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## The Suggested Correlation Formula between (HPF) and (OPMUF) Parameters over Middle East Region

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**Abstract:** In this project, a study of the behavior and correlation between High Possible Frequency (HPF) and Optimum Maximum Usable Frequency (OPMUF) parameters for the communication links distributed over Middle East Region were made. A mutual correlation equation between the two parameters has been suggested. The analytical test of the monthly and annual variation of the (HPF) and (OPMUF) parameters have been conducted for the gathered theoretical dataset which calculated using the VOACAP and REC533 international HF models for the solar activity year of 2000. According to the results of this test, the correlation between the two parameters is simple and can be expressed by a linear regression formula. The predicted values using the suggested equation gave a good fitting with the theoretical values generated from the international HF-communication models.

**Key words-** High Possible Frequency (HPF), Ionospheric parameters, Optimum Maximum Usable Frequency (OPMUF), Radio wave propagation.

### I. Introduction

The ionosphere is represented one of the regions of the Earth's atmosphere which is extended approximately from 60 to 1000 km. this region is formed by interaction of solar radiation with uncharged particles of uppermost part of earth's atmosphere resulting ions and electrons. The ionosphere layer is depending on the electron density, so this layer is subdivided into four layers: D-layer (60 to 90 km), E and E<sub>s</sub> layers (90 to 140 km), F1 and F2 layers (140 to 420 km) and Topside layer (420 to 1000) [1].

The Highest Possible Frequency (HPF) and Optimum Maximum Usable Frequency (OPMUF) are two of the ionospheric parameters. The (HPF) is defined as "*the highest possible frequency can be reflected from the ionosphere layer*". It is working the upper usable limit exceeded 3 days per month. The (OPMUF) is defined as "*the effective optimum maximum usable frequency can be reflected from the ionospheric layer*".

As these parameters strongly depends on the ionization level of the F-layer, so the values of these parameters increases at strong solar activity and conversely occurs at week solar activity the ionospheric parameters values decreases [2]. The HPF & OPMUF are important to determine the best highest frequency that used to maintain the link between two locations.

Many experiments were made from number of researchers to studying the ionospheric parameters like Lincoln and Godley Head [1960], Jones M. R. and Stephenson J. J. [1975], Bröms M. and B. Lundborg [1994] [3], Obrou O. K. [2003], Olga A. Maltseva [2006], Chunxu Liu [2008] [4], Jian Wang [2010] [3] and Michael Warrington [2012] [4].

In this research, the correlation relation between HPF and OPMUF has been studied for maximum solar activity of solar cycle 23 over Middle East region.

### II. Radio Communications

Radio waves are electromagnetic waves that have rang of frequency from 3 Hz to 300 GHz. Most modern communication used the propagation of radio waves through the ionosphere especially the earliest form of radio communication used High Frequency (HF) (3-30) which are experimented by Hertz and Marconi [5].

Ionosphere layer is considered an important layer for reflection HF band to the surface of the earth. The most technique used for propagation of HF signals through ionosphere layer from point to point is known as *sky wave propagation* which is also used for many purposes like civil and military and other uses.

The HF radio communication for long distance is utilized sky waves technique because these waves are affected by ionized layer at least three ways [6].

Firstly under suitable conditions, the energy of sky waves is absorbed by charge particles, causing attenuation for these waves. Secondly due to the randomly distribution of electron density in ionosphere layer is lead to change the direction of sky waves traveling from one place to another. Thirdly occasionally the sky waves have ability to penetrate ionosphere layer, because these waves have enough energy to penetrate ionosphere layer [7], as shown in figure (1).

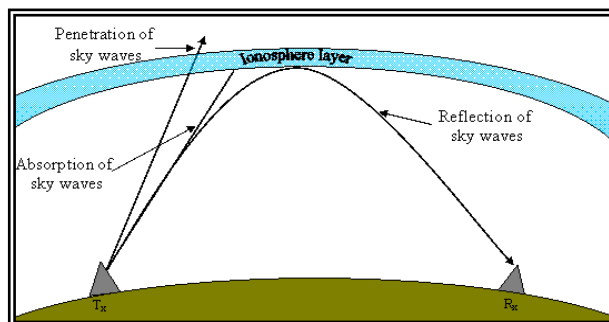


Fig. 1. Illustrates the propagation of sky waves [7].

The International Telecommunications Union (ITU) was established many international standard models for ionospheric characteristics. On advice from its International Radio Consultative Committee (CCIR) and, more recently, its Radio Communication Sector (ITU-R) has issued a standard set of models like CCIR [1966 - 1991], ITU-R [1997] and other. The CCIR models and related software are released by ITU [8]. Most HF communication models intended for direct reception from large number of public broadcasting stations which are also known as “world band radio”, because these models used analog modulation techniques which is employed for broadcasting in HF band.

### III. HF International Communication Models

In this project, the “VOACAP” and “REC533” international HF communication models has been adopted to predict the expected performance of high frequency band. Most of broadcasting stations in the world (British Broadcasting Corporation (BBC), United State International Broadcasting (USIB) and others) use VOACAP and REC533 models because these models represent last and best models to analysis HF band.

