5

A Practical Approach on Frequency Prediction and Optimum HF Antenna Deployment

5.1. INTRODUCTION

HF frequencies experiences large variation in day, night and transition periods. Variation of frequency leads to variation in height of HF antenna to establish optimum contact. Therefore, it is not practically feasible to change the height of antenna with respect to change in time. Present work considers different sets of frequencies at four different time slots (Day, Night, Transition day. Transition Night) and subsequently selection of frequencies based on MUF, FOT. Based on the predicted frequency, optimum height of HF antenna for various receiver distances has also been proposed in this work. This new approach provides efficient solution by providing optimum spot during a particular time slot for HF communication at specified distances.

Many previous research work considered antenna height requirements which may not be practically feasible while establishing HF contacts specially within geographic locations of a country. As shown in Figure. 5.1, ideal antenna height requirements vary from 30 meter to 70 meter while considering frequencies between 14 to 6 MHz. Antenna deployments above 30 meter height leads to impractical solution while establishing HF contacts. Present work provides the practical approach to the problem while considering acceptable loss and introducing linear approximation between antenna height and its wavelength within specific time slots and distances. Along with HF band frequency prediction technique, 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. The required height reduces drastically in this case simultaneously maintaining the high probability and strength of HF contact.

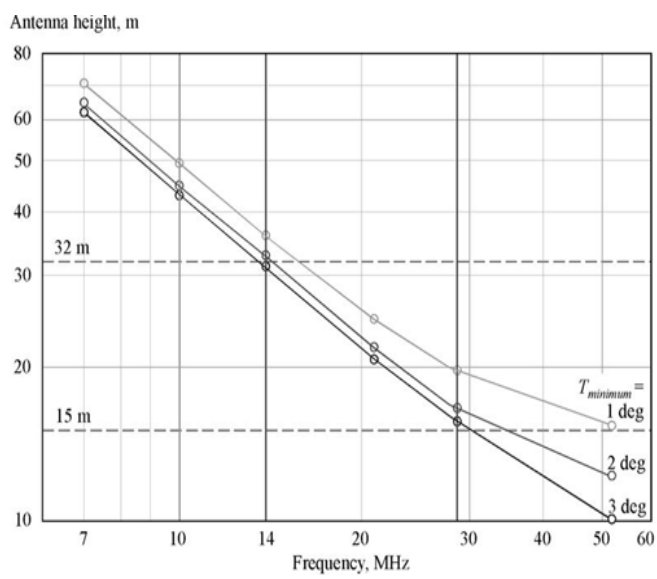

Figure.5.1: Ideal antenna height over even terrain for various frequencies

The present chapter has been broadly covers in two categories of proposed work as 'Prediction of HF frequency' and 'Optimum deployment of HF Antenna' to establish high strength of HF contact along with minimal antenna height variation.

5.2. PREDICTION OF HF BAND FREQUENCY

During planning and implementation of HF trials Optimum Traffic Frequency (FOT) and Maximum UsablBANe Frequency (MUF) are required to get desired frequency prediction. Due to variation in frequencies for different times of a day (due to atmospheric changes of ionosphere layers), four time slots have been chosen considering the rapid variation of day and night frequencies, frequencies during day and night transition periods. Different time slots considered for optimum HF contact are as follows:

1. **Day** slot (IST 0800 hrs to 1900 hrs)

2. **Transition-1** slot (IST 1900 hrs to 2100 hrs)

3. **Night** slot (IST 2100 hrs to 0600 hrs)

4. **Transition- 2** slot (IST 0600 hrs to 0800 hrs)

Following steps have been adapted while selection of optimum HF frequencies:

1. As shown in Figure 5.2 and Table 5.1, through efficient HF prediction tool (VOACAP) hourly data of FOT and MUF on 24 hrs basis (local time period) to be captured and divide the 24-hour data for four different time slots.

2. In next step, we have to take the median value (middle of the maximum and minimum values) of the FOT and MUF in the selected time period.

