HF Wave Propagation Prediction Based On Passive Oblique Ionosonde

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Abstract *– **High frequency (HF) communications have an important role in long distances wireless communications. This frequency band is more important than VHF and UHF, as HF frequencies can cut longer distance with a single hopping. It has a low operation cost because it offers over-the-horizon communications without repeaters, therefore it can be used as a backup for satellite communications in emergency conditions. One of the main problems in HF communications is the prediction of the propagation direction and the frequency of optimum transmission (FOT) that must be used at a certain time. This paper introduces a new technique based on Oblique Ionosonde Station (OIS) to overcome this problem with a low cost and an easier way. This technique uses the international shortwave radio stations and the global beacons as the OIS transmitter and a normal HF receiver as the OIS receiver to verify the direction of propagation and the FOT. In addition, the critical frequency for F2 layer (fof2) was estimated in this paper for Iraq experimentally. The proposed technique was tested practically, and FOT range between Baghdad and other remote stations was estimated successfully using a radio receiver from Kenwood model R 1000 with a long wire antenna as a passive OIS system receiver.***

Keywords: ***Oblique Ionosonde Station; fof2 of Iraq; frequency of optimum transmission; single hopping.***

I. INTRODUCTION

High frequency (HF) communications has been used for many years. Frequency planning for this band is difficult and needs a lot of attention because the ionosphere variables such as critical frequency f_0f_2 and layer height $h'f_2$ are affected by the sun activities during a single day and over the year[1, 2] If the values for these variables are available, the circuit link between any two points on earth could be estimated. The mathematical models that were proposed to predict the ionosphere variables based on either statistics, empirical, numerical or ray tracing are expensive and not 100% accurate[3]. The most accurate method is to measure the instantaneous values for f_0f_2 and $h'f_2$. This can be done by probing the ionosphere by a special radar system called Vertical Ionosonde or Oblique Ionosonde station[4-6]. Although this technique is the most accurate one but it is not available everywhere on earth, because they are Costly and cannot be located in oceans or deserts. According to[7], the authors proved that signal propagation of radio broadcasting stations schedule received in France was identical to the result of SATIS prediction software but no information about FOT or direction of propagation. This paper introduces a simplified oblique Ionosonde technique, which will be called as Passive Oblique Ionosonde Station (POIS). This proposed technique and algorithm is useful at emergencies or expedition where neither power nor internet is available. In this new technique, the prediction of f_0f_2 or FOT and the direction of propagation will be found by using the international shortwave radio broadcasting stations or beacons as the OIS transmitter and any radio receiver with directive or portable antenna as the OIS receiver. The working frequencies, coverage areas and transmission power for each international radio station have been assigned carefully under the supervision of International telecommunication Union (ITU) to prevent interference with other working radio stations. The received frequency f_r for each radio station will be processed mathematically to predict the FOT range between Baghdad and that received radio station. This predicted information will be useful for establishing a two way radio communication between Baghdad and any point around the world using HF transceiver. This paper also presents an algorithm to estimate f_0f_2 above Iraq. These estimated results were compared with real data supplemented by global Ionosonde stations.

II. OBLIQUE IONOSONDE STATION (OIS)

The operation principle of the OIS is shown in Fig. (1). If the incident signal angle β is approximately less than $\pi/2$, then the transmitted signal can be received obliquely at a distance d from the transmitter side using a frequency higher than the critical frequency f_c. This is called oblique transmission and the frequency used is called f_{ob} , where f_{ob} for any layer could be calculated using (1) [8]. For F2 layer the critical frequency f_c will be referenced here as f_of_2 . As show in Fig. (1), θ is the take off angle of the antenna radiation pattern, which will be used to calculate the distance of transmission d and the coverage area. The relationship between θ and β is derived using the trigonometric identities of the triangle shown in Fig. (1).

$$f_{ob} = f_c \sec\beta \tag{1}$$

$$\cos\beta = \cos\left(\frac{\pi}{2} - \theta\right) \tag{2}$$

$$\cos\beta = \sin\theta \tag{3}$$

From (3), (1) can be rewritten to be:

$$f_{ob} = \frac{f_o f_2}{\sin\theta} \tag{4}$$

OIS is useful in studying the Ionosphere of oceans and deserts where no vertical Ionosonde found[9]. For HF communication, OIS is used to give the frequency of optimum transmission FOT between two points separated by a distance d. This is done by sending a chirp signal from TX side covering the HF band (from 2 to 30 MHz) swapping at a rate equals to 100 kHz/s and received at RX side [10,11].The received signal to noise ratio SNR displayed as Ionogram form which is shown in Fig.(2) [12]. From Fig. (2), the FOT range was found to be from 7 to 24 MHz with different SNR, also shows the following:

1- 7 to 15 MHz the propagation mode was in multi-hopping.
2- 15 to 19 MHz no propagation.
3- 19 to 24 MHz the propagation done in one hop.