In 1985, the broadcasting of Voice of America (VOA) was utilized the Ionospheric Communications Analysis and Prediction Program (IONCAP) which is represented the first professional ionospheric signal model. The name of this program was changed to the Voice of America Coverage Analysis Program (VOACAP) in order to distinguish it from the official “National Telecommunications and Information Administration” (NTIA) of “IONCAP” program. The development of VOACAP was accomplished by the Naval Research Laboratory (NRL) and Institute for Telecommunication Sciences (ITS) [9]. The Recommendation 533 model (REC533) was released by the ITU in July 1993 by Working Party 6A (WP6A). It was developed and was maintained by the United States, Department of Commerce, National Telecommunications and Information Administration, Institute for Telecommunication Sciences (NTIA/ITS) [10]. VOACAP and REC533 models were design to measure the characteristics of ionosphere and to analysis the range of HF band for a specified path between a transmitter and a receiver stations.

### IV. Test And Results

The aim of this research is to study the behavior and correlation between High Possible Frequency (HPF) and Optimum Maximum Usable Frequency (OPMUF) parameters for the communication links between the transmitting and receiving stations over Middle East Region. The year of 2000 has been adopted to be a year of study, because the selected year represents a maximum active cycle of the solar cycle 23. The monthly sunspot numbers of the selected year are shown in table (1):

Table 1 Shows the monthly sunspot number of the year 2000.

Month Name	Sunspot Numbers (SSNs)
Jan	90.1
Feb	112.9
Mar	138.5
Apr	125.5
May	121.6
Jun	124.9
July	170.1
Aug	130.1
Sep	109.7
Oct	99.4
Nov	106.8
Dec	104.4

The Middle East Region has been adopted to be the region of study, so the capital Baghdad was considered as a transmitting station while other thirty five different locations which are spreading around Baghdad city have been considered as receiving stations, as shown in figure (2):-



Fig. 2. Show the selected receiving stations around the capital Baghdad (Transmitting station).

The geographical locations (Latitude and Longitude) and distance of the selected receiving stations are listed in table (2):-

Table 2 Show Latitude, Longitude and distance of the receiving stations.

Station Name	Geographical location		Distance (Km)
	Latitude (N)	Longitude (E)	
Al-Abilah	23.5	50.43	1244.2
Al-Aqabah	29.25	35	985.9
Halab	36.20	37.17	730.5
Al-Hazakah	36.48	40.75	480.2
Al-Jawf	29.86	39.87	576.9
Al-Jufur	32.53	38.23	580.9
Al-Qatif	26.93	50	894.8
Al-Ragqah	35.93	39.02	567.9
Amman	31.95	35.93	806
Ar'ar	30.95	41	415.2
Ba'ar	30.78	36.68	779.6
Buraydah	26.33	43.98	781.5
Dayr Alzawr	35.33	40.15	446.3
Demascuse	33.5	36.25	754.5
Diyarbakir	37.91	40.24	630
Erzurum	39.92	41.28	781
Ha'il	27.55	41.7	694
Hamadan	34.8	48.5	412.3
Hamah	35.13	36.75	728.5
Isfahan	32.67	51.63	680.1
Karmanshah	34.32	47.07	270
Kharmah	23.61	41.4	1221.3
Kuwait	29.33	47.98	562.7
Mahabad	36.72	45.70	393.5
Malatya	38.35	38.32	779
Masjed Sul.	31.98	49.51	503.6
Riyadh	24.63	46.72	995.9
Shiraz	29.6	52.53	877.8
Tabriz	30.08	46.3	553.7
Tabuk	28.38	36.58	926.7
Tadmur	34.6	38.25	581.9
Tayma'a	27.5	38.48	1053.1
Tahrir	27.63	51.43	695.4
Van	38.55	43.36	585.4
Zanjan	36.68	48.49	526.4

In this research the international communication model “VOACAP” has been used to calculate the dataset of the HPF parameter, while the dataset of the OPMUF parameter has been determined using the “REC533” international communication model.

Table (3), shows samples of the output dataset of the (OPMUF) & (HPF) parameters from the execution of the picked international models for the link (Baghdad - Van).

Table 3 Shows samples of the dataset of the (OPMUF) & (HPF) parameters.