3. Now, we have to select a frequency near to the value of median FOT in such a way that it should be sufficiently below to medium MUF at that time period. Same Way median frequencies of other time slots can be chosen. After selecting the frequency spots the consistency, reliability and quality of different frequencies may be compared by checking S/N ratio and reliability factor with the help of HF prediction Tool. Although these frequencies should be changed as per specific time slots, however in practice operators can exercise their own decision when to switch over the frequencies to next time slot depending on local climatic conditions.

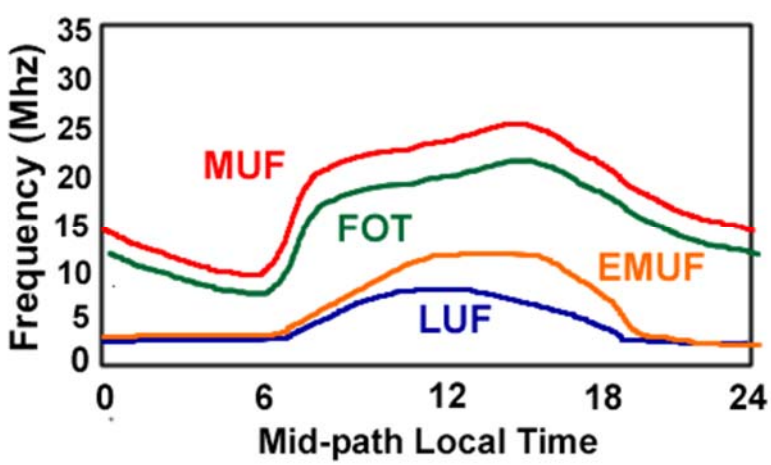

Figure.5.2: Variation of HF frequency w.r.t. time

Table.5.1: HF Prediction at various time slots for 500 KM distance between transmitter and receiver
(Software: Voice of America Coverage Analysis Program VOACAP)

SLOT	TIME(IST)	FOT (MHz)	MUF (MHz)	FOT (Median)	MUF (Median)
Transition -1	6:30	6.5	8.34		
Transition -1	7:30	8.06	10.34	8.06	10.34
Transition -1	8:30	8.77	11.25		
Day	9:30	9	11.41		
Day	10:30	10.17	11.67		
Day	11:30	10.86	12.61		
Day	12:30	11.31	13.8		
Day	13:30	12.17	14.84	12.17	14.84
Day	14:30	12.16	15.6		
Day	15:30	12.48	16		
Day	16:30	12.54	16.07		
Day	17:30	12.55	16.09		
Transition 2	18:30	11.06	15.09		
Transition 2	19:30	10.88	14.91	10.88	14.91
Transition 2	20:30	9.47	12.97		
Night	21:30	7.9	10.83		
Night	22:30	7.21	9.36		
Night	23:30	6.7	8.71		
Night	0:30	6.55	8.5		
Night	1:30	6.49	8.43	6.49	8.43
Night	2:30	5.59	8.1		
Night	3:30	5.03	7.29		
Night	4:30	4.45	6.45		
Night	5:30	4.6	6.66		

5.3. OPTIMUM DEPLOYMENT OF HF ANTENNA

Height of HF antenna above ground plays vital role for establishing a successful HF contact. Effective HF communication is dependent on radiation angle / Take off angle achieved by the transmitting antenna. Desired radiation / take of angle can be achieved by keeping the antenna height (in terms of wave length λ) above ground as per operating frequency. This work presents the novel technique to evaluate the required height of the HF antenna for effective HF communication. The procedure for calculating the height of the antenna is explained below.

First selection has been made for the Median HF frequencies for Day, Night, Transition-1 and Transition-2 as described above. These frequencies to be used for calculating initial wave length (λ). The value of wave length (λ) to be recalculated in case of any change in mid frequencies during subsequent trials.

