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Key Points:
- 10 MHz bent wire antenna for airborne Geo RADAR application is proposed along with the analysis of the effect of dipole armbend angles
- Modified lumped element equations of the four element equivalent circuit for the 10 MHz antenna and testing of 1 GHz scale down antenna
- Bandwidth improvement of the 10 MHz antenna using a lumped element matching circuit have been simulated

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Correspondence to:
J. A. Baskaradas,
jamesbaskaradas@ece.sastra.edu

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Analysis of Bent Wire Antenna Resonant Frequency for Different Bent Angles

J. Suganya[1], Umberto Sciacca[2], James A. Baskaradas[1], and Achille Zirizzotti[2]

[1]School of EEE, SASTRA Deemed to be University, Thanjavur, India, [2]Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy

Abstract For the bedrock survey in the temperate glacier regions, low frequency antenna system of the airborne ground penetrating RADAR plays a very important role. A small size antenna, working at 10 MHz, would make its use easier in various radar applications. Reducing the resonant frequency of the wire dipole antenna structure, without increasing the physical size, can be attained by introducing bents in the existing structure. This paper introduces a new bent wire dipole antenna and presents the effects of bent angle of 80°, 70°, 60°, 50°, 45° and 40° of the wire antenna on the antenna parameters such as resonant frequency, S11, VSWR, gain and radiation pattern. A broadband four element equivalent circuit model of a straight dipole is used with some modifications in the R, L, C equations for the new bent wire dipole antenna by utilizing the bent angle. The frequency response of the equivalent circuit model, calculated resonant frequency values using the equations and the simulated results of the bent wire dipole antenna is compared and analyzed. As the antenna placement area inside the anechoic chamber is limited, the size of the 10MHz antenna has been scaled down by a factor of 0.01. This modifies the resonant frequency of the new structure to 1GHz. The scaled down antenna system are simulated, analyzed and tested in a GTEM cell. For bandwidth improvement of the 10 MHz antenna, a lumped element matching circuit has been designed and simulated.

1. Introduction

RES (Radio Echo Sounding) techniques are widely used in glaciology to study many properties of glaciers, such as the total thickness, possible layering and heterogeneity, the characteristics of the ice-bedrock interface, and possible subglacial lakes. Typical frequencies used for bedrock sounding in the polar zones are in the range 50-150 MHz, but for surveying the alpine glaciers lower frequencies should be used, this is due to their higher temperature that affects the attenuation of the radio waves. A sounding frequency of 10, or better 5 MHz, would experience less attenuation, but that increases the antenna dimensions, that make it impossible to be safely mounted under a helicopter. So, for such low-frequency applications, there is the need for the designers to reduce the overall size of the antenna.

Operating frequency and wavelength are inversely proportional to each other; as a rule, the length of the wire antenna depends on the antenna operating wavelength. The wavelength value of a 10 MHz radio wave is 30 m, so using a half wavelength dipole, its length would be 15 m. Difficulties are persisting in reducing the antenna size without affecting antenna frequency. Modification in the existing dipole antenna structure can lower the frequency of operation (Byers et al., 2012; Choi et al., 2016; Howlader & Sattar, 2016; Liu et al., 2013; Rao & Sarabandi, 2018; Smith & Jol, 1995). In literature, 350 MHz top shielded hemispherical butterfly dipole antenna, wire folded dipole antenna working at 60 MHz, 150 MHz BGR, programmable antenna between 20 MHz and 400 MHz, resistively loaded planar dipole antennas 55 MHz to 275 MHz with a central frequency around 150 MHz, 12 MHz wire antenna are some of the different antenna systems used for glacier studies (Blindow et al., 2012; Eisenburger et al., 2008; Lei et al., 2014; Rodríguez-Morales et al., 2014; Rutishauser et al., 2016; Sciacca et al., 2016; Singh et al., 2017; Urbini et al., 2015; Urbini et al., 2017). The great increase in the different practical applications leads to the designing of new shapes of wire antenna in low frequency range.

An effective, efficient way to lower the resonant frequency of a dipole antenna is the inclusion of bents in the existing structures (Olaode et al., 2012) that do not increase the overall mechanical size. In the meandered - line dipole antenna, the same physical size of the dipole antenna is maintained with an increase of its electrical length (Marrocco, 2003; Pisano & Butler, 2004; Seeley, 1956; Warnagiris & Minardo, 1998). Using the

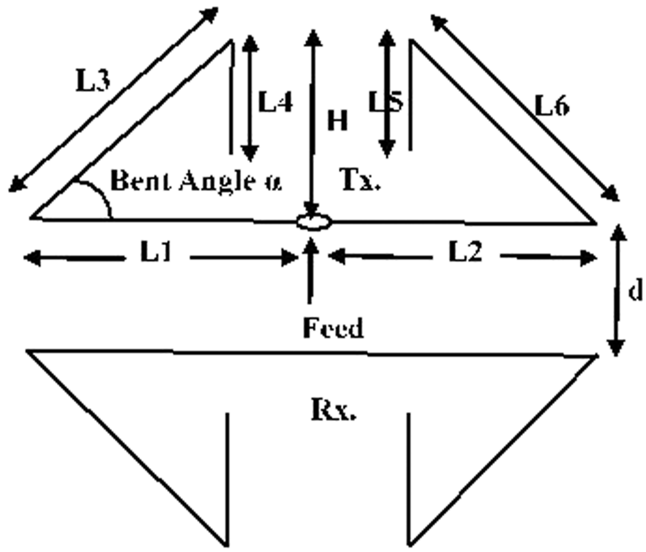

Figure 1. Structure of the bent wire dipole antenna with transmitting and receiving unit.

impedance of the same antenna in the air, five elements equivalent circuit has been framed for the uninsulated antenna in a lossy medium (Yi Liao et al., 2012). Feed point impedance of antennas can be represented using the lumped element equivalent circuits. Reasonably small size and a decrease in the resonant frequency are achieved with meander line structure (Hamid & Hamid, 1997; Rambabu et al., 1999; Tang et al., 1993; Zhonghao et al., 2009). The formula for current, equivalent admittances and loading effects for dipole antenna have been discussed by Shen et al. (1968); Harrington and Mautz (1967); Streable and Pearson (1981).

