna whose far field equation can be derived using Maxwell's equations.

2.2 Antenna equations

Starting from Maxwell's equations, equations for scalar potential φ and vector potential $\boldsymbol{A}$ can be derived with the help of Gauge Transformation and Lorentz conditions (Ofandis et al., 2013).

In order to calculate the field components $E_Z(z,\rho)$, $E_\rho(z,\rho)$ and $H_\varphi(z,\rho)$ it is sufficient to know $A_z(z,\rho)$ the *z*-component of $\boldsymbol{A}$. $A_Z(z,\rho)$ is given by

$$A_Z(z,\rho) = \frac{\mu}{4\pi}\int_{-h}^{h} I(z')\frac{e^{-jkR}}{R}dz', \; R = \sqrt{\rho^2 + (z-z')^2} \tag{1}$$



μ – permeability, ε – permitivity, k – wave number, $2h_p$ – length of the p^{th} element

Figure 5: Field components of a half wave dipole.

Figure 5 shows various field components at a point X due to a half wave dipole. Using the relationship $j\omega\mu\varepsilon E_z(z,\rho) = \partial_z{}^2 A_z + k^2 A_z$ in the above equation with the assumption that $I(z)$ is distributed sinusoidally, we can write $I(z)$ as:

$$I(z) = I_0 \frac{\sin(k(h-|z|))}{\sin kh} = I_m \sin(k(h-|z|))$$

$E_z(z,\rho)$ can be written as $E_z(z,\rho) = -\frac{j\eta I_m}{4\pi}\left[\frac{e^{-jkR_1}}{R_1} + \frac{e^{-jkR_2}}{R_2} - 2\cos(kh)\frac{e^{-jkR_0}}{R_0}\right]$

In a similar manner, field components $E_\rho(z,\rho)$ and $H_\varphi(z,\rho)$ can be derived.

$$H_\varphi(z,\rho) = \frac{jI_m}{4\pi\rho}\left[e^{-jkR_1} + e^{-jkR_2} - 2\cos(kh)e^{-jkR_0}\right]$$

$$E_\rho(z,\rho) = \frac{jI_m}{4\pi\rho}\left[\frac{z-h}{R_1}e^{-jkR_1} + \frac{z+h}{R_2}e^{-jkR_2} - 2\cos(kh)\frac{z}{R_0}e^{-jkR_0}\right]$$

Above field components can be used to calculate the normalized gain $g(\theta,\varphi)$, where θ and φ are the elevation angle and the azimuth angle respectively. If sinusoidal distribution of current is assumed, polar gain $g(\theta,\varphi)$ can be written as

$$\left|\sum_{p=1}^{k} I_p \frac{\cos(kh_p\cos\theta) - \cos kh_p}{\sin kh_p \sin\theta} e^{jkx_p \sin\theta\cos\varphi}\right|^2$$

In the case of a dipole antenna alone (without reflectors or directors) the value of k reduces to 1 and the gain of the antenna becomes equal to;

$$|g(\theta,\varphi)| = I_1 \frac{\cos(kh_1\cos\theta) - \cos kh_1}{\sin kh_1 \sin\theta} \tag{2}$$

In an antenna array, the mutual impedance Z_{pq} on p^{th} element due to q^{th} element can be calculated from the E field strength at p^{th} element due to q^{th} element:

$$Z_{pq} = -\frac{1}{I_p I_q}\int_{-h_p}^{h_p} E_{pq}(z) I_p(z)\,dz$$

I_p - current in p^{th} element, I_q - current in q^{th} element, $2h_p$ - length of p^{th} element.
When $p = q$, Z_{pq} becomes the self-impedance of p^{th} element.

This concept can be extended for an array consisting of k elements, so that we end up with an impedance matrix $[Z]_{k\times k}$ consisting of self-impedances and mutual impedances.

$$[Z] = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1k} \\ Z_{21} & Z_{22} & \cdots & Z_{2k} \\ \cdot & \cdot & \cdots & \cdot \\ Z_{k1} & Z_{k2} & \cdots & Z_{kk} \end{bmatrix}$$, a matrix with diagonal symmetry $Z_{pq} = Z_{qp}$