Selection of antenna height has broadly divided in four categories based on distance between transmitting and receiving stations as follows:

5.3 .1. Selection of optimum Ant height for Long haul distance (More than 1000 KM)

In case of long haul communication (1000 KM-1600 KM) calculation of effective height of Antenna in terms of wave length (λ) for four time slots has been depicted through VOACAP HF prediction tool and same is shown in Figure 5.3. The Long haul distance has been considered up to 1600 KM approximating the geographic limit of an average size country. Firstly, antenna radiation pattern/ radiation angle has been predicted w.r.t median frequency of different time slots for particular distance of long haul. Subsequently as shown in the Figure 5.3, antenna height in terms of wave length (λ) has been predicted based on radiation losses measured from peak of radiation pattern angles

RADIATION ANGLE AND EFFECTIVE HEIGHT CALCULATION W.R.T FREQUENCY & DISTANCE(LONG HAUL)

FREQ (MHz)	Period/TIME	Distance (KM)	Radiation Angle	loss at(.65λ)	loss at(.6λ)	loss at(.55λ)	loss at(.5λ)	loss at(.45λ)	loss at(.4λ)	Effective Height of Ant(λ)	Effective Height of Ant(M)
18	Angle at Gmax/Directivity gain			21/7.4	22/7.3	24/7.1	25/6.7	27/6.5	31/6.5		
	Day/ 1300 Hrs	1600	14.2	1.1	1.5	1.8	2.1	2.6	3.4	0.65	10.85
		1500	15.5	0.8	1.1	1.25	1.5	2	3.2	0.6	10.02
		1400	17.1	0.3	0.6	0.8	1	1.4	2.1	0.55	9.18
		1300	19	0.1	0.2	0.4	0.6	0.9	1.5	0.5	8.35
		1200	21.4	0	0	0.1	0.2	0.5	1	0.45	7.51
		1100	24.7	0.3	0.1	0	0	0.1	0.3	0.4	6.68
14	Angle at Gmax/Directivity gain			21/7.4	23/7.3	24/7.1	25/6.8	27/6.6	31/6.6		
	Tran1/ 1900 Hrs	1600	13.5	1.3	1.9	2.3	2.6	3.1	3	0.65	13.92
		1500	15	0.8	1.1	1.4	1.7	2.2	2.9	0.6	12.85
		1400	16.9	0.4	0.6	0.8	1	1.5	2.1	0.55	11.78
		1300	19.2	0.1	0.2	0.4	0.6	0.9	1.5	0.5	10.73
		1200	22.3	0	0	0.1	0.1	0.3	0.8	0.45	9.64
		1100	29.6	1.5	0.9	0.6	0.4	0.1	0	0.4	8.57
8	Angle at Gmax/Directivity gain			21/7.6	23/7.5	24/7.3	25/6.9	27/6.8	31/6.8		
	Night/ 0100Hrs	1600	13.3	1.6	2	2.3	2.6	3.2	4	0.65	24.37
		1500	14.8	0.9	1.2	1.5	1.7	2.2	3	0.6	22.5
		1400	16.6	0.4	0.6	0.9	1.4	1.5	2.2	0.55	20.62
		1300	18.8	0.1	0.3	0.4	0.6	0.9	1.6	0.5	18.75
		1200	21.7	0	0	0.1	0.1	0.3	0.8	0.45	16.87
		1100	26.3	0.4	0.2	0.1	0	0	0.2	0.4	15
14	Angle at Gmax/Directivity gain			21/7.4	23/7.3	24/7.1	25/6.8	27/6.6	31/6.6		
	Tran2/ 0700 Hrs	1600	13.8	1.1	1.5	1.8	2.1	2.6	3.4	0.65	13.92
		1500	15.1	0.8	1.1	1.4	1.7	2.2	2.9	0.6	12.85
		1400	21.9	0	0	0.1	0.1	0.3	0.8	0.55	11.78
		1300	23.7	0.2	0	0	0	0.1	0.5	0.5	10.73
		1200	25.6	0.5	0.2	0.1	0	0	0.2	0.45	9.64
		1100	27.8	0.9	0.5	0.3	0	0	0.1	0.4	8.57