In 2008, Gaetano Marrocco have used different methods of impedance matching techniques for antennas like T-match, inductively coupled loop and Nested slot for obtaining better bandwidth and gain. Loop parasitic elements have also been used for improving the impedance bandwidth of the wire antennas (da Costa et al., 2009). Varying the length and the position of the parasitic wire in a hemispherical helical antenna can also increase the bandwidth (Latef & Khamas, 2010). Inclusion of parasitic wire arms near to the feed of the dipole antenna is improving the bandwidth (Hoch et al., 2015). With and without the parasitic elements, the analysis of the radiation characteristics and S11 of the planar dipole antenna have been discussed in the previous works (Ayop et al., 2007). With five discrete components, a lumped circuit network is proposed in 2010, by Vishwanath Iyer et al., for short dipole and monopole antenna in VHF and UHF bands for improving the bandwidth. For enhancing the bandwidth, small fractal elements have been added to the antenna structure by Fallahi and Atlasbaf (2015). Bandwidth of the monopole antenna have been optimized with the addition of loads at two points, along with the sections of different length and radii, is discussed in 2018, Omid Manoochehri et al. Impedance bandwidth improvement have also been attained in the monopole antenna with the inclusion of parasitic resonators on the ground plane is reported by Yadav et al. (2018).

In this paper, bent wire dipole antenna which can be used for temperate glacier bedrock survey is analyzed for different bent angles, for reducing the operating frequency using the HFSS software. The four element equivalent circuit (Olaode et al., 2012) is used and the frequency response simulation is done with the help of ADS for the same bent wire antenna. Testing the original sized 10 MHz large sized antenna in the anechoic chamber is impossible, because of the antenna placement size limitation in the anechoic chamber. So scaling down the antenna size is essential to characterize the antenna in the chamber. Here the antenna is scaled down in its size, with the frequency value of 1 GHz. While doing scaling down of the antenna, the shape of the antenna is not changed. The bent wire antenna is composed of different wire segments and those segment length values of the 10 MHz antenna structure in meters are scaled down to centimetres for the new small sized structure. The bandwidth of the 10 MHz bent wire dipole antenna is very low. This can be improved by doing modification in the existing structures or by using the lumped element matching circuit. Here, with two inductors and one capacitor, the lumped element matching circuit have been designed for improving the bandwidth of the antenna.

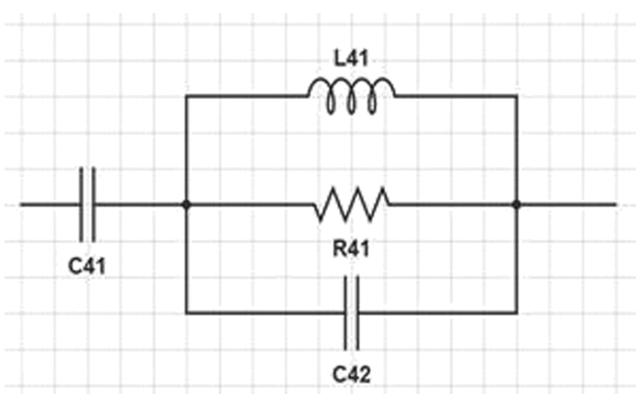

Figure 2. Four element equivalent circuit of a dipole (Olaode et al., 2012).

2. Structure of the Bent Antenna

The structure of the bent wire dipole antenna with transmitting and receiving unit for the GPR system is as shown in figure 1. The wire radius is considered to be as r = 0.0025 m. The feeding for the wire bent structure is at the center and the material of the wire is copper. The length of the straight wire is designated here as L1 and L2 (L1 =L2). The bent wire lengths are L3, L4, L5 and L6 (L3 =L6, L4 =L5). The distance from the bottom straight wire to the top bent is named as H. H is maintained as constant for all the bent angles. With respect to the bent angles, the corresponding slanting wire length L3 and L6 vary. L3 and L6 increases

Table 1
Simulations Results of the Bent Wire Antenna for Various Bent Angles

Bent Angle α	L3 = L6 (m)	Overall length of the wire (m)	Resonant Frequency (f_1) (MHz)	S11 (dB)	VSWR	Z parameter (Ω)
80°	2.29	14.5	11.5	-6.5	2.7	88.8 - j59.6
70°	2.41	14.7	11.2	-8.8	2.1	74.9 - j40.1
60°	2.61	15.1	10.8	-10.6	1.8	65.7 - j31.6
50°	2.95	15.8	10.3	-15.4	1.4	53.9 - j17.4
45°	3.20	16.3	10.0	-20.9	1.2	59.9 + j00.1
40°	3.52	16.9	9.5	-15.7	1.4	55.1 + j16.7

with a decrease in the bent angle value. The remaining length of the wire L1, L2, L4, L5 and H are kept as constant. The values are L1=L2=3.25 m, L4=L5=1.7 m and H=2.26 m. L_{wire} is the half of the overall length of the wire. The same transmitting unit wire structure dimension is used for the receiving wire unit also.

L1, L2, L3, L4, L5, L6: the length of the various segments in the bent wire antenna

d = 0.6 m: distance between the transmitting and receiving antenna unit

H: distance between the bottom straight wire and top bent of the wire

α: bent angle of the wire

Tx: transmitting antenna unit

Rx: receiving antenna unit

3. Equivalent Circuit Modeling

The four element equivalent circuit model of the straight line dipole (Olaode et al., 2012) shown in figure 2 is used for the bent wire dipole antenna also with the modifications in the R, L, C parameter equation (1)-(5) values (Olaode et al., 2012; Tang et al., 1993). For this bent wire dipole, the ratio between the half of the constant height in the bent and sine of the bent angle value has been subtracted from the lumped element parameter values of the straight line dipole. C_{41}, C_{42}, L_{41} and R_{41} are the series capacitance, parallel capacitance, inductance and resistance of the four element equivalent circuit of the bent antenna. The ADS equivalent circuit simulation results are then compared with the simulation output values of the bent wire dipole antenna using ANSYS HFSS.

