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# COMPARATIVE ANALYSIS OF SLIM JIM ANTENNA FOR HAM RADIO APPLICATIONS

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## ABSTRACT

Ham radio applications demand antenna design with an aim of achieving maximum gain, which is affected by several factors. Impedance matching is one such factor which plays a vital role in such condition, as of improper impedance matching causes the formation of standing waves resulting in the reduction of gain. Generally wire antennas have an input impedance of 68Ω, which are detuned to 50Ω to have proper impedance matching with a co-axial cable; as a result it leads to decrease in gain. Slim Jim is a special wire antenna which has impedance selectivity of 50Ω, 100Ω, 200Ω and 400Ω. Due to the addition of a parallel element, the Slim Jim antenna has a considerable horizontal gain over the J-pole antenna. This paper provides a comparative analysis of four wire antennas mainly used by HAMs with the appropriate calculations using velocity factor and the results are discussed in detail.

**Keywords:** slim jim antenna, ham radio application, impedance matching.

## INTRODUCTION

Wire Antennas have substantial applications in day-to-day life uses. Basic wire antennas like dipoles, folded dipoles are well known to the world of communication; this paper provides an analytical study of J-pole and Slim Jim Antennas. These antennas have been profoundly used in Ham Radios. The dipole antennas are widely used antennas across the UHF, VHF and lower-microwave bands. Ham radio or amateur radio is operated on a designated radio frequency spectrum with a valid license for the purpose of non-commercial transfer of messages, wireless experimentation, private recreation and communication. The term amateur is used to specify that it is different from commercial broadcasting and the people who are interested in radio techniques with personal aim.

The amateur radio service is established by the International Telecommunication Union (ITU). FCC allocates the frequency band for operation of Amateur Radio. The operation frequency range of amateur radio is classified into bands. The International amateur satellite frequency allocations range from 7 MHz to 250 GHz [1, 2]. Some of the amateur bands are used for the entire amateur radio band and a few for uplinks and downlinks of information to and from the satellite. The 1.25 Meter band Slim Jim Antenna is designed in this paper which operates over the VHF band at 300MHz. Now a day, many apps for HAM Radio have been developed by various world leading software companies, Google play and Apple on various working platforms. Apps were developed on Linux, Windows platforms. It has significant usage in present day-to-day life. Ham Radio Tools is an app, developed by Google play, which is a simple program; purpose is to assist Ham Radio operators. It provides the basic operations as: to look up call sign information, find current GPS location information, save each contact to a log database stored on a phone, calculate a simple quarter and half wave antenna length, calculate wavelength of a frequency. HAM Radios are operated across the world with in the regulations of ARRL. A license provides access to HAM Radio operators to operate on radio frequencies known as Amateur Bands. Generally, wire antennas have been used in development of HAM Radios. This paper provides an analytical study of four wire antennas designed at operating frequency of 300MHZ for better usage in HAM Radios.

## WIRE ANTENNAS

Wire Antennas are basic antennas made of two tuneable simple wires. They are widely used in automobiles, buildings, ships, aircraft and spacecraft and so on. Dipole, Folded dipole antennas are the widely used wire antennas. The J-pole and Slim Jim antennas belong to the recent era of wire antennas being used and these four antennas are discussed and compared in this paper.

### Dipole antenna

Dipole antenna is the simplest and widely used antenna in radio and telecommunications. It has two identical conducting elements such as rods or metallic wires which are symmetrically arranged. For the transmitter, the driving current is applied and for receiver antenna, the output signal is taken in between the two half's of the antenna. Half wave Dipole antennas are used in present day-to-day communication systems. It is a centre fed antenna, where feed is inserted into the gap separating two conductors. In this paper, a lumped port is used as feeding element to dipole in HFSS Software. The electrical length of dipole is λ/2, where each arm is of λ/4. The standing waves flow back and forth between the ends of a dipole, making the dipole a resonant antenna. The length of a dipole is determined by the wavelength of radio waves used.

### Folded dipole

Folded Dipole antenna is a two element radiator antenna consisting of two parallel radiators. The main radiator is of length λ/2. The two half parallel elements are of length λ/4 each. Dipoles, as antennas in FM band are known as folded dipoles [3]. The legs of antenna are folded in such a way that they at most meet the feed point, such that, the antenna comprises one entire wavelength. The currents in each leg are in phase. The folded dipole has similar directional properties of dipole antenna. The advantage of folded dipole is improved bandwidth over standard half wave dipole. It exhibits good impedance matching compared to ordinary dipole.