Figure. 5.3: Radiation angle and effective height calculation w.r.t. Frequency and distance (Long haul)

In order to keep practical antenna height, acceptable radiation losses from 0.1 dB to 1.5 dB w.r.t. peak of radiation pattern (Figure 5.4) has been considered and a linear pattern between distance and optimum antenna height of HF antenna approximated which is highlighted in Table 5.2 and Figure 5.3 (Green highlighted portion). It is visible from Figure 5.3 that the acceptable losses are considered in linear pattern w.r.t. antenna gain in order to form a linear generalized equation for calculation of antenna height.

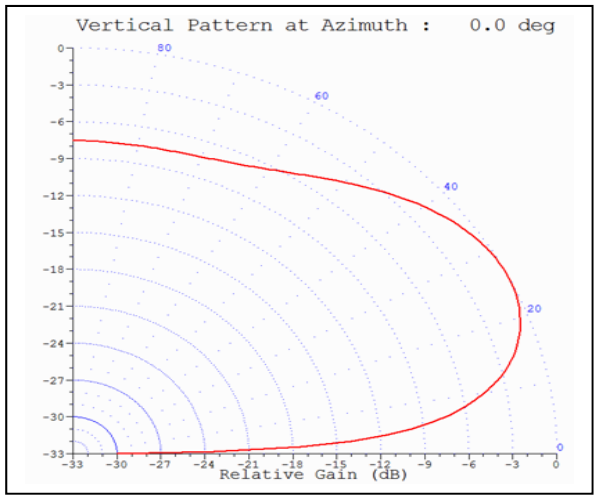

Figure.5.4: Radiation Lobe Pattern with relative gain

Table 5.2: Selection of Effective Antenna Height (Long Haul)

FREQ(MHZ)	TIME PERIOD	DISTANCE(KM)	EFFECTIVE HEIGHT OF ANTENNA (λ)
18	DAY 1300 HRS	1600	0.65
		1500	0.60
		1400	0.55
		1300	0.50
		1200	0.45
		1100	0.40
14	TRANSITION-1 1900 HRS	1600	0.65
		1500	0.60
		1400	0.55
		1300	0.50
		1200	0.45
		1100	0.40
8	NIGHT 0100 HRS	1600	0.65
		1500	0.60
		1400	0.55
		1300	0.50
		1200	0.45
		1100	0.40
14	TRANSITION-2 0700 HRS	1600	0.65
		1500	0.60
		1400	0.55
		1300	0.50
		1200	0.45
		1100	0.40

Based on above said pattern, Table 5.2 shows effective antenna height prediction w.r.t. various long haul distances. Due to linear approximation between effective antenna height and distance, Eq (5.1) has been formulated and same can directly be used to calculate effective height

of the antenna for all distances above 1000 KM between Transmitter and Receiver stations during Long haul communication as follows:

$$H = K\lambda$$
$$K = (D - 1100) \times 0.0005 + 0.4 \qquad (5.1)$$
$$\lambda = 300 / f$$

(H= Effective antenna height in Meter)
(f = Frequency in MHz)
(D= Distance between Transmitter & Receiver Station in KM)

5.3 .2. Selection of Antenna Height using HF Prediction Tool for Medium haul distance (500-1000 KM)

Medium haul distance (500 KM to 1000 KM) calculation of effective height of HF antenna in terms of wave length (λ) is shown in Figure 5.5. For practical antenna height calculation, acceptable radiation losses up to 1 dB w.r.t. peak of radiation pattern has been considered and a linear pattern between distance and optimum antenna height of HF antenna approximated and same is highlighted in Figure 5.5. (Green highlighted portion).