Since the voltage across the p^{th} element consists of self-induced voltage due to Z_{pp} and the induced voltages due to rest of the $k-1$ elements, V_p can be written as

$$V_p = \sum_{q=1}^{k} Z_{pq} I_q \ , \ p = 1,2,\ldots,k$$

Therefore, the voltage vector for the *k* elements can be calculated using the matrix equation

$$\begin{bmatrix} V_1 \\ V_2 \\ \cdot \\ V_k \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} & \ldots & Z_{1k} \\ Z_{21} & Z_{22} & \ldots & Z_{2k} \\ \cdot & \cdot & \ldots & \cdot \\ Z_{k1} & Z_{k2} & \ldots & Z_{kk} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ \cdot \\ I_k \end{bmatrix}$$

For an array consisting of a single dipole (only the active element), a reflector and *k*-2 directors (then all *k*-1 elements become passive elements), all the voltages in the vector except V_2 become zero. If V_2 is set to 1 unit, the voltage vector can be written as $[V] = [0,1,0,\ldots 0]^T$, so that the currents in the elements $I_1, I_2, \ldots, I_k$ can be calculated from $[I] = [Z]^{-1}[V]$.

These current values can be substituted in the equation for $g(\theta, \varphi)$ to calculate azimuthal- and polar gains.

2.3 Polar- and azimuth radiation patterns of FM antennae

2.3.1 Motor vehicle antenna

Since the signals are vertically polarized, for a motor vehicle antenna (can be considered as a virtual vertical dipole) the azimuthal gain should be a constant. Therefore, the azimuthal radiation pattern becomes a constant.

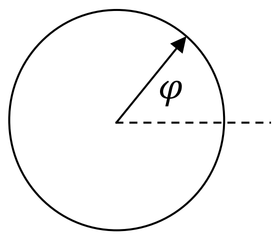


Figure 6: Azimuthal radiation pattern

The polar pattern can be plotted using (1). But it does not have much influence on the signal reception ($g(\theta,\varphi) = g(0,\varphi) = const.$) if the distance between the receiving antenna and the transmitting tower is large.

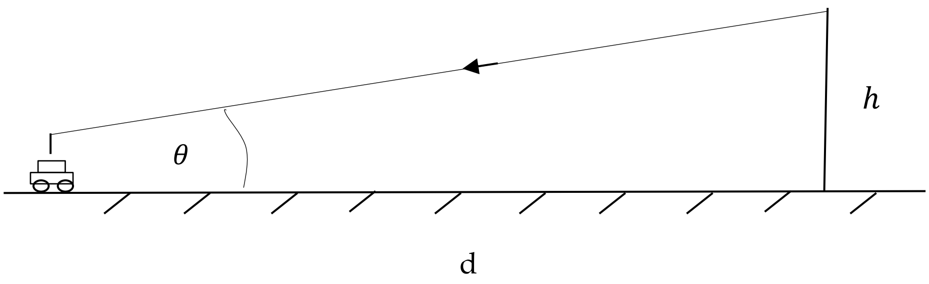


Figure 7: The influence of the elevation of the transmitting antenna

If θ is very small (ie. $\frac{h}{d} \ll 1$), the azimuth gain can be considered a constant and hence the radiation pattern becomes a circle as shown in the Figure 6.

When θ becomes larger directional properties of the polar radiation pattern plays a vital role.

2.3.2 Household antenna

A house hold customer will have to go for a fixed type directive, high gain antenna when the signal strength of region is weak. For example, a vertically polarized Yagi-array given in Fig.3 can be a good option. Such an array shows directional properties both in vertical- and horizontal planes.

3 METHODOLOGY

The investigation was mainly based on the polar radiation patterns of the antenna. The equation for $g(\theta,\varphi)$ was used to plot the radiation pattern of the antenna. In the case of the motor vehicle, a single dipole was used for the simulation.

Polar radiation pattern was plotted for a range of values of h_1 and investigated the directional gain behaviour. This behaviour was used to investigate the ability of the vehicle to receive FM channels when the transmitting tower is not far away from the vehicle.

For a household customer, simulation was done with a dipole array consisting of a single active element (dipole) and 3 passive elements. Here the main concern was to optimize azimuth gain. The length h_1 was changed in the vicinity of $\frac{\lambda}{2}$ to find optimum values. MATLAB was used for all the simulation work.

4 RESULTS AND DISCUSSION

4.1 Motor vehicle antenna

When the physical antenna length $\left(\frac{h_1}{2}\right)$is less than $\frac{\lambda}{2}$ (i.e. when the total electrical length of the antenna h_1 is less than λ) antenna shows a polar radiation pattern without side lobes. This is very much suitable when the vehicle is far away from the transmitter.