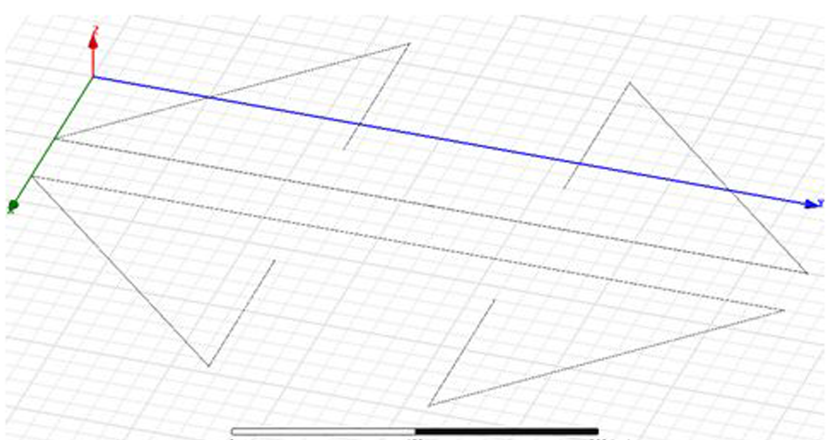

Figure 3. Structure of the 45° Bent Wire Dipole Antenna

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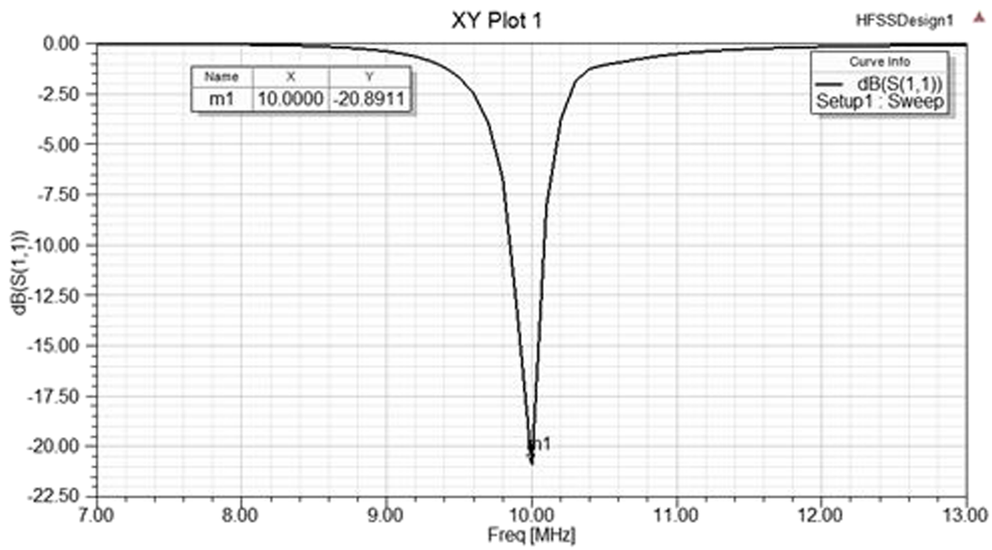

Figure 4. Reflection coefficient vs Frequency for 45° Bent Wire Dipole Antenna

$$C_{41}=\left\{\frac{12.0674L_{wire}}{\log\left(\frac{2L_{wire}}{r}\right)-0.7245}\right\}-\left\{\frac{(H/2)}{\sin\alpha}\right\}pF \tag{1}$$

$$C_{42}=\left\{2L_{wire}\left(\frac{0.89075}{\left[\log\left(\frac{2L_{wire}}{r}\right)\right]^{0.8006}-0.861}-0.02541\right)\right\}-\left\{\frac{(H/2)}{\sin\alpha}\right\}pF \tag{2}$$

$$L_{41}=\left\{0.2L_{wire}\left(\left[1.48131\log\left(\frac{2L_{wire}}{r}\right)\right]^{1.012}-0.6188\right)\right\}-\left\{\frac{(H/2)}{\sin\alpha}\right\}\mu H \tag{3}$$

$$R_{41}=\left\{0.41288\left[\log\left(\frac{2L_{wire}}{r}\right)\right]^{2}+7.40754\left(\frac{2L_{wire}}{r}\right)^{-0.02389}-7.27408\right\}-\left\{\frac{(H/2)}{\sin\alpha}\right\}K\Omega \tag{4}$$

