

Declaration

I hereby declare that the work presented in this thesis titled *Studies on Beam Steerable Dipole Antenna* submitted to Indian Institute of Technology Jodhpur in partial fulfillment of the requirements for the award of the degree of Doctor of Philosophy, is a bonafide record of the research work carried out under the supervision of Dr Sandeep Kumar Yadav and Dr. Soumava Mukherjee. The contents of this thesis in full or in parts, have not been submitted to, and will not be submitted by me to any other Institute or University in India or abroad for the award of any degree or diploma.

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Certificate

This is to certify that the thesis titled *Studies on Beam Steerable Dipole Antenna*, submitted by *Rajesh Shukla (P15EE201)* to Indian Institute of Technology Jodhpur for the award of the degree of *Doctor of Philosophy*, is a bonafide record of the research work done by him under my supervision. To the best of my knowledge, the contents of this report, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.



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Abstract

HF communication using sky wave propagation through ionosphere plays a vital role for short and long distance communication specially in the fields of Defence, maritime role, police and remote sensing. For reliable and efficient HF communication various adaptive data transmission schemes have been formulated. This require selection of best channel frequency through ALE (*Automatic Link Establishment*) and choosing of best modulation to provide highest possible bit rate. Optimum deployment of HF antenna after predicting accurate frequency spots for real-time communication at various ranges is essential due to HF link limitation of impulsive atmospheric noise, multipath propagation, limited band width and interference. However, changes in HF dipole antenna height with respect to range and time was still needed to be addressed. Height of HF antenna above ground plays a vital role for establishing successful HF contact. Effective HF communication is dependent on accurate radiation / take off angle achieved by the transmitting antenna. The height of HF antenna to be adjusted either while variation of frequency during different time slots or variation of distance between transmitting and receiving stations. Desired radiation / take of angle can be achieved by adjusting the antenna height above ground while variation of operating frequency during different time slots i.e. Day, Night, Transition1 and Transition2. The variation in take of angle is maintained by modifying the radiation pattern of the antenna by changing the height or other critical dimensions of the antenna system. Several techniques are being adapted for variation of antenna height e.g. mechanical/physical variation of the antenna height, deployment of various height of multiple HF Antenna at different time slots etc. These methods require additional infrastructure and assets resulting in enhancement of time, cost and complexity. To address this limitation, a beam steerable inverted V HF dipole antenna has been proposed in thesis as an effective solution for beam steering of HF antenna without changing antenna height. To provide adequate beam steering a reactive circuit with parallel variable capacitor and inductor has been positioned at one end of dipole. Tilting of antenna pattern has been controlled by variable capacitor keeping fixed value of parallel inductor. Continuous beam steering of 60 degree (± 30 degree) has been achieved by changing the capacitive value from 26.6 PF to 27.7 PF at 9.3 MHz frequency by adjusting the Capacitor biasing voltage from 1.24 V to 1.10 V. The present work provides novel technique for electronically adjusting radiation beam take off angle to maximize HF coverage throughout the elevation plane with no variation in physical height of HF antenna. The steering of ± 30 degree beam takes off angle has been achieved electronically without varying physical height of HF antenna.

In thesis, an efficient solution for selection of HF frequencies along with optimum deployment of antenna system for various ranges has been proposed. The optimum HF prediction presented in previous works provides contours of the probability of successful HF transmission as a function of frequency and time of day which presents means for HF spectrum utilization, giving a probability number to any assigned frequency at a given time of day. However external environment strongly influences HF communication frequencies due to

variation of ionosphere layers along with variation of time as well as environmental changes. Therefore, it is not always feasible to change the height of antenna with variation in time. Present work considers different sets of frequencies at four different time slots and subsequently selection of frequencies carried out based on maximum usable frequency (MUF), frequency of optimum traffic (FOT) predicted from HF prediction software. The proposed work provides efficient solution for finding out optimum frequencies during various time slots and HF antenna height estimated accordingly for different path lengths. Based on linear approximation between effective antenna height and frequency of operation, a new set of equations has been proposed in thesis which can directly be used to calculate effective height of the HF antenna for all distances between transmitting and receiving stations during various ranges of HF communication.