**J-pole antenna**

The J-pole antenna is a half-wave vertical element end-fed by a quarter wave matching stub; consisting of a half wavelength arm connected to a quarter wavelength feed pair. [3] The lower end of the matching stub may be grounded directly. The J pole antenna is an Omni directional antenna. Matching to the feed-line is obtained by sliding the connection of the feed-line back and forth along the stub to obtain the voltage wave Standing Wave Ratio is as close as possible to 1:1 [4].

The operation of J-pole is assumed to be that; the top ½ wavelength section is the radiation portion of the antenna, while the lower ¼ wavelength stub is used for matching purpose and doesn't radiate. But, this assumption is not entirely correct. If the assumption that; only the top ½ wavelength potion of J-pole radiates, then there wouldn't be any difference between the field patterns of J-pole and ½ wave dipole. For negligible radiation to take place from the ¼ wave matching stub, certain conditions prevail. First, the spacing between the two parallel conductors must be very close in terms of wavelength. Second, the currents in each conductor should be out of phase by $180^0$. The open end of the stub exhibits infinite impedance as no current exhibits at that point. At the adjacent contrasting point of the stub, where it connects to ½ wavelength element the impedance is high, but not infinite. Consequently, the current amplitudes between the parallel lines of the matching stub will not be equal [5]

**Slim jim antenna**

Slim Jim antenna is generally characterized as an end fed vertical folded dipole antenna. It has radiation efficiency 50% better than a conventional ground plane due to its low angle radiation. It has no ground radials, and therefore has low wind resistance. Similar to all folded dipoles, the currents in each leg are in phase, whereas in a matching section they are out of phase. [6] So, negligible radiation comes out of matching stubs. In general, the end fed antennas have high impedance at the feed point; so matching is needed to down the SWR. So, in this case matching to input feed is given through J match. The lower U section provides the match in which the feed point can be moved to reduce the impedance. The feed point allows us to match impedance with the co axial cable. The lower portion of an antenna below the break point do not radiate since the currents are equal and opposite. Portions above the break point which are parallel have in phase currents so they radiates. The name slim Jim is derived from its slender construction which uses J type integrated matching stub that facilitates feeding at the aerial base and thus overcoming the problems between the feeder and aerial. The feed impedance is 50 ohms since the vertical angle of radiation is narrow about 8 degrees toward the horizon.

## IMPEDANCE MATCHING

Impedance Matching is the essential criteria to be considered in designing an antenna. Improper Impedance matching results in the formation of back scattered waves or standing waves, which obviously results in the reduction of gain, directivity and other directional parameters of an antenna. Impedance matching results in the maximum power transfer through the antenna, making an antenna to produce maximum radiation. This is especially predominant while dealing with low amplitude signals. In HAM Radio, to get a good reception, every bit of the signal needs to be used and the user can't afford any signal loss. There are broadly two approaches to impedance matching; the first is the distributed impedance matching approach which involves the modification of antenna geometry itself by identifying appropriate degrees of freedom within the structure. The second method is the lumped element approach to impedance matching. In this method, a matching circuit attempts to equalize the impedance mismatch between the source and the antenna load without the involvement of modifying the antenna geometry. [7] In most of the applications, matching circuits comprises of discrete inductors and capacitors, or the transmission lines which are used to improve the impedance matching characteristics of an antenna. Matching circuits can be optimized to enhance the performance of an antenna. The lumped element approach provides several advantages: tuning the antenna to operate at a desired frequency range is much easier than modifying the antenna geometry [8, 9]. Though the lumped element approach provides many advantages, they are time consuming and cost effective. The design and optimization of matching circuits may be cost effective.

To eradicate these problems, Slim Jim Antenna is introduced in this paper. It offers an impedance selectivity of 50Ω, 100Ω, 200Ω and 400Ω making it suitable to match to external components. It is best suitable in tropical regions, to resist wind effects. Today amateur's normally use coax transmission line to feed an antenna. The transmission line radiation resulting due to common mode currents caused an increase in higher angle radiation patterns. Mounting a J-pole or Slim Jim directly to a common mode current may lead to higher take-off angles. These higher take-off angles may reduce the gain. An end of the coax should be sealed to prevent moisture penetration into the antenna. For better performance of the J-pole antenna, a balun is to be added to the coax.

## RESULTS AND DISCUSSIONS

**Velocity factor**

Velocity factor can be defined as a factor at which the velocity of energy in a conductor gets scaled down compared to that of in free space. It gets slightly aberrant from usual, depending on conducting material. In this paper, the conducting material is considered to be aluminium. Velocity factor can be well described in perspective of attenuation offered by the medium, which results in scaling down the velocity of energy in a conductor.

Velocity factor plays a predominant role in design of an antenna. Antenna can be designed to achieve maximum gain by acquiring an effective length to resonate at the desired frequency of operation. The effective length can be derived by multiplying the electrical length of antenna with the scaling factor.