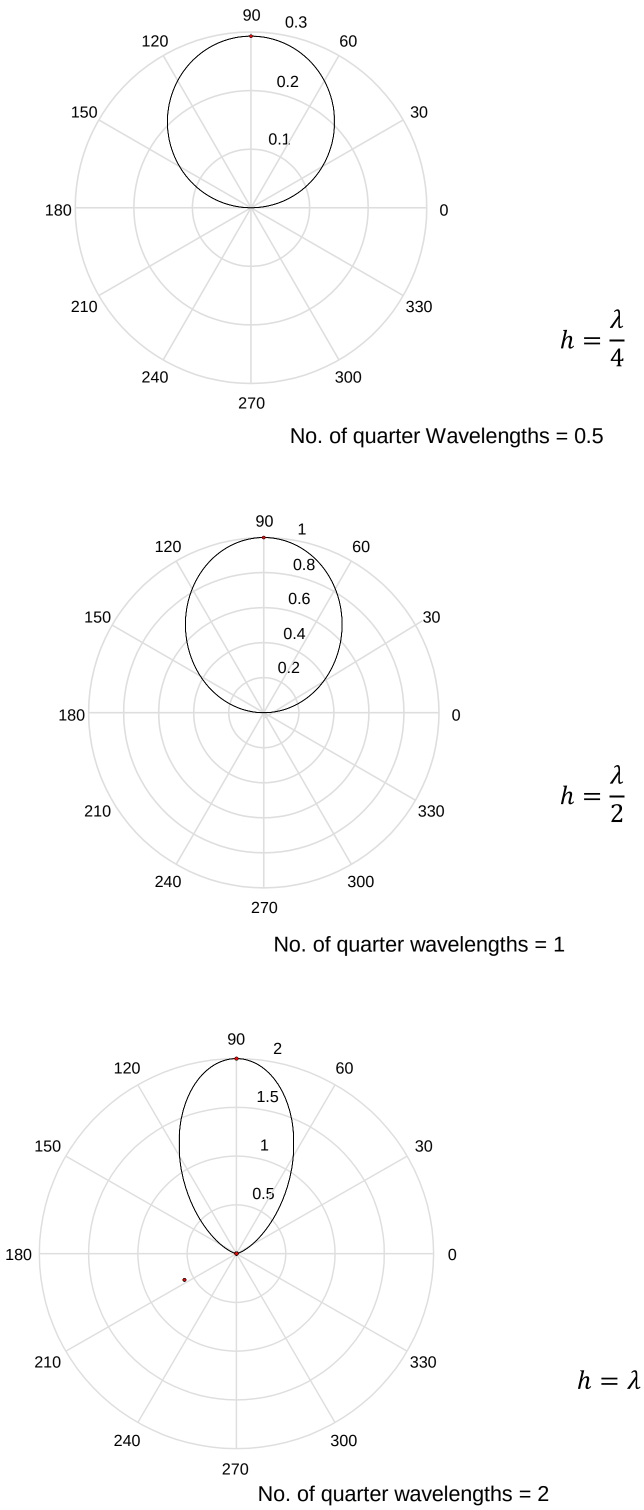
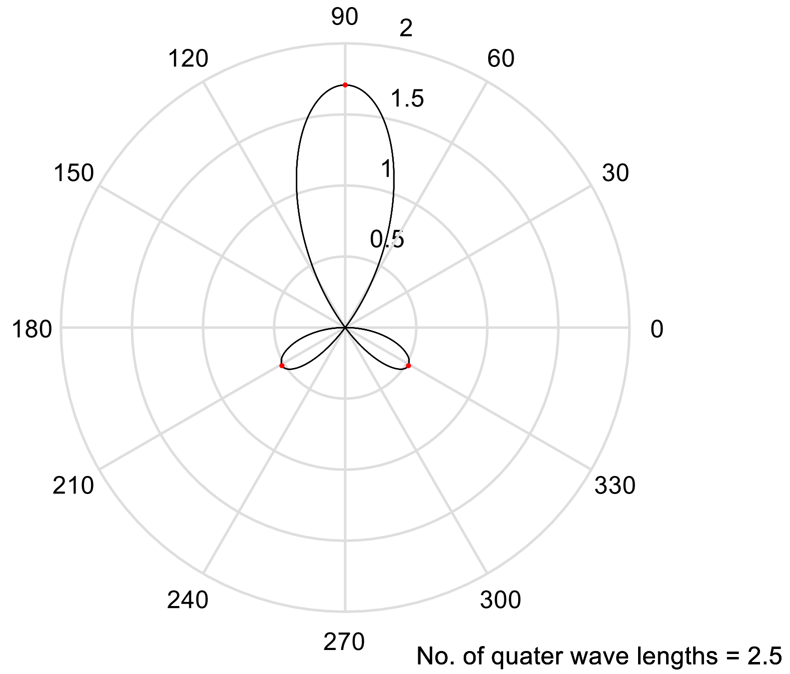