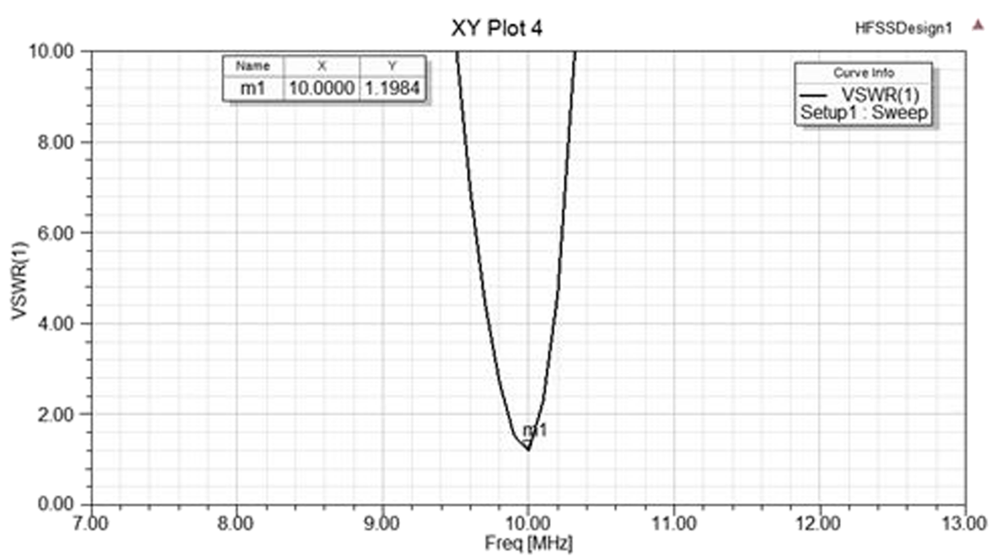

Figure 5. VSWR vs Frequency for 45° Bent Wire Dipole Antenna

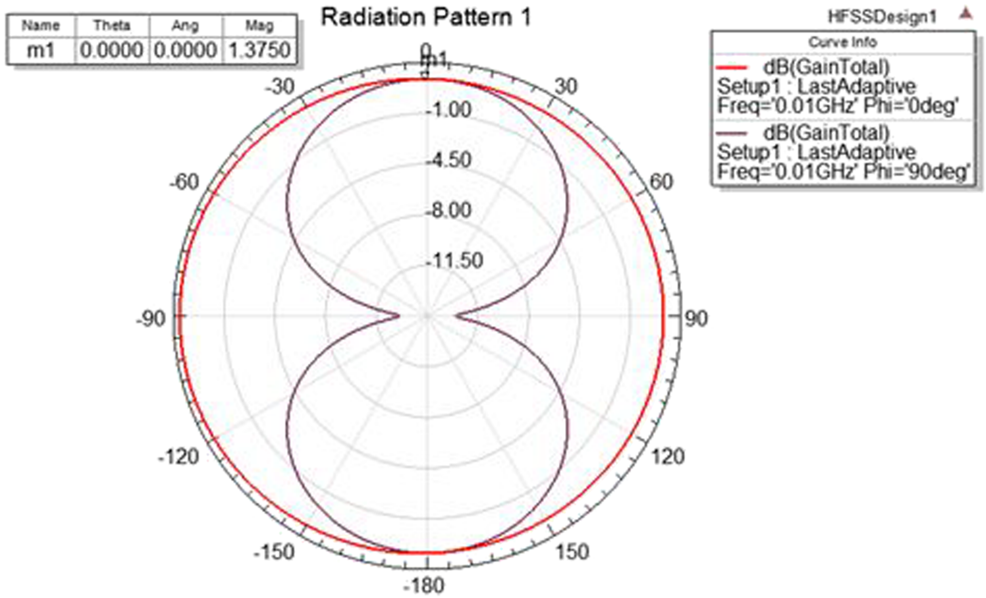

Figure 6. Radiation Pattern for 45° Bent Wire Dipole Antenna

$$f_{resonant} = \left(\frac{1}{2\pi\sqrt{L_{41}(C_{41}+C_{42})}}\right)Hz \tag{5}$$

$$L_{wire} = \left(\frac{L1+L2+L3+L4+L5+L6}{2}\right)m \tag{6}$$

4. Simulation Results and Discussions for the 10 MHz Bent Wire Antenna

The bent angle α is varied from 80° to 40°. Thesimulated resultant antenna parameters of resonant frequency, S11, VSWR and Z parametervalues have been tabulated in Table 1. Increasing the bent angle, the resonant frequency keeps on decreasing from 11.5 MHz to 10.5 MHz. The S11 value is found to be acceptable at the bent angle of 60°, 50°, 45°and 40°. It is less than -10 dB and the corresponding VSWR value is less than

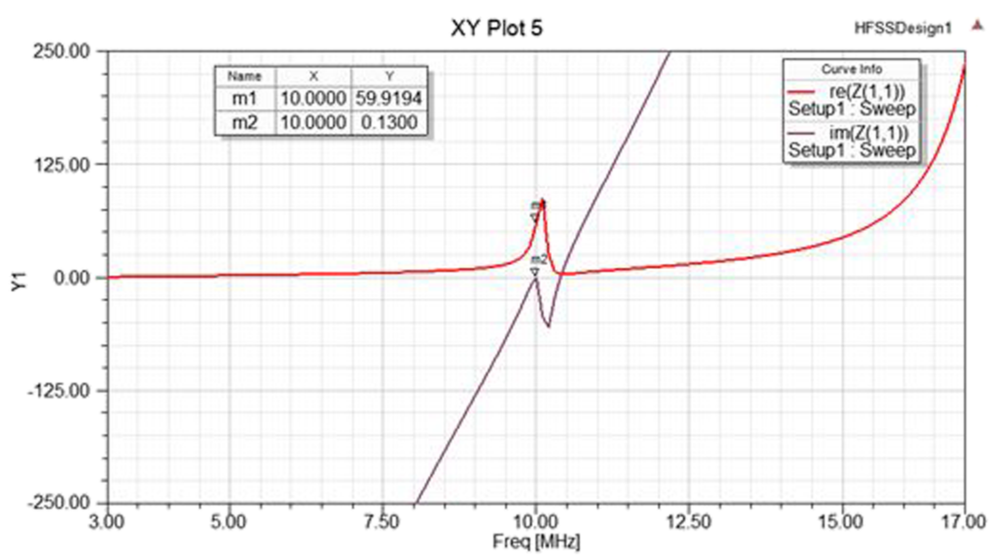

Figure 7. Z Parameter – Real and Imaginary parts vs Frequency for 45° Bent Wire Dipole Antenna