**Dipole antenna**

Designing a dipole Antenna, defines the frequency selectivity for the specific application. The design follows with the selectivity of the radius of the conductor element and gap between the two conducting elements. Although the radius and the length of a conducting element have a well-defined relation, for this case, the radius is assumed to be constant for all the lengths. The effect of diameters and lengths of conducting elements have a significant effect on measured gain as, the larger diameter elements yield maximum gain at shorter lengths, while the smaller diameter elements yielded maximum gain at correspondingly greater lengths. Figure-1 shows the simulation of dipole antenna in HFSS.
Specifications: for all cases, r = 0.5mm, the gap = 2mm.

**Table-1.** Comparison of various parameters for a dipole antenna.

| Parameters | Quantized length | V.F length | Normal length |
|---|---|---|---|
| Length (cm) | 23.5 | 23.8 | 25 |
| Frequency (MHz) | 302.02 | 297.9798 | 281.8182 |
| Return loss (dB) | -14.8374 | -14.8831 | -14.8722 |
| Field strength (dB) | 20.310 | 20.39 | 19.338 |
| Gain (dB) | 2.6606 | 2.7891 | 2.6446 |
| Directivity (dB) | 2.5403 | 2.6373 | 2.5372 |

Table-1 shows the comparative results which depict the variation of parameters Gain, Directivity, Field Strength, Return Loss, and Resonant Frequency with the respective lengths of conducting element. The dipole antenna was designed for an operating frequency of 300 MHz; the electrical length of dipole is of 25cm from the classical relation of a wavelength of wave to the length of conducting element. The results depicts that the antenna possesses maximum radiation at length of 23.8cm. As the length increases; Gain, Field Strength, Directivity, have been increased. It is observed that Return Loss has been decreased further, but which is not considered to be a major factor. Maximum gain is attained at the conductor length of 23.8cm which has a linear relation with the electrical length of dipole scaled by a factor, termed as the velocity factor. It is based on the fact that the propagation of energy in a conductor is slower than in free space. The value is dependent on the; length to the diameter of a conducting element. In this case it is found to be 0.952. The velocity factor can also be termed as a delay of the wave through the antenna. Figure-2 shows the Rectangular plot of dipole antenna, where it resonates exactly at 297.98 MHz making it suitable to the application. Gain of dipole antenna-2.7891 dB is shown in the Figure-3 proven to be the maximum gain of all the antennas designed at various lengths. The azimuthal pattern shown in Figure-4 resembles the dumbbell shape of the radiation of the dipole antenna.

**Design methodology**

Resonating length = Velocity Factor * Electrical length of antenna.

$$R_L = V_f * L; \quad (1)$$

Where

$R_L$ = the resonating length.
L = actual length of arm.
$V_f$ = the velocity factor.
Considering velocity factor for f =300 MHz, λ =1m, L = 25cm
$R_L = 0.952 * 25 = 23.8$ cm

The resonating length is found to be 23.8 cm, which is accurate with the value mentioned in the Table. Thus a λ/2 dipole resonates at 300 MHz, of length, L=23.8cm with maximum gain.

**Simulation results of the dipole antenna**

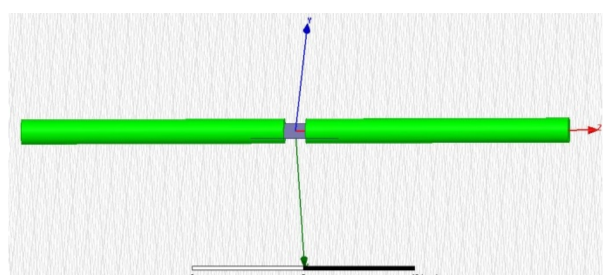

**Figure-1.** Dipole antenna.

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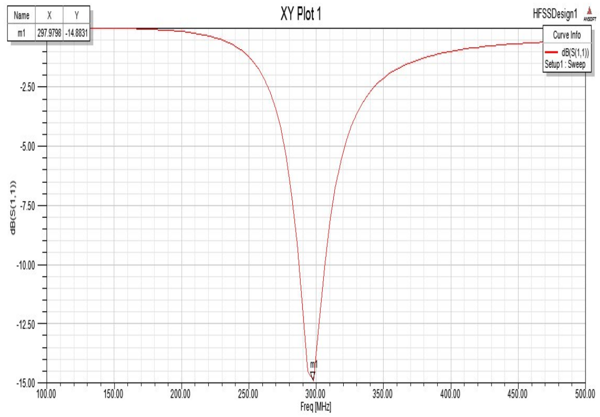