From the above information, the best FOT values used for link circuit between Svalbard to Chilton were 20 to 24 MHz because the propagation mode was done through a single hop This Will reduce signal attenuation and fading. The OIS system is costly and needs high synchronization between TX and RX frequency oscillators using GPS to overcome the drifting in time between OIS ionograms because time delay between TX and RX can be calculated[13].

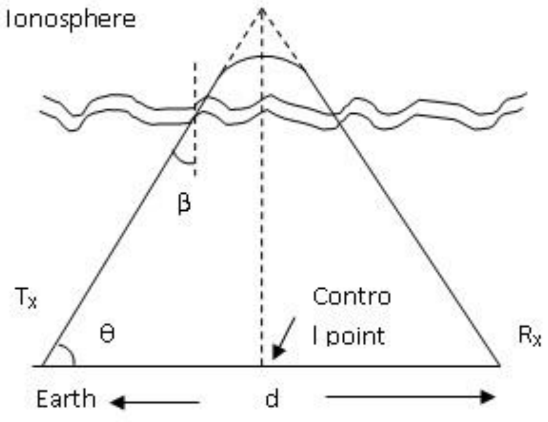


Fig.1 Oblique Ionosonde Station (OIS)

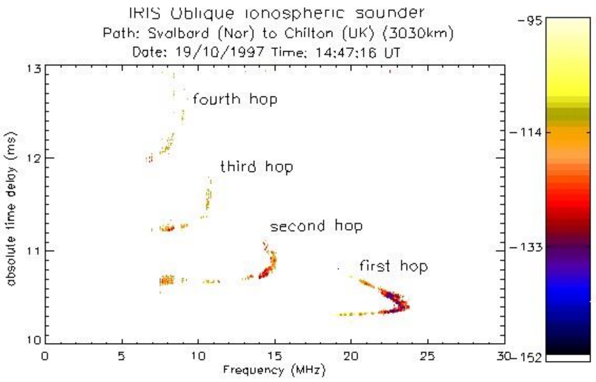


Fig.2 Sample of OIS Ionogram

This paper introduces a new simplified and cheap method that will be used to predict the FOT for any direction. This technique will be named as Passive OIS (POIS) because no synchronization between TX and RX oscillators is needed.

III. PASSIVE OBLIQUE IONOSONDE STATION (POIS)

International shortwave radio broadcasting stations and beacons are highly reliable, because their working frequencies estimated with high accuracy .Using active international shortwave radio broadcasting stations and beacons around the world as transmitters, and a normal HF radio receiver for example Kenwood R-1000 as a receiver, f_of_2 or FOT could be estimated. The received frequency f_r from any active international shortwave radio station or beacon can provide a good estimation for FOT range during the period of reception in that direction, this can be done by using the following equations:

$$FOT = kMUF \tag{5}$$

Where k is the correction factor that depends on the distance and the height of the reflection layer and it is hard to calculate its exact value, it has been found the k range is from 0.5 to 0.85 [14]. The MUF represents Maximum Usable Frequency for the HF communication link. FOT range could be defined according to (6) as:

$$f_1 \le FOT \le f_2 \tag{6}$$

$$f_1 = 0.5MUF \tag{7}$$

$$f_2 = 0.85MUF \tag{8}$$

By substituting (7) into (8) yields to

$$f_2 = 1.7f_1 \tag{9}$$

For simplicity let f_r be in the middle range of f_2 and f_1 with the value greater than or less than f_2 and f_1 by x so that let:

$$f_2 = f_r + \mathrm{x} \tag{10}$$

$$f_1 = f_r - \mathrm{x} \tag{11}$$

Adding (10) and (11) yields

$$f_2 + f_1 = 2f_r \tag{12}$$

Sub (9) into (12) yields (13) and (14)

$$f_1 = 0.74f_r \tag{13}$$

$$f_2 = 1.25f_r \tag{14}$$

$$\theta = \tan^{-1}\left(\frac{2h' f_2}{d}\right) \tag{15}$$

To find the direction of transmission simply a long wire antenna used with altitude of h meter above ground as shown in Fig.3. The antenna radiation pattern and antenna parameters could be simulated using EZNEC antenna simulation program as shown in Fig.4.