FREQ (MHz)	Period/TIME	Distance (KM)	Radiation Angle	loss at(.4λ)	loss at(.37λ)	loss at(.33λ)	loss at(.29λ)	loss at(.25λ)	Effective Height of Ant(λ)	Effective Height of Ant(M)	Dbi at effective height
	Angle at Gmax/Directivity gain			31/6.6	34/6.6	38/6.5	45/6.5	56/6.5			
14	Day/ 1300 Hrs	1000	24.63	0.3	0.6	1.1	1.8	2.7	0.4	8.57	6.3
		900	27.73	0.1	0.2	0.6	1.2	2	0.37	7.92	6.4
		800	21.84	0	0	0.2	0.6	1.3	0.33	7.07	6.3
		700	37.87	0.4	0.1	0	0.2	0.6	0.29	6.21	6.3
		600	50.53	2.7	1.3	0.5	0.1	0	0.25	5.35	6.5
	Angle at Gmax/Directivity gain			31/6.6	34/6.6	38/6.5	45/6.5	56/6.5			
14	Tran 1/ 1900 Hrs	1000	32.09	0	0	0.2	0.5	1.3	0.4	8.57	6.6
		900	34.95	0.2	0	0.1	0.4	0.9	0.37	7.92	6.6
		800	38.23	0.4	0.1	0	0.2	0.6	0.33	7.07	6.5
		700	43.38	3.1	0.5	0.1	0	0.3	0.29	6.21	6.5
		600	46.36	1.8	0.9	0.2	0	0.1	0.25	5.35	6.4
	Angle at Gmax/Directivity gain			31/6.8	34/6.8	39/6.8	46/6.8	58/6.9			
8	Night/ 0100Hrs	1000	32.51	0	0	0.25	0.65	1.4	0.4	15	6.8
		900	35.49	0.15	0	0.1	0.35	0.95	0.37	13.87	6.8
		800	38.86	0.5	0.2	0	0.2	0.6	0.33	12.37	6.8
		700	44.15	1.2	0.6	0	0	0.3	0.29	10.87	6.8
		600	47.23	2	0.9	0.2	0	0.2	0.25	9.37	6.7
	Angle at Gmax/Directivity gain			31/6.8	34/6.8	39/6.8	46/6.8	58/6.9			
8	Tran 2/ 0700 Hrs	1000	21.69	0.8	1.2	1.9	2.7	3.7	0.4	15	6.0
		900	24.77	0.4	0.7	1.2	1.9	2.9	0.37	13.87	6.1
		800	28.99	0	0.2	0.6	1.2	2	0.33	12.37	6.2
		700	35.91	0.2	0	0	0.3	0.9	0.29	10.87	6.6
		600	46.33	1.8	0.8	0.2	0	0.2	0.25	9.37	6.7

Figure 5.5: Radiation angle and effective height calculation w.r.t. Frequency and distance (Medium Haul)

Based on Figure 5.5, the effective height of HF antenna has been placed in Table 5.3. for HF communication w.r.t. 600, 700, 800, 900, 1000 KM distance in all four time periods Day, Transition-1, Night, Transition-2. It is visible from Figure 5.5 that the acceptable losses are

considered in linear pattern w.r.t. antenna gain in order to form a linear generalized equation for calculation of antenna height.

Table 5.3: Selection of Effective Antenna Height (Medium Haul)

FREQ(MHZ)	TIME PERIOD	DISTANCE(KM)	EFFECTIVE HEIGHT OF ANTENNA (λ)
14	DAY 1300 HRS	1000	0.4
		900	0.37
		800	0.33
		700	0.29
		600	0.25
14	TRANSITION-1 1900 HRS	1000	0.4
		900	0.37
		800	0.33
		700	0.29
		600	0.25
8	NIGHT 0100 HRS	1000	0.4
		900	0.37
		800	0.33
		700	0.29
		600	0.25
8	TRANSITION-2 0700 HRS	1000	0.4
		900	0.37
		800	0.33
		700	0.29
		600	0.25