**Figure-2.** Return loss of dipole antenna.

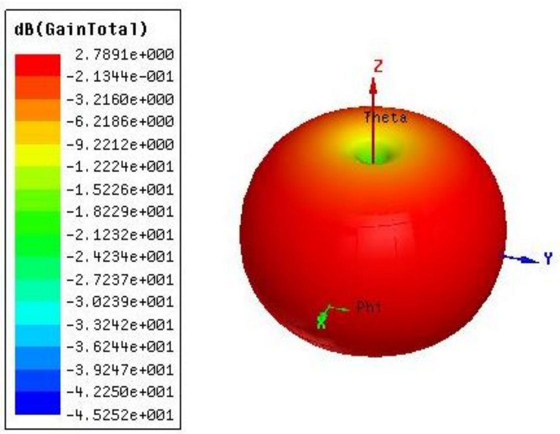


**Figure-3.** Gain of dipole antenna.

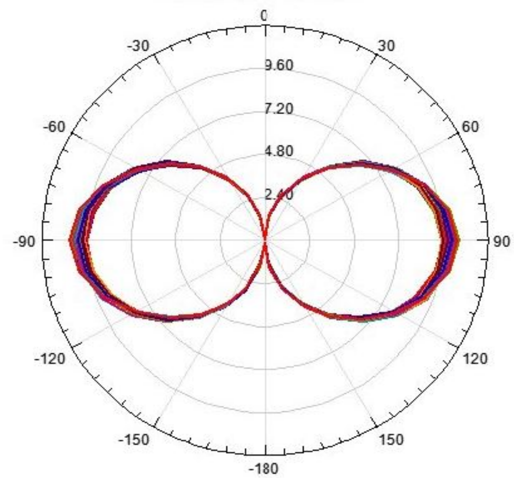


**Figure-4.** Azimuthal pattern of dipole antenna.

**Folded dipole**

Designing a folded dipole antenna differs from that of the usual dipole, as it consists of two additional parallel elements attached to the main radiator. The electrical length of the main radiator is of λ/2; as well the length of parallel arms is of λ/4 each. The design follows with the selectivity of the radius of the conductor elements and gap between the two short parallel elements. Figure-5 shows the simulation of folded dipole using HFSS.

- Specifications: for all cases, r = 0.5mm, the gap = 10mm, spacing = 21.75mm (not critical).

**Table-2.** Comparison of various parameters for a folded dipole antenna.

| Parameters | Quantized length | V.F length | Normal length |
|---|---|---|---|
| Length - Main radiator (mm) | 460 | 470 | 476 |
| Parallel element | 225 | 230 | 233 |
| Frequency (MHz) | 297.9798 | 289.8990 | 285.8586 |
| Return loss (dB) | -30.9837 | -29.1111 | -15.3040 |
| Max field strength (dB) | 20.264 | 20.223 | 19.798 |
| Gain(dB) | 2.4915 | 2.5144 | 2.4603 |
| Directivity(dB) | 2.4095 | 2.4314 | 2.3795 |

Table-2 shows the comparative results which depict the variation of parameters Gain, Directivity, Field Strength, Return Loss, and Resonant Frequency with the respective lengths of conducting element. The dipole antenna was designed for an operating frequency of 300 MHz; the electrical length of folded dipole is of 500mm from the relation of the wavelength of a wave to the, length of conducting element. It was found that; the designed antenna radiates maximum power at an electrical length of 470 mm, due to its compact structure. Though, as per the electrical length of the antenna calculated from the velocity factor equation is 476mm, the antenna tends to radiate maximum power at 470mm shown in Figure-7; gain to be 2.5144 dB, maximum of all the various lengths simulated. The overlap of two elements results in the decrease in gain. Though the antenna tends to resonate correctly at an electrical length of 460mm at 297.9798 MHz at a Return Loss of -30.9837 dB, but the electrical length of 470mm is suggestible for antenna design. As the deviation of 5% frequency bandwidth is acceptable, the electrical length of 470mm shown in Figure-6; is best suitable for the design of folded dipole antenna at

300MHz. Figure-8 clearly depicts the dumbbell shape of folded dipole antenna radiation.

**Comparison of dipole and folded dipole**

The bandwidth of a dipole antenna can be increased if the antenna elements are designed with a full electrical length (λ/2), considering the velocity factor for dipole and lesser (λ/D) ratio. [11] The increase in the electrical length shifts the resonant frequency towards the lower frequency side and the antenna can be realized in lesser length. [12] Folded dipole naturally provides more bandwidth because its elements behave as short circuited stubs at lower frequencies and compensate the capacitive reactance of the antenna. [13, 14] As both Dipole and Folded Dipole have same directional properties, Folded Dipole provides more bandwidth and preferable impedance matching over the Dipole antenna.