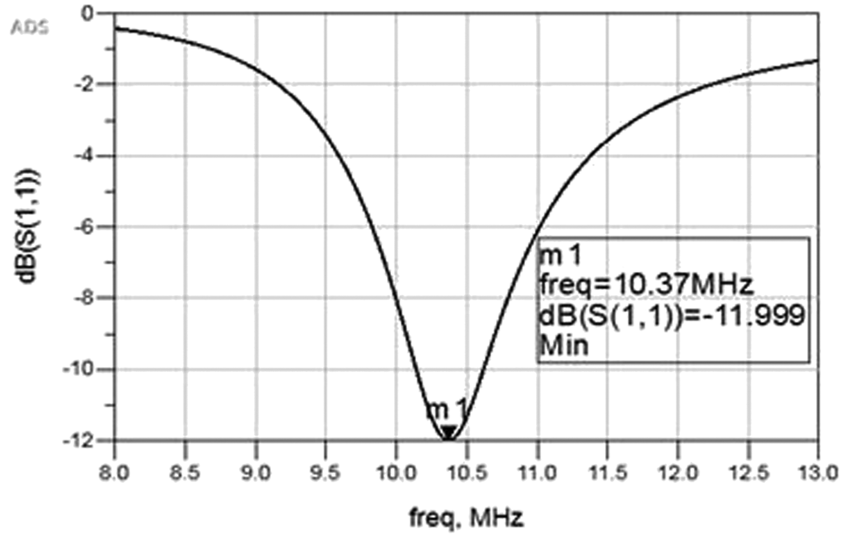

Figure 8. S11 Vs Frequency – Equivalent Circuit Simulation corresponding to45° Bent Wire Dipole Antenna

2. The overall wire length including the bent structure wire length is increasing which leads to the decrease in the resonant frequency value. The bent dipole antenna is also maintaining the figure of eight radiation pattern of the straight dipole with variation impacts are there in the reflection coefficient, gain and bandwidth. The imaginary part of the Z parameter is also increasing from its negative value with the decrease in the bent angle of the wire antenna. The calculated λ/2 dipole length values using the formula $\lambda/2 = c/(f \times 2)$ are 13 m, 13.4 m, 13.9 m, 14.6 m, 15 m and 15.8 m for the simulated bent wire antenna resonant frequency values 11.5 MHz, 11.2 MHz, 10.8 MHz, 10.3 MHz, 10 MHz and 9.5 MHz using HFSS respectively. Reducing the bent angle is making the wire segments coming closer to the bottom fed segments L1 and L2 on both sides. This leads to the reduction in the gain value of the bent wire antenna. With a bentangle of 45°, the overall length of the wire is 16.3 m. The structure, reflection coefficient vs frequency, VSWR vs frequency, radiation pattern and the Z parameter values are shown in the figures 3, 4, 5, 6 and 7. The resonant frequency, S11 and VSWR values are 10 MHz, -20.9 dB and 1.2 respectively. The peak gain of the bent wire antenna for the tilt angles of 80°, 70°, 60°, 50° are same and is found to be 1.76 dBi. For the tilt angles 45° and 40°, the peak gain of the antenna is 2.04 dBi and 0.79 dBi respectively.

The equivalent circuit simulation has been done with ADS software. S11 vs Frequency of the four element equivalent circuit for the 45° bent wire structure is as shown in figure 8. The C_{41}, C_{42}, L_{41}, R_{41}, comparison of resonant frequency values are tabulated in Table 2. The overall length of the wire antenna is increasing and is not constant. Hence the capacitance and the inductance values are also increasing with increasing overall length of the bent wire antenna. Without changing the overall length of the wire, bending the wire will reduce the capacitance value. Here the overall length of the wire changes because of the change in the bent angle value of the wire segment. Comparing the results obtained using a simulation of the bent wire

Table 2
Lumped Parameters values and comparison of Resonant Frequency Values with respect to the bent angles

Bent Angle α	C_{41} (pF)	C_{42} (pF)	L_{41} (μH)	R_{41} (KΩ)	S11 (Equivalent Circuit) (dB)	Simulation - Equivalent Circuit - Resonant Frequency (f_2) (MHz)	Calculated Frequency ($f_{resonant}$) (MHz)	Simulation - Bent Wire Antenna - Resonant Frequency (f_1) (MHz)
80°	27.65	4.84	6.20	3.448	-13.6	11.29	11.2	11.5
70°	27.89	4.86	6.26	3.409	-13.4	11.18	11.1	11.2
60°	28.49	4.89	6.39	3.340	-13.1	10.97	10.9	10.8
50°	29.51	4.98	6.62	3.224	-12.5	10.61	10.5	10.3
45°	30.10	5.00	6.79	3.131	-11.9	10.37	10.2	10.0
40°	31.04	5.08	6.98	3.022	-11.5	10.10	10.0	9.5

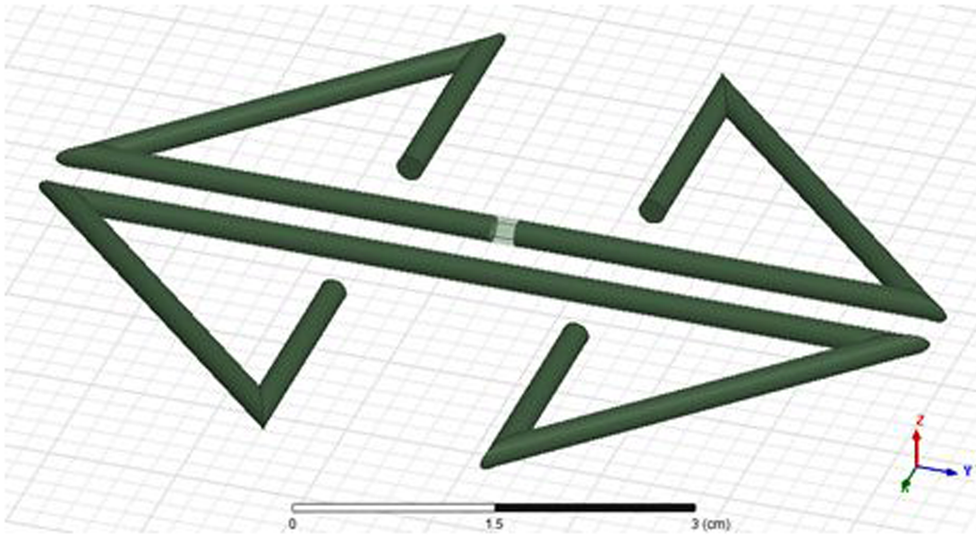

Figure 9. Structure of the scaled down bent wire dipole antenna

antenna, the four element equivalent circuit and the modified lumped parameters equations, there is less than 0.2 MHz variation is existing in the resonant frequency value. The radiation resistance and ohmic losses in the antenna are represented by R_{41} and it will not influence the change in the resonant frequency of the antenna. The magnitude of the S11 value is determined by the resistance value of the antenna.