Figure 8: Polar radiation patterns for a vehicle antenna when $\boldsymbol{antenna\ length} \leq \frac{\lambda}{2}$

When the physical antenna length increases beyond λ, side lobe level starts to increase. When the antenna length becomes approximately equal to 1.43 λ, in addition to the main lobe equally large 2 side lobes appear in the radiation pattern. One of these side lobes can be useful when the vehicle is closer to the transmitting tower.



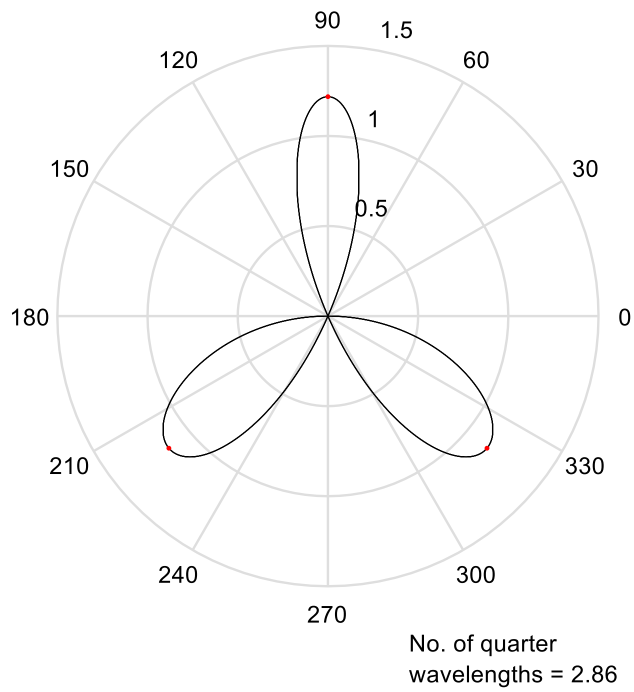


Figure 9: Polar radiation patterns for a vehicle antenna when $\boldsymbol{antenna\ length > \frac{\lambda}{2}}$

4.2 Domestic FM antenna

Results show that highly directive polar gain, with good a beam width can be achieved using a 4-element antenna with following specifications:

The length of the dipole = 0.48λ,
The length of the reflector = 0.5 λ
The length of the first director = 0.47 λ
The length of the second director = 0.46 λ
The spacing between the dipole and the reflector = 0.25 λ
The spacing between the dipole and the first director = 0. 5 λ
The spacing between the first- and the second directors = 0. 5 λ

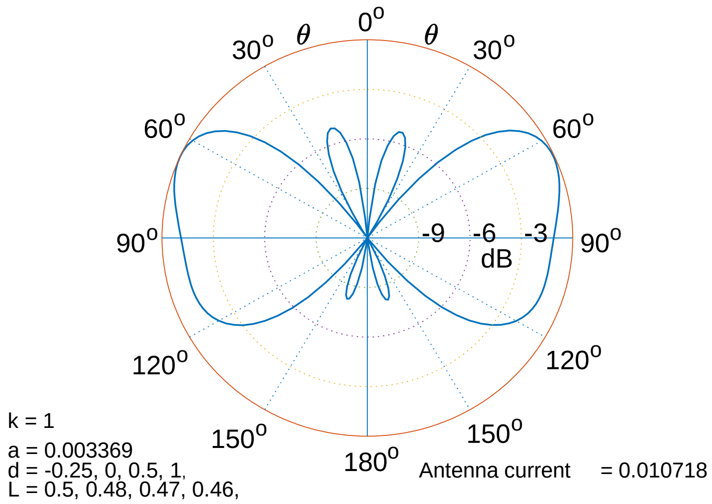


Figure 10: Polar radiation pattern for a domestic antenna with 4 elements

If the above antenna is somewhere in the middle of the local FM range (97.6 MHz), response of the antenna to lowest and highest frequencies (FM channels corresponding to 87.8 MHz and 107.4 MHz) can be plotted by changing the frequency by ±10% or the wavelength by factors $^1/_{0.9} \approx 1.1$ and $^1/_{1.1} \approx 0.9$ as shown below:

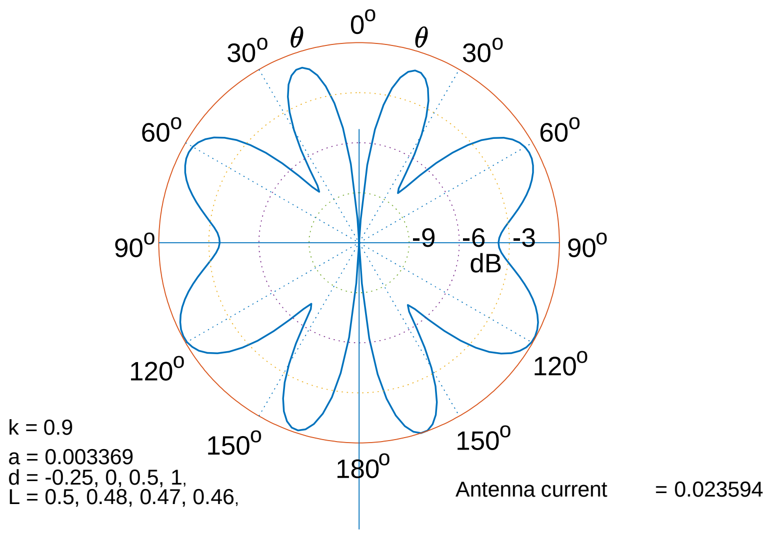


Figure 11: High frequency response of the domestic antenna

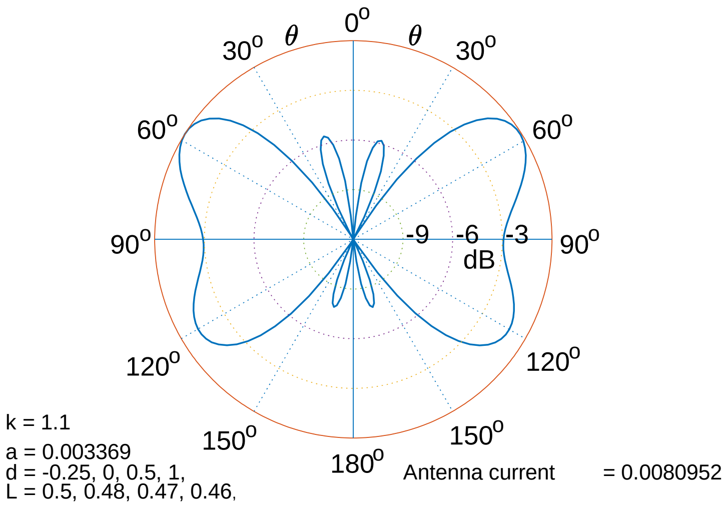


Figure 12: Low frequency response of the designed antenna

The Figure with k = 0.9 corresponds to an FM channel at high frequency end (ie. 107.4 MHz). This shows that the antenna beam width increases for FM channels at the high end.

5 CONCLUSION

The work here is mainly focussed on the areas where the FM reception shows some difficulties. In the case of vehicles FM reception is very much smooth in Colombo and suburbs. When car antenna length is adjusted its positive and negative repercussions are discussed in the paper. Due to the change in the current distribution pattern main lobe of the radiation pattern tends to split causing additional side lobes. One of these side lobes might be useful in the reception when the vehicle is closer to the transmitting station even though the antenna directive gain slightly drops. The signal strength of a car antenna is also dependent on the surrounding structures e.g. A congested road can change the received signal strength due to the signal reflections on the metallic surfaces of the vehicles. These factors were not taken for granted in this investigation.

In the case of a household antenna Yagi array with 4-elements shows good reception properties. It is interesting to observe that an array designed for a particular FM station shows higher beam width for higher frequencies. That is the multi-directional nature of the array improves while keeping the directive gain at an acceptable value.

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