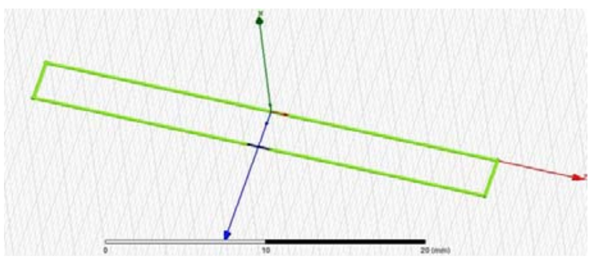

**Figure-5.** Folded dipole.

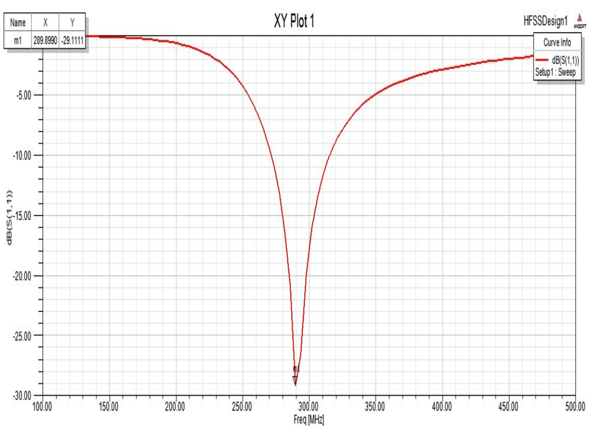


**Figure-6.** Return loss of folded dipole.

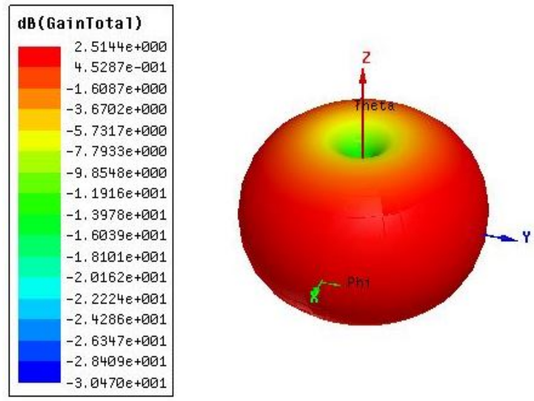


**Figure-7.** Gain of folded dipole.

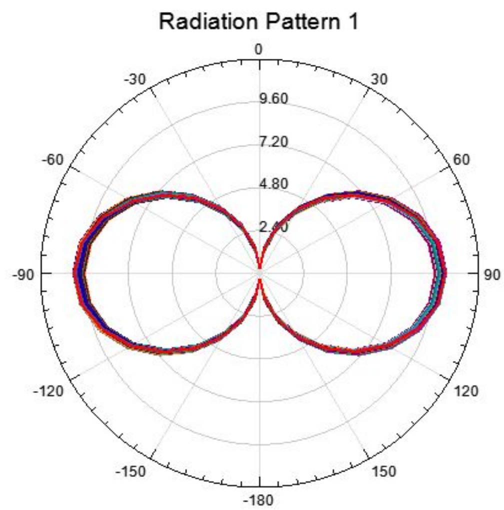


**Figure-8.** Azimuthal pattern of folded dipole.

**Table-3.** Comparison of bandwidth of a dipole and a folded dipole antenna.

| Parameter | Dipole | Folded dipole |
|---|---|---|
| Bandwidth(MHz) | 68.9516 MHz | 154.8387 MHz |

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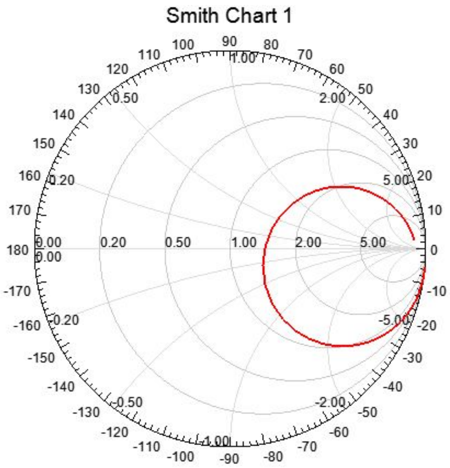


**Figure-9.** Dipole smith chart.

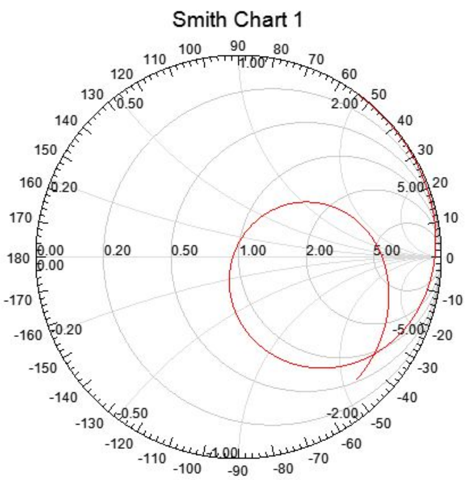


**Figure-10.** Folded dipole smith chart.

The above results depict that folded dipole provides more bandwidth and good impedance matching; from Figure-9 and Figure-10, over the dipole antenna. Both the antennas have similar directional properties in all aspects.