The resonant frequency of 10 MHz is obtained for the bent wire antenna at the bent angle of 45°. While comparing this new 10MHz bent wire antenna structure with the already existing broadband butterfly terminated dipole antenna working in the range of 3MHz to 30MHz with omnidirectional radiation pattern needs the total wire length of 82.3 m which is found to be larger than the new bent wire antenna. For operating at 10 MHz, the new bent wire antenna makes use of 16.3 m length wire for transmitting antenna unit and another 16.3 m wire length for receiving antenna section of the ground penetrating RADAR system. The overall length of the wire is greatly reduced for the bent wire antenna structure for operating at 10 MHz. For the bent wire antenna, the radiation pattern is in the shape of a figure of eight which is similar to that of the normal dipole. The application of this designed 10 MHz antenna is to use it in the helicopter borne temperate glacier studies. For that application, we need the radiation of the antenna towards the glacier ice while the helicopter is flying for surveying. The 10 MHz bent wire antenna system is placed in the XY plane. Towards the antenna axis, Y axis, the radiation is very low. The electric field value towards the direction of theta = 90° & phi = 90° is 1.7 V which is very low when compared to the other direction electric field values. The cross polarization effect is very minimum and it is less than − 40 dB. Antenna performance plays the significant

Table 3
Scaled down Antenna parameters values for different scaling factor

Sl. no	Scaling Factor	Resonant Frequency (MHz)	S11 (dB)	VSWR	Z parameter (Ω)	Bandwidth (MHz)	Radiation Efficiency (%)
1	1/1	10.0	-20.9	1.20	59.9 + j0.1	0.24	96.2
2	1/10	101.1	-34.1	1.04	50.5 – j1.9	2.5	97.9
3	1/20	204.2	-36.5	1.04	50.9 - j1.2	5.5	98.6
4	1/30	306.9	-42.1	1.02	50.6 - j0.4	9.0	98.9
5	1/40	412.9	-40.4	1.02	50.3 – j0.9	12.9	99.1
6	1/50	517.5	-36.9	1.02	50.7 – j1.3	17.1	99.2
7	1/60	627.3	-31.7	1.05	51.2 – j2.3	21.8	99.2
8	1/70	729.0	-32.9	1.04	51.1 – j2.0	26.3	99.3
9	1/80	834.6	-37.7	1.02	50.6 – j1.2	30.9	99.3
10	1/90	933.0	-41.1	1.02	49.7 – j0.8	35.1	99.4
11	1/100	1047	-32.7	1.04	51.2 – j1.98	41.0	99.5

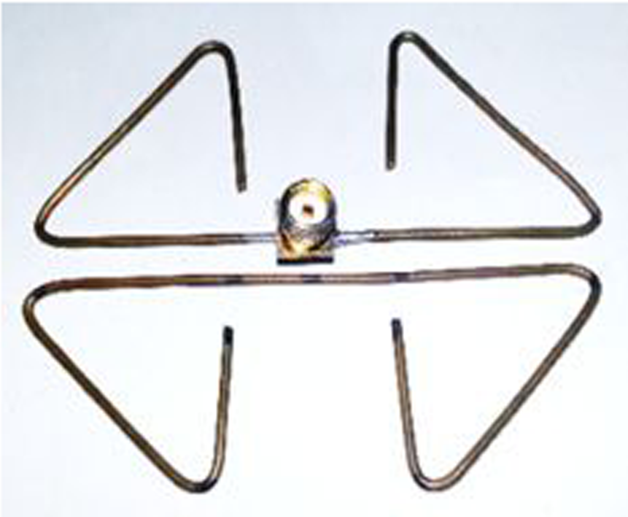

Figure 10. Designed 1 GHz scaled down bent wire dipole antenna

role in the airborne ground penetrating radar system. To study the temperate glaciers covered with rock debris, ground penetrating radar operating in low frequencies (lower HF band) are more suitable. This 10 MHZ bent wire antenna system is designed specifically for airborne survey of temperate glaciers where it will be hanged at least 10 m below the helicopter to reduce the interference from the helicopter. So, this application demands light weight and high structural stability with a reasonable gain of the antenna. The proposed 10 MHz bent wire antenna system in this paper is having the peak gain of 2.04 dBi. This gain value is acceptable for the airborne GPR antenna system to do the temperate glacier bedrock survey. From the literature survey papers of the airborne ground penetrating RADAR system for glacier studies, the gain of the 12 MHz wire antenna (Sciacca et al., 2016), 40 MHz wire antenna (Stefano Urbini et al., 2017), 60 MHz wired folded dipoles (1995) & 150 MHz rigid folded dipole (2009) is around 1.6 dBi and for the 150 MHz dipole array antennas (2011) (Urbini et al., 2015), the gain is 15.5 dBi. In (Rodríguez-Morales et al., 2014) the Twin Otter, NASA P-3, NASA DC-8 airborne platforms for polar research, the 195 MHz antenna system gain values of the (1) Folded dipole arrays: 6-element Tx/Rx, 6-element Rx; (2) Planar dipole arrays: 7-elements Tx/Rx, two 4-element Rx; (3) Planar dipole array:5-element (Tx/Rx) is (1) Tx array: 15.5 dBi, Single Rx: 7.8 dBi; (2) Tx array: 15.5 dBi, Single Rx: 7 dBi; (3) Tx array: ~6.3 dBi, Single Rx: ~2 dBi respectively.