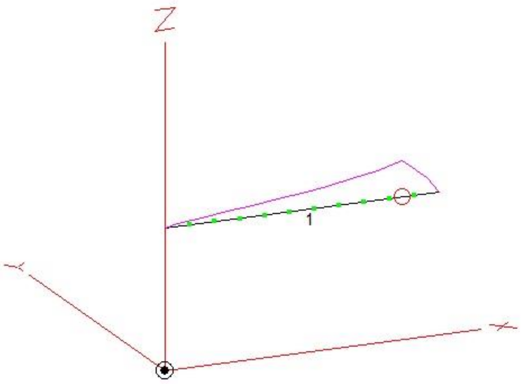
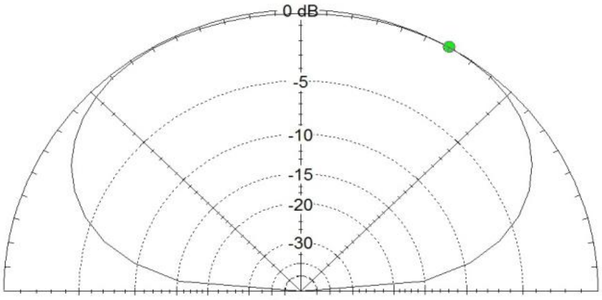
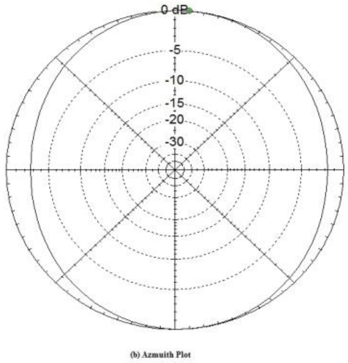


Fig.3 Long wire Antenna

From Fig.4.a the angel of arrival beam width (the antenna used for receive only) is 130.7 deg @ 24.4deg. to 155.1 deg. In addition, from Fig4.b the antenna azimuth beam width is approximately 360 deg., to establish a two-way communication calls using HF band between Baghdad and any point round the world using HF transceiver and a dipole antenna of the pattern shown in Fig.5 it could be carried on depending on FOT range supplemented by (6) and antenna direction, by choosing FOT value close to f_2 than f_1 the probability of propagation in one hopping is high [11].



(a) Elevation Plot

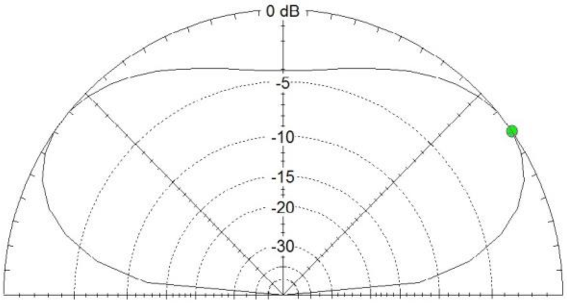


(b) Azmuith Plot

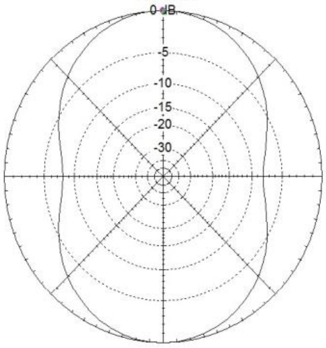
Fig.4 RX Antenna Radiation Pattern

IV. THE CRITICAL LAYER FREQUENCY (f_of_2) ESTIMATION ALGORITHM FOR IRAQ

To find the f_of_2 of Iraq using the proposed POIS technique R . Kuwait was selected. The reason beyond selecting this station no other neighbouring radio stations is the mid-point (control point) at which f_of_2 will be calculated lays within the Iraqi Territory. Referring to Fig.(1), the distance d between Baghdad and Kuwait is constant, which is approximately 875Km. The height of F2 layer is changing during 24 hours, causing f_of_2 value to vary accordingly. To get a successful reception of R. Kuwait programs in Baghdad during the whole 24 hours a day, TX antenna Height (antenna radiation take off angle θ) must be changing also.