**J-Pole antenna**

Designing a J-Pole antenna differs from that of the usual dipole, as it consists of a parallel element attached to the main radiator. The electrical length of the main radiator is of 3λ/2; as well the length of parallel arm is of λ/4. Its geometrical configuration consists of a main radiator and a parallel element. The design follows with the selectivity of the radius of the conductor elements and gap between the main radiator and the parallel element, although it is not critical. Figure-11 shows the simulation of J-pole antenna in HFSS. The feeding method is an end-fed, which is aberrant from usual dipoles.

**Design methodology**

The lengths of J-pole's two elements can be determined as [10]:

$$L_{3/4} = 8856 * V/f \quad (2)$$

$$L_{1/4} = 2952 * V/f \quad (3)$$

Where

$L_{3/4}$ = Length of the ¾ wavelength radiator in inches.
$L_{1/4}$ = Length of the ¼ wavelength stub in inches.
V = Velocity Factor of Conducting material (aluminium).
f = the design frequency in MHz

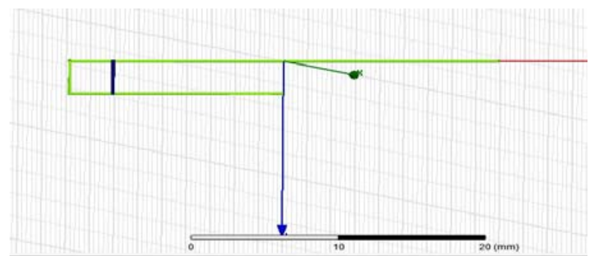


**Figure-11.** J-Pole antenna.

Specifications: for all cases, r = 0.5mm, the gap = 21.75mm (not critical).

**Table-4.** Comparison of various parameters for a J-pole antenna.

| Parameters | V.F length | Normal length |
|---|---|---|
| Main Radiator length (mm) | 716 | 730 |
| Parallel element | 238 | 240 |
| Frequency(MHz) | 316.6667 | 311.6162 |
| Return loss(dB) | -37.0566 | -30.7688 |
| Max field strength(dB) | 16.7673 | 18.669 |
| Gain(dB) | 2.9507 | 2.9341 |
| Directivity(dB) | 3.0423 | 3.0173 |
| Feed position(mm) | 24 | 24 |

The above results depict the variation of parameters Gain, Directivity, Field Strength, Return Loss, and Resonant Frequency with the respective lengths of a conducting element. The j-pole antenna was designed for an operating frequency of 300 MHz; the electrical length of j-pole is of 750mm from the relation of wavelength of wave to the length of conducting element. It was found that; designed antenna radiates maximum power at an electrical length of 730mm shown in Figure-13, a maximum gain of 2.9341 dB, greater than usual dipoles. The J-pole antenna resonates at 311.6162 MHz an acceptable value, as shown in Figure-12. It was named so because of its J-type integrated match.

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From the analysis, it was inferred that, the more the spacing between the parallel conductors of the stub was increased, the more skewing of the azimuth pattern resulted, shown in Figure-14. Although it was mentioned above, the spacing between the parallel conductors is not critical, but it has a significant effect on the skewing of the patterns as shown in Figure-14. It is suggested that, increasing the top portion of a J-pole to 5/8 wavelength would improve performance. But, analysis of that configuration resulted in a much higher imbalance in current amplitudes and phase relationships within the matching stub section. This resulted in greater pattern skewing and distortions [5]. Therefore, using a 5/8 wavelength top section of a J-pole would not be a preferable choice.