5. Size scaled down 1 GHz antenna structure - Simulation results and Discussions

The 10 MHz lengthy antenna can be scaled down to a small sized antenna with an operating frequency of 1 GHz. The new size scaled down antenna is having the same shape as that of the 10 MHz antenna structure. All the length parameters are reduced by the scaling factor of 0.01. The frequency and wavelength of an antenna are inversely proportional to each other. The old frequency 10 MHz value is designated as f_{old} and the new scaled down frequency 1 GHz is assigned as f_{new}. The scaling factor can be defined in terms of frequency of the antenna structure or with the wavelength of the antenna under consideration. The wavelength corresponding to 10 MHz is λ_{old} and the new wavelength for the 1 GHz is λ_{new}. The scaling factor for the scaled down antenna is defined as the ratio of the new wavelength λ_{new} to the old wavelength λ_{old}. The scaled down antenna is having its size value in centimetre. The structure for the scaled down bent wire

Figure 11. Scaled down bent wire dipole antenna characterisation in GTEM cell setup

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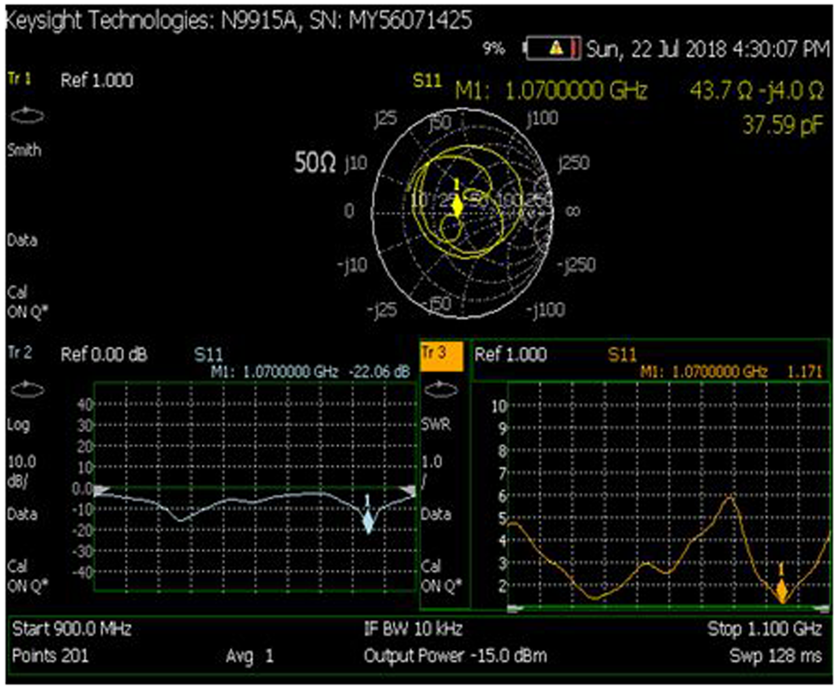

Figure 12. Smith chart, S11 and VSWR vs. frequency of the scaled down bent wire dipole antenna kept at GTEM cell

dipole antenna are shown in the figure 9. The bent angle value is 45° in both cases, without scaling and with scaling. The diameter of the wire in the scaled antenna is considered as 0.2 cm.

If the original sized 10 MHz antenna has been scaled down in its size by a factor of 1/10, 1/20, 1/30, 1/40, 1/50, 1/60, 1/70, 1/80, 1/90 and 1/100 means, the corresponding simulated results will be having the following values of resonant frequency, S11, VSWR, Z parameter, bandwidth and radiation efficiency. The values are tabulated in the table 3. The bandwidth and the resonant frequency of those sizes scaled down antenna goes on increasing with the decrease in the overall size of the antenna. In all cases, the VSWR value is less than two. The overall length of the wire is reduced in the scaled down version of the 1 GHz antenna leads to the decrease in the inductance value. The capacitive reactance dominates in the scaled down bent wire dipole antenna.

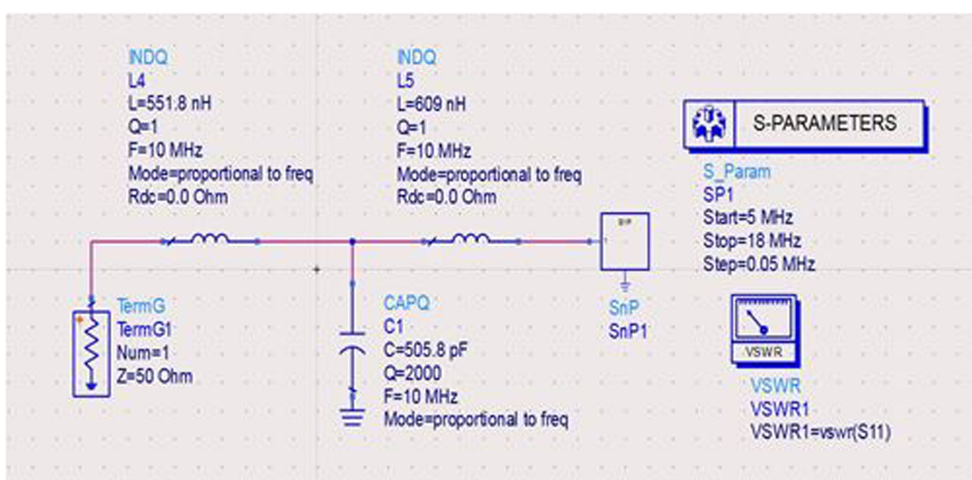

Figure 13. Lumped element matching circuit with the load as the 10 MHz bent wire dipole antenna