Due to linear approximation between effective antenna height and distance, Eq (5.2) has been formulated and same can directly be used to calculate effective height of the HF antenna for all distances of medium Haul (500KM to 1000KM) between Transmitter and Receiver stations during HF communication as follows:

$$H = K\lambda$$
$$K = (D - 600) \times 0.0004 + 0.25 \qquad (5.2)$$
$$\lambda = 300 / f$$

(H= Effective antenna height in Meter)
(f = Frequency in MHz)
(D= Distance between Transmitter & Receiver Station in KM)

5.3.3. Selection of Ant Height using HF Prediction Tool for Short haul distance (300-500 KM)

In case of short haul HF communication (300 KM to 500 KM distance), calculation of effective height of Antenna in terms of wave length (λ) is shown in Figure 5.6. For practical antenna height, acceptable radiation losses up to 0.8 dB w.r.t. peak of radiation pattern has been

considered and a linear pattern between distance and optimum antenna height of HF antenna approximated and same is highlighted in Figure 5.6. (Green highlighted portion).

FREQ (MHz)	Period/TIME	Distance (KM)	Radiation Angle	loss at(.225)	loss at(.20λ)	loss at(.175λ)	Effective Height of Ant(λ)	Effective Height of Ant(M)	Dbi at effective height
	Angle at Gmax/Directivity gain			73/6.8	90/6.7	90/6.3			
8	Day/ 1300 Hrs	500	44.93	0.5	0.8	1.1	0.225	8.43	6.3
		400	51.43	0.2	0.3	0.6	0.2	7.5	6.4
		300	59.7	0	0.1	0.2	0.175	6.56	6.1
	Angle at Gmax/Directivity gain			73/6.8	90/6.7	90/6.3			
8	Tran1/ 1900 Hrs	500	43.68	0.6	0.9	1.2	0.225	8.43	6.2
		400	52.44	0.2	0.3	0.55	0.2	7.5	6.4
		300	62.94	0	0.1	0.1	0.175	6.56	6.2
	Angle at Gmax/Directivity gain			86/7.2	90/7.0	90/6.6			
4	Night/ 0100Hrs	500	43.26	0.8	1.2	1.4	0.225	16.87	6.4
		400	51.47	0.3	0.3	0.65	0.2	15	6.7
		300	61.23	0.1	0.1	0.2	0.175	13.12	6.4
	Angle at Gmax/Directivity gain			76/7.0	90/6.8	90/6.4			
6	Tran2/ 0700 Hrs	500	44.73	0.6	0.9	1.1	0.225	11.25	6.4
		400	56.27	0.1	0.3	0.4	0.2	10	6.5
		300	65.31	0	0.1	0.1	0.175	8.75	6.3

Figure.5.6: Radiation angle and effective height calculation w.r.t. Frequency and distance (Short haul)

Based on Figure 5.6, the effective height of HF antenna has been placed in Table 5.4. for HF communication w.r.t. 300, 400, 500 KM distance in all four time periods Day, Transition-1, Night, Transition-2. It is visible from Figure 5.6 that the acceptable losses are considered in linear pattern w.r.t. antenna gain in order to form a linear generalized equation for calculation of antenna height.

Table 5.4: Selection of Effective Antenna Height (Short Haul)

FREQ(MHZ)	TIME PERIOD	DISTANCE(KM)	EFFECTIVE HEIGHT OF ANTENNA(λ)
8	DAY 1300 HRS	500	0.225
		400	0.2
		300	0.175
8	TRANSITION-1	500	0.225
		400	0.2
		300	0.175
4	NIGHT	500	0.225
		400	0.2
		300	0.175
6	TRANSITION-2 0700 HRS	500	0.225
		400	0.2
		300	0.175

Due to linear approximation between effective antenna height and distance, Eq (5.3) has been formulated and same can directly be used to calculate effective height of the HF antenna for

all distances of Short Haul (300 KM to 500 KM) between Transmitter and Receiver stations during HF communication as follows:

$$H = K\lambda$$
$$K = (D - 300) \times 0.00025 + 0.175 \qquad (5.3)$$
$$\lambda = 300 / f$$