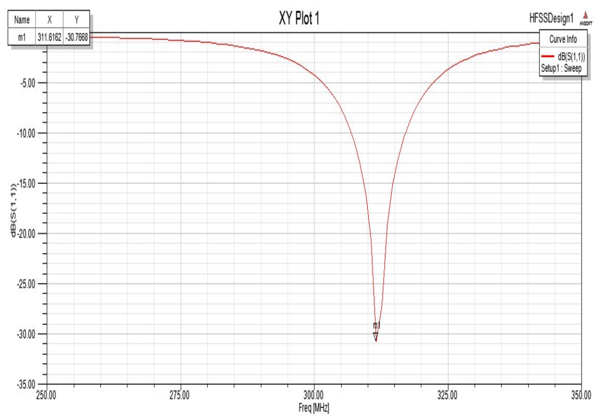


**Figure-12.** Return loss of J-Pole antenna.

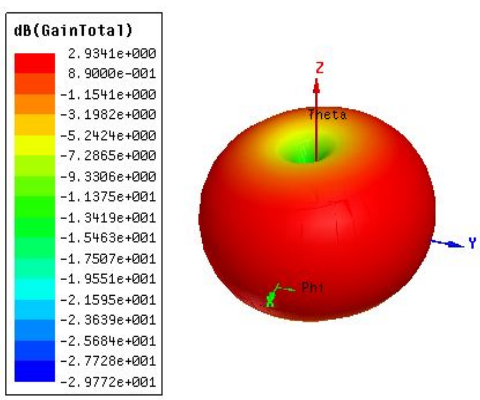


**Figure-13.** Gain of J-pole antenna.

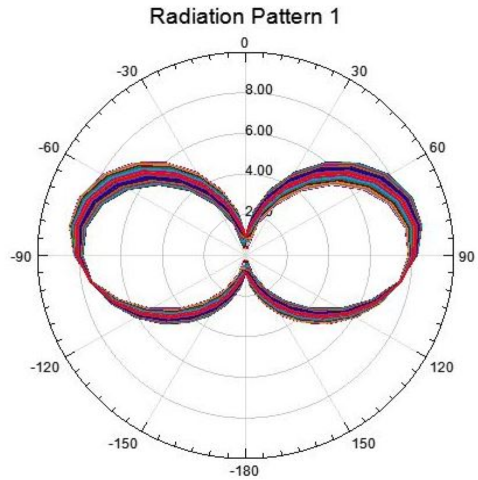


**Figure-14.** Azimuthal pattern of J-pole antenna.

**Slim jim antenna**

Designing a Slim Jim Antenna is similar to that of J-Pole antenna, by adding a parallel element to the Main radiator. The electrical length of the main radiator is of $3\lambda/2$; as well the length of parallel arm is of $\lambda/4$. Its geometrical configuration consists of a main radiator and a parallel element. The design follows with the selectivity of the radius of the conductor elements and gap between the main radiator and a parallel element, although it is not critical. Figure-17 shows the simulation of Slim Jim antenna in HFSS.

**Comparison of J-Pole and Slim Jim**

Specifications: for all cases; r = 0.5mm, gap = 21.75mm (not critical).

**Table-5.**

| Parameters | J-Pole | Slim Jim |
|---|---|---|
| Main radiator length (mm) | 730 | 730 |
| Parallel element 1 | 240 | 480 |
| Parallel element 2 | NA | 240 |
| Frequency(MHz) | 318.6869 | 318.6869 |
| Return Loss(dB) | -21.8277 | -11.7430 |
| Max field strength (dB) | 17.349 | 18.20 |
| Gain(dB) | 2.9040 | 3.0983 |
| Directivity(dB) | 2.9918 | 3.1355 |
| Feed position(from bottom) (mm) | 50mm | 50mm |
| Bandwidth (MHz) | 38.6437 | 43.00 |

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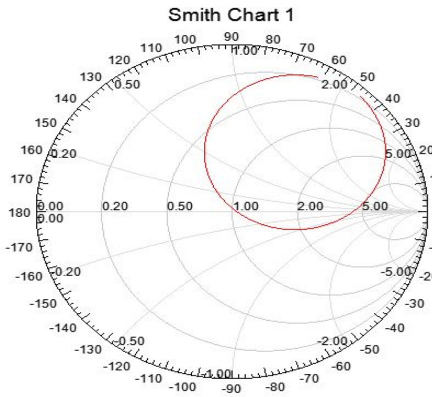


**Figure-15.** J-Pole smith chart.

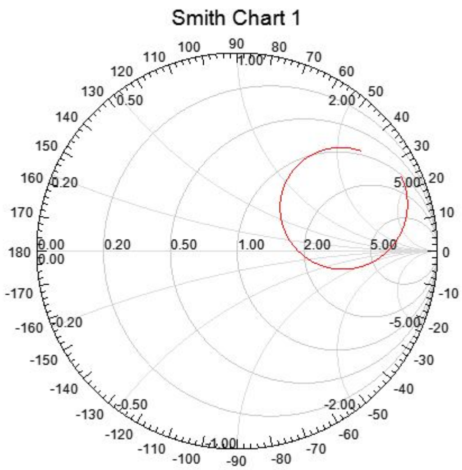


**Figure-16.** Slim jim smith chart.

The above results depict that Slim Jim antenna provides maximum gain, directivity, maximum field strength greater than the J-pole antenna. It is inferred that; the Slim Jim antenna possesses more gain over the J-pole antenna. For both the antennas, the feed position is at 50mm from the bottom. Figure-15 and Figure-16 depicts the impedance matching of J-pole and Slim Jim antennas, where Slim Jim provides good impedance matching for the applications. The change in the position of feed may result in the decrease of gain, when not given at the appropriate position (1:1 VSWR).