(a) Elevation Plot



(b) Azmuith Plot

Fig.5 TX Antenna Radiation Pattern

The algorithm proposed in this paper to calculate the f_of_2 for Iraq using R. Kuwait is described in the flow chart of Fig.(6). Fig. (5) Shows the proposed algorithm for f_of_2 estimation; this algorithm has the following assumptions:

1- Choosing of $h'f_2$ will be in the range = [200,500] km, which is the height of F2 layer according to [10].

2- Choosing θ between the interval = [5, 75] degree because θ (even with good ground) will not approach zero degree and for higher values of θ the hopping will be small. The algorithm of finding $h'f_2$ and f_of_2 for Iraq will start by selecting the first value of θ (which is 5 degrees) from the range in assumption (2). After that, d will be calculated each 20 km starting from the first value of $h'f_2$ range in assumption (1) using (15). This process will be repeated after incrementing θ by 5 degrees and it will stops when θ become 75 degrees. The calculated values of d will be plotted against the different θ values as shown in Fig. (6). From Fig.(6), the intersection of red dashed line (represents the real distance between Baghdad - Kuwait which is around 900km) with the plotted curves deduced.

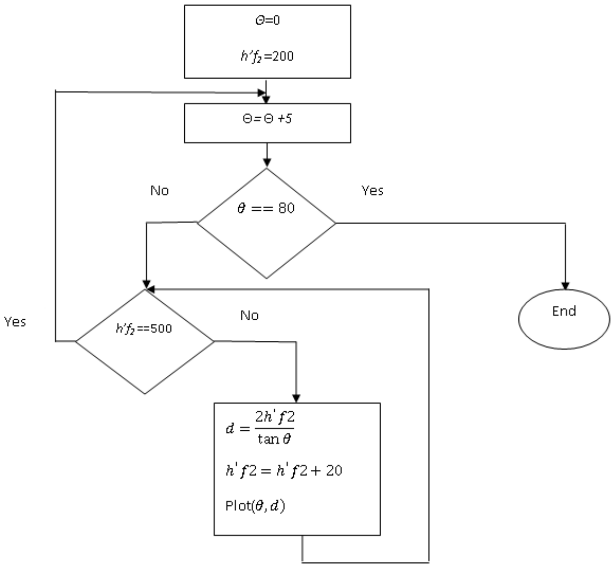


Fig.6 $fof2$ Estimation Algorithm of Iraq

The values of θ interval from 10 to 45 degrees. Using (4) with the deduced θ interval, f_of_2 interval will be estimated.

V. EXPERIMENTAL RESULTS

The first part of the experiment started with scanning the HF bands that received in Baghdad during September 2018 using Kenwood R-1000 receiver with a long horizontal wire antenna of 16 m length raised 8 m above ground ,the direction of its terminals in the direction of North – South of Iraq. The stations that were received were radio stations and beacons because that, time schedules for any radio stations will cover ITU Zones at specified time (where the propagation was opened) while the beacons transmit 24 hours. The samples of the received beacons and the radio stations summarized in table (1) and table (2) shows the prediction of FOT and coverage area. From f_r column of table (1) the FOT range was calculated for each frequency received using (13) and (14). From table (2) the predicted FOT range starts from 4.5 to 21.8 MHz in the direction of Asia and Europe from 55 UTC to 605 UTC. The second part of the experiment was to use the predicted frequency range and try making a number of successful voice calls with Asia and Europe using a licensed transceiver (on Ham Band) from Kenwood model TS-130SE with a dipole antenna of 10m length raised 8m above ground beamed toward north of Iraq and a matching circuit as shown in Fig.8.The received stations were from Russia on 14.19MHZ at 0440UTC and Greece on14.2 MHZ at 0458UTC.To find the f_of_2 of Iraq using the proposed POIS algorithm, R. Kuwait was selected to be the system TX and the RX was our receiver from Kenwood R 1000 located in Baghdad. The received frequency f_r was 5960KH$_Z$ at 609UTC, using this frequency value the f_of_2 interval for Iraq was from 1.5 to 2.9 MH$_Z$ at that time. The f_of_2 interval will be reduced to [2.5,2.9] MH$_Z$ because at 609UTC the ionization of the ionosphere layers spotted above Iraq was high , also at that time D,E layers exist, so lower values of f_r will be absorbed. According to Fig. (7), f_of_2 was approximately 2.4 MHz for Iraq this value derived from the oblique Ionosonde network round the world. The Space Weather Services Bureau of Methodology Australian Government collects these approximated data and provides them for the public [15].