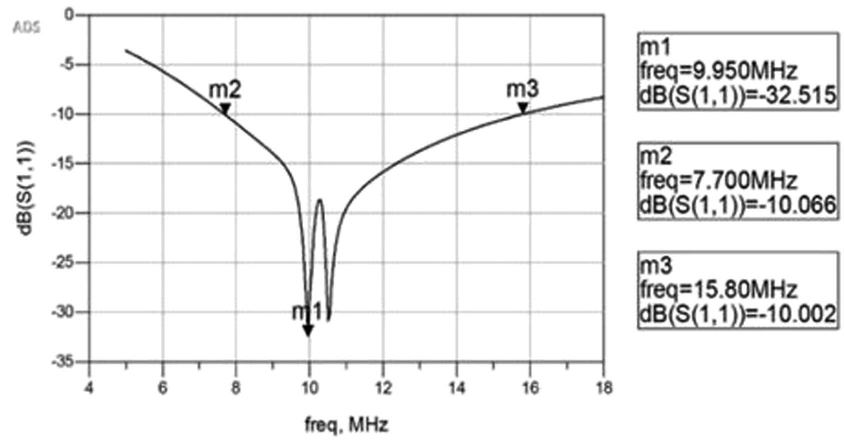

Figure 14. Reflection coefficient vs. frequency for the 10 MHz antenna with lumped element matching circuit

The impedance bandwidth with respect to the center frequency of the resonant antenna is the ratio of the difference between the highest cut off frequency and the lowest cut off frequency to the center frequency of the considered antenna. Better bandwidth is obtained in the high frequency antenna compared to the low frequency range antennas. In the case of HF wire antenna dipole, the bandwidth obtained is very narrower which limits the practical applications. Here, in the original sized antenna the center resonant frequency is 10 MHz and for the scaled down antenna, the resonant frequency is 1.04 GHz. For all the cases of the scale down bent wire antennas, the peak gain of the antenna structure is unchanged and is 2.04 dBi. The impedance bandwidth of the original sized bent wire dipole antenna is 2.4% and for the scale down antenna is 4%. This is due to the variation in the wire thickness of the antenna in without scaling and with scaling cases. For simulation, the 10 MHz copper antenna is considered to be lossless. So, the conduction efficiency and the dielectric efficiency is also approximated to 1. Hence the radiation efficiency of the antenna is high.

6. Antenna in GTEM cell - Test Results and Discussions

A Gigahertz Transverse Electro Magnetic (GTEM) cell is used here to test and find out the S11, VSWR values of the scaled down 1 GHz antenna. The designed and modelled 1 GHz antenna is shown in figure 10. The scaled down 1 GHz antenna is placed inside the GTEM cell in the antenna placement area. Figure 11 depicts the setup of the scaled down 1 GHz bent wire dipole antenna characterisation in GTEM cell. The scaled down 1 GHz bent wire dipole antenna S11, VSWR values are recorded with the vector network analyzer. Figure 12 gives the details about the smith chart, S11 and VSWR vs. frequency of the 1 GHz scaled down bent wire dipole antenna kept at GTEM cell. The obtained operating frequency of the scaled down antenna is 1.07 GHz with the S11 value as -22.06 dB and the VSWR value is 1.17 at the resonant frequency.

7. Lumped element matching circuit - Simulated Results and Discussion

With the use of lumped element matching circuit the bandwidth of the 10 MHz antenna can be increased. It is designed for increasing the impedance bandwidth of the HF antenna. The matching circuit for the bent wire antenna is designed with the help of the ADS software and is shown in the figure 13. The transmitter impedance is considered to be as 50 ohm. The load for the matching circuit is the 10 MHz bent wire dipole antenna. The matching network is the T network with two inductors and one capacitor. The reflection coefficient vs. frequency and VSWR vs. frequency for the bent wire dipole antenna with lumped element matching circuit is given in the figure 14 and 15 respectively. The bandwidth of the system after including the matching circuit is 8.1 MHz. The two inductors values are 551.8 nH and 609 nH. The capacitor value is 505.8 pF.

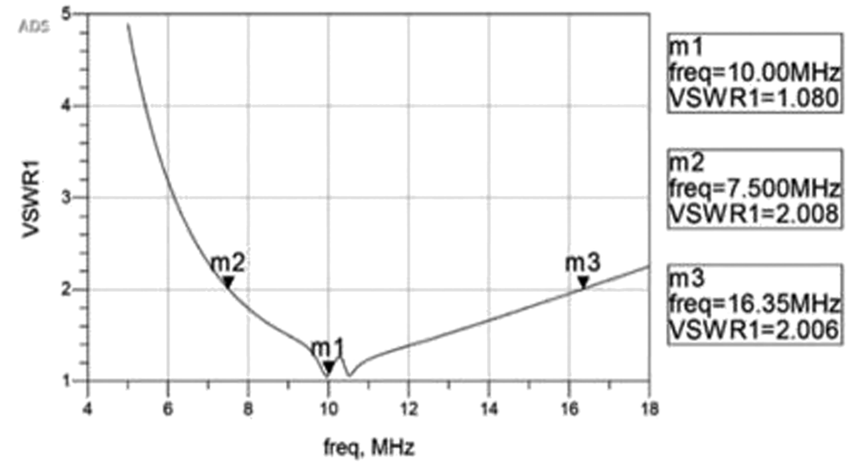

Figure 15. VSWR vs. frequency for the 10 MHz antenna with lumped element matching circuit

8. Conclusion

The bent wire antenna for different bent angles has been analyzed with the structure simulation and four-element equivalent circuit simulation with the modified equations have also been done. For 45° bent angle of the wire from the main arm, towards the feed, on both sides, yields the resonant frequency of 10 MHz with the S11 and VSWR value as -20.9 dB and 1.2 respectively, in simulation. The basic performance of 10MHz bent wire dipole have been studied using a scaled down model, as the original size requires a big chamber. A scaled down antenna with a scaling factor of 0.01, whose resonance frequency is at 1 GHz, has been designed, simulated and tested in the GTEM cell. The bandwidth of the 10 MHz antenna is enhanced using a lumped element matching circuit model. After the inclusion of the lumped element matching circuit, the bandwidth have increased to the value of 8.1 MHz. Such an increased bandwidth for a 10 MHz antenna is very ideal for temperate glacier survey and mapping the bedrock effectively and efficiently.

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