(H= Effective antenna height in Meter)
(f = Frequency in MHz)
(D= Distance between Transmitter & Receiver Station in KM)

5.3.4. Selection of antenna height using HF prediction tool for Near Vertical Incidence Sky-wave (NVIS) mode (less than 300 KM)

HF Communication below 300 KMs can be established as per NVIS based communication. In NVIS mode radiation take-off angle becomes very high (more than 70 degree) and almost perpendicular to ground plane. Hence below 300 KM HF communication can be effectively achieved by keeping HF antenna height 0.17 λ as sown in Table 5.5.

Table 5.5: Selection of Effective Antenna Height (NVIS Mode)

FREQ(MHZ)	TIME PERIOD	DISTANCE(KM)	EFFECTIVE HEIGHT OF ANTENNA (λ)
8	DAY 1300 HRS	250	0.17
		150	0.17
		50	0.17
8	TRANSITION-1	250	0.17
		150	0.17
		50	0.17
4	NIGHT	250	0.17
		150	0.17
		50	0.17
6	TRANSITION-2 0700 HRS	250	0.17
		150	0.17
		50	0.17

Optimum height of the HF antenna for all distances below 300 KM distance between Transmitter and Receiver stations during HF communication is as follows:

$$H = K\lambda$$
$$K = 0.17 \qquad (5.4)$$
$$\lambda = 300 / f$$

(H= Effective antenna height in Meter)
(f = Frequency in MHz)
(D= Distance between Transmitter & Receiver Station in KM)

5.4. HF TRIAL RESULTS

Extensive HF trials were conducted in short, medium and long haul by generating optimum frequencies and deploying antenna with optimum height. The purpose of these trials was to validate the HF propagation frequencies along with calculated height across the board and to provide structured guidelines for antenna deployment and selection of HF Spot frequencies.

The strength of HF trails has been measured based on R-S-T system used for HF radio operators as shown in Table 5.6, where R stands for readability (data communication), S stands for Strength (voice communication) and T stands for tone (CW communication). As shown in Table 5.6, HF signal strength above 5 is fairly good signal, strength above 4 is fair signal and strength below 3 considered to be weak signal.

Table 5.6: HF signal strength classification as per R-S-T system for HF radio operators

R-S-T Numeric Value	**Strength S**
1	Faint signals, barely perceptible
2	Very weak signals
3	Weak signals
4	Fair signals
5	Fairly good signals
6	Good signals
7	Moderately strong signals
8	Strong signals
9	Extremely strong signals

Table.5.7: HF communication performance trial result

Distance (Transmitter-Receiver) KM	**Contact% Strength > 5**	**Contact% Strength <4**	**Contact% Strength <3**
470	90%	5%	5%
770	95%	5%	-
1410	83%	12%	5%

The validation of antenna deployment was carried out using WDA 200 wide band dipole antenna. Total 3 trials carried out at various ranges of 470 KM, 770 KM and 1410 KM respectively. The performance of HF contact using TR 2400 HF set found reasonably good as shown in Table 5.7. The strength of HF signal measured as per R-S-T system used for HF radio operators. The trail result shows considerably high % of HF contact above signal strength 5 (fairly good signal) and very low % of HF contact below strength 3(weak signal) which considered as reasonably successful HF communication.

5.5. CONCLUSION

In this chapter a novel methodology for HF frequency prediction based on HF prediction tool and HF antenna deployment at various heights has been formulated which can be highly useful during HF communication specially in strategic fields. External environment strongly influence HF communication due to variation of ionosphere layers along with variation of time as well as environmental changes. Therefore, it is essential to provide standard guidelines for optimum HF propagation by selection of HF spot frequencies along with optimum deployment of antennae system for various ranges. The proposed technique provides the practical solution for HF frequency prediction and optimum antenna deployment. Hence the proposed approach can directly be implemented as standard guidelines for optimum HF contacts within specified geographical region.