Various past research work with respect to HF frequency tuning focuses on either electrically small antennas or narrow band, dual band frequency tuning. However long-range wide band HF antenna frequency tuning needed to be addressed. In the thesis, a frequency tunable HF antenna with feeding network modification technique has been proposed to vary the long range inverted 'V' HF dipole antenna resonant frequency while maintaining the fixed dipole length. With the implementation of feeding network modification technique most of day/night frequencies can be covered in a particular time slot resulting in highly effective and accurate HF contact with least variation of antenna height. Resonance frequency shifting (3 MHz) from 7.5 MHz to 10.5 MHz has been demonstrated with gain of 5.4 dB by varying length of feeding network for 10 MHz inverted 'V' HF dipole antenna. Extensive trials were conducted to validate the performance results and same found as desired.

Open Space radiation pattern measurement of wide band HF dipole antenna is a cumbersome process due to its long dipole length in meters and possible usage of Unmanned Aerial Vehicle (UAV) or airborne object based systems for antenna measurements. This is a complex and expensive setup. To verify the concept of proposed beam steerable HF antenna, a low cost, small form factor model at ISM band has also been proposed as beam steerable printed dipole antenna. The radiation pattern of beam steerable printed dipole antenna has been measured and same concept can be extended to beam steerable HF antenna also. Hence, there was a need to study on novel approaches to design beam steerable antenna for different operating frequency with reduced complexity.

Similar to design topology of inverted V HF antenna, a small form factor model as beam steerable inverted V printed dipole antenna has been proposed in thesis using single dipole integrated with a varactor diode and parallel inductor in one arm of antenna. Most of previously fabricated electrically tuned antennas requires more than one dipole and multiple tuning elements mounted on common platform for scanning between two angles / switching at different elevation angles. Proposed Planar Inverted V Dipole Antenna is capable of continuous beam steering (± 30 degree) electronically using Single Printed Dipole and single varactor diode. Hence, resistive and parasitic losses of proposed antenna is considerably low along with low design cost and the least space requirements. Steering angle for antenna radiation pattern has been controlled by gradually varying the capacitance value keeping fixed value of parallel inductance. Required biasing circuit for varactor diode is intentionally placed on substrate at back side of dipole arm to avoid losses. Antenna gain for proposed design observed to be 4.1 dB with less than 1 dB scan loss and cross-pol well below -25 dB. The antenna is capable of steering

beam ± 30 degree in elevation plane at 2.35 GHz by tuning varactor diode bias voltage to achieve various capacitance values.

Beam steerable printed antennas are useful for various applications e.g. mobile communication, Internet of Things (IoT) application, vehicular communication, sensor etc. For such applications large phased array or reflect array antennas are less suitable in comparison to compact planar tunable antennas. Several designs topologies have been proposed to achieve beam steering using phase shifter, varactor diode and PIN diode-based feeding network. However, such circuits have limitation of high parasitic loss, high insertion loss and space complexity. A digitally controlled beam steerable printed dipole antenna operating in Industrial, Scientific, and Medical (ISM) band has been proposed at 2.45 GHz operating frequency with 120 MHz bandwidth and 4.57 dB max gain using PIN diodes switching mechanism. The fabricated antenna provides effective solution of beam steering by establishing adequate coverage in elevation plane using a single dipole element. The beam steering of antenna has been digitally controlled by varying the effective length of one dipole arm by switching the PIN diodes integrated on it. For effective digitally controlled beam steering, the DC biasing voltage applied for switching PIN diodes is regulated by Pulse Width Modulation (PWM) signal generated from microcontroller through RC filter. Biasing elements for antenna is intentionally placed on back side of substrate through via to minimize the effect on radiation pattern. The proposed antenna is capable of steering beam up to 45 degrees in elevation plane. The present method eases the fabrication and measurement setup. However, the concept can be rescaled to other frequency of interest including HF communication for conventional HF horizontal dipole antenna.

The proposed work in thesis will definitely enhance the efficiency of short and long range communication, especially in the field of HF communication to provide a novel platform for optimum deployment of HF antenna ensuring the high operational efficiency of defense and other strategic fields of national security.

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Ph.D. Student

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List of Symbols

<i>Symbol</i>	<i>Description</i>
V_f	Forward Voltage
V_{br}	Breakdown Voltage
C	Capacitance
R_s	Forward Resistance
L	Inductance
$S79$	Industry Std Package
$D1, D2, D3$	PIN Diodes
θ	Theta (Angle)
H	Effective height
f	Frequency

List of Abbreviations

Abbreviation Full form

WDA	Wide Band Dipole Antenna
IOT	Internet of Things
ISM	Industrial, Scientific and Medical
EUV	Extreme Ultraviolet
MOF	Maximum Operating Frequency
FOT	Optimum Traffic Frequency
VOACAP	Voice of America Coverage Analysis Program
SNR	Signal to Noise Ratio
HF	High Frequency
AI	Artificial Intelligence