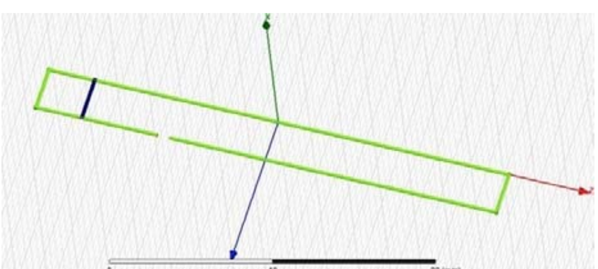

**Figure-17.** Slim jim antenna.

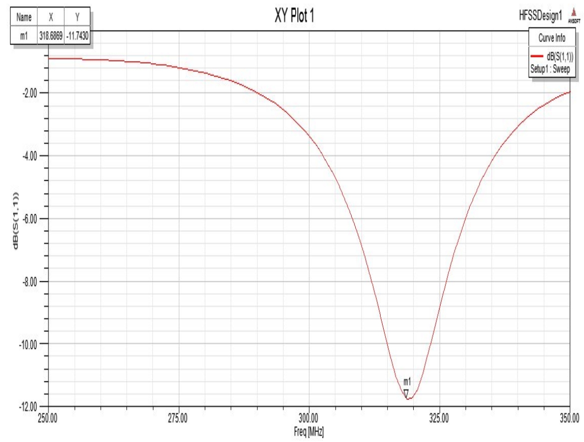


**Figure-18.** Return loss of slim jim antenna.

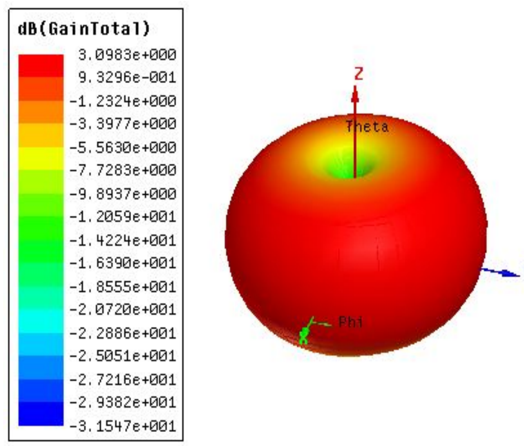


**Figure-19.** Gain of slim jim antenna.

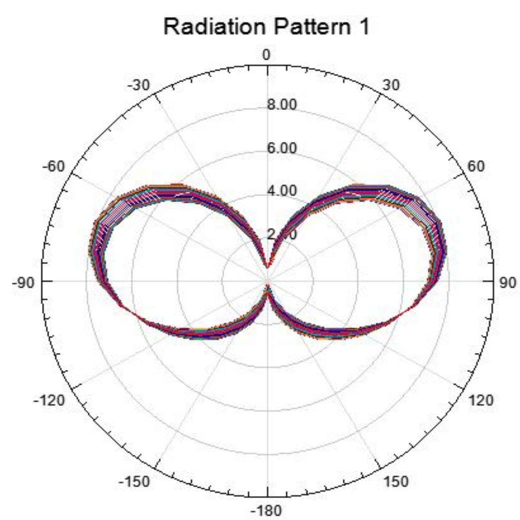


**Figure-20.** Azimuthal pattern of slim jim antenna.

The Slim Jim Antenna offers maximum gain of 3.0983 dB, as shown in Figure-19, which is maximum of all the wire antennas. This result make it more suitable in

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Communiaction world along with its good impedance matching property. The Azimuthal patterns of J-Pole and Slim Jim Antenna, shown in Figure-20 depicts that; the Slim Jim antenna provides substantially more gain than the J-Pole antenna, making it more suitable to the usage in HAM Radios.

## CONCLUSIONS

The four wire antennas have been simulated, for their applications in HAM Radio communication, which resulted in substantial proof, describing the better usage of Slim Jim Antenna in HAM Radio Applications. Slim Jim Antenna provides the best impedance selectivity to a specific application, resulting in maximum gain with the calculated values which are presented in this work.

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