VI. CONCLOSIONS

Prediction of f_of_2 is important to establish communication using HF band. Prediction using the available OIS technology or prediction software is complex and costly. The proposed technique and algorithm in this paper provides an alternative cheap solution for predicting the sky wave communication link circuit in case of emergency, working on field and in expedition. This technique was tested by establishing communication link between Baghdad and many points around the world, this was done first by listening to a beacon or short wave radio station at that direction and using the received frequency to predict the FOT range. After that, successful voice calls were done to communicate the stations on the same direction using the predicted FOT. The system described here is a simple passive OIS without Ionogram because TX side (broadcasting radio or beacon station) had only one frequency not a chirp signal. All the practical measurements were done using the HF radio receiver from Kenwood R-1000 with a long horizontal wire.

VII. LIMITATIONS OF THE POIS EXPERIMANT

In this paper the prediction of FOT and the direction of Propagation depends on basic mathematical equations and available cheap tools ,the suggested algorithm for finding HF variables has some limitations, which are:

1 - Take off angle value was simulated not measured because according to the basics the propagation through F layer one hop at low θ value is around 3000 Km [14] and also finding exact value of θ is out of paper scope.

2 - Using only one type of antenna for receiving the signal like long horizontal wire because of the limitation in working area simply setting up the antenna above the building. For vertical antenna on HF band with long active element and radials, it needs larger area and good grounding.

3 - Prediction of fading, SNR of the received signal and mode of propagation ,they need much more information and complex algorithm and this is out of POIS scope.

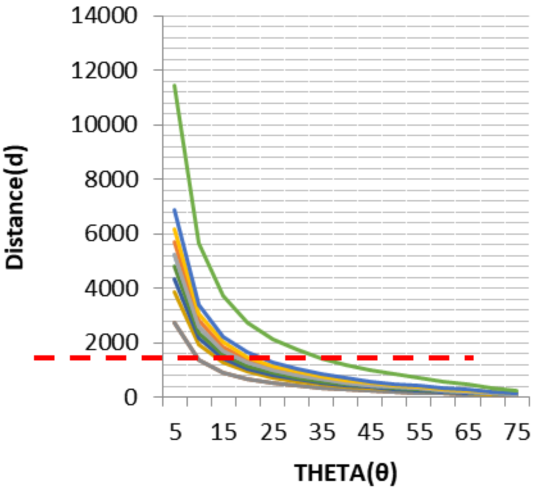


Fig. 6. the Relationship between Coverage Distance (d) and take off Angle (θ) for Baghdad-Kuwait HF circuit

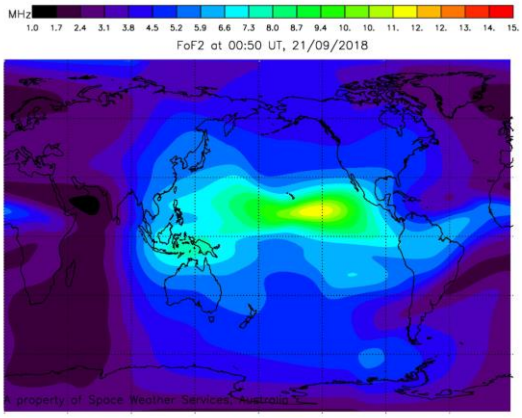


Fig. 7. S real values of the $f_o f_2$ round the world supplemented by Space Weather Services Bureau of Methodology Australian Government

Table (1) Samples of the received short wave radio stations and beacons on 21 September 2018

Station	f_r/ KHz	Time/ UTC	Signal µV	Location
R. Romania	7395	55	3.2	Romania
R.China int.	7385	55	12.6	China
RWM	9996	105	0.8	Moscow
RWM	4996	157	3.2	Moscow
R.China int.	9815	201	50.2	China
BBC	7360	230	25.1	Belgium
R. Kuwait	5960	609	0.8	Kuwait
V. of America	15580	609	12.6	Botswana

Table (2) Sample of the Predicted FOT and coverage Area on 21 September 2018

Predicted FOT Range		Time/ UTC	Predicted covarge area (ITU Zone)
f_1/kHz	f_2/kHz		
5472.3	9243.75	55	28
5464.9	9231.25	55	29
7397.04	12495	105	30
3697.04	6245	157	31
7263.1	12268.75	201	32
5446.4	9200	230	33
4410.4	7450	609	34
11529.2	19475	609	35

Fig. 8 TS-130SE Transceiver and R-1000 receiver antenna.

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