OPMUF (REC533) (Baghdad – Van)												
Time	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sep.	Oct.	Nov.	Dec.
0	6.7	8.4	11.3	12.9	12.8	12.7	13.1	11.3	10.3	9	8.3	7.3
1	7	8.4	11	12.5	12.4	12.2	12.6	11.1	10	9	8.5	7.5
2	7.4	8.6	10.6	11.9	11.9	11.5	12.1	10.7	9.7	8.9	8.7	7.7
3	7.2	8.4	9.9	11.1	11.4	10.9	11.4	10.1	9.2	8.4	8.2	7.3
4	6.3	7.4	9	10.5	11.1	9.8	10.1	9.8	8.6	7.7	7.3	6.3
5	5.6	6.7	8.8	10	10.6	10.2	10.5	9.4	9.1	8	7.2	5.9
6	5.8	7.2	9.6	11.5	11.6	11.2	11.6	10.7	10.2	9.4	9	7.2
7	8.1	10.2	12.6	13.6	12.8	12.1	12.5	12	12.6	12.4	11.7	9.5
8	11.5	14	15.9	15.5	13.5	12.4	12.6	12.7	14.2	15	15.2	12.9
9	14.6	16.9	18.1	16.6	13.8	12.4	12.4	12.7	14.8	16.4	17.6	15.6
10	16.3	18.1	18.9	17.3	14	12.5	12.6	13	15	16.9	18	17
11	16.4	18.3	19.2	18.1	14.7	13	13.3	13.7	15.3	16.9	18.3	17.2
12	15.8	18	19.3	18.8	15.5	13.6	14	14.4	15.5	16.7	17.9	16.4
13	15.4	17.8	19.1	19	15.9	13.9	14.5	14.6	15.5	16.6	17.6	15.5
14	15.2	17.6	18.6	18.6	15.7	13.7	14.5	14.4	15.4	16.6	17.4	15.1
15	14.9	17.6	18.2	18.1	15.3	13.3	14.1	14.1	15.3	16.6	17.3	14.9
16	14.2	17.4	17.9	17.7	14.9	12.9	13.6	13.8	15	16.3	16.6	14.5
17	12.9	16.6	17.3	17.3	14.5	12.9	13.4	13.5	14.5	15.3	15.2	13.2
18	12.1	14	15.9	16.3	14.1	12.7	13.3	13.1	13.6	13.7	13.1	11.5
19	10.1	13.5	15.5	15	13.4	12.4	13	12.7	12.5	13	12	10.7
20	8.3	11.2	13.9	14.9	12.6	11.9	12.5	13.2	12.3	11.3	10.4	9.4
21	7.3	9.7	12.9	14.1	13.3	12.7	13.4	12.5	11.5	10.1	9.5	8.5
22	6.9	9	12.1	13.6	13.1	12.8	13.5	11.9	10.9	9.5	8.9	7.9
23	6.7	8.6	11.6	13.3	13	12.9	13.4	11.6	10.6	9.2	8.5	7.5

HPF (VOACAP) (Baghdad – Van)												
Time	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sep.	Oct.	Nov.	Dec.
0	6.41	7.16	9.92	11.4	11.7	11.5	12.5	10.3	9.08	8.5	7.12	6.32
1	6.73	7.22	9.67	11	11.35	11	12.1	10	8.9	8.48	7.28	6.47
2	6.54	7.34	9.43	10.5	10.97	10.4	11.6	9.67	8.71	7.99	7.5	6.58
3	6.35	7.12	8.79	9.83	10.48	9.86	11	9.2	8.18	7.52	7.13	6.25
4	5.56	6.33	8.02	9.35	10.21	9.6	10.6	8.9	7.73	6.92	6.36	5.44
5	4.94	5.75	7.84	9.62	10.54	9.98	10.9	9.27	8.15	7.2	6.24	5.08
6	5.27	6.54	9.24	11.1	11.62	12.4	13.6	11.9	9.9	9.08	7.85	6.08
7	7.29	9.13	12.1	13	12.74	13.3	14.5	13.3	12.1	11.9	10.9	8.57
8	10.2	12.5	15.2	14.7	13.34	13.6	14.5	13.9	13.6	14.4	14.1	11.6
9	12.9	15	17.1	15.6	13.5	13.4	14.2	14	14.1	15.6	16.2	14
10	14.6	15.4	17.7	16	13.51	13.1	14.1	13.8	14.1	16.2	16.7	14.6
11	14.6	15.6	17.9	16.6	14.08	13.7	14.8	14.5	14.2	16.2	16.5	14.6
12	14.1	15.3	17.8	17.2	14.81	14.3	15.6	15.2	14.4	16	16.2	14
13	13.7	15.1	17.8	17.6	15.32	14.7	16.2	15.5	14.5	15.8	15.8	13.2
14	13.6	14.9	16.8	16.8	14.72	13.6	15.3	14.4	13.9	15	15.2	12.8
15	13.3	14.9	16.4	16.3	14.35	13.3	14.9	14.1	13.8	15.1	15.1	12.8
16	12.7	14.8	16.2	16	13.97	13	14.4	13.8	13.6	14.9	14.6	12.4
17	11.7	14.3	15.7	15.6	13.72	12.9	14.1	13.5	13.2	14	13.4	11.5
18	11.5	13.5	14.8	15.1	13.59	12.5	13.7	12.9	12.7	13.3	11.9	10.6
19	9.63	11.4	13.4	14	12.98	12.2	13.4	12.6	11.7	11.7	10.1	9.13
20	7.96	9.51	12.1	12.9	12.34	11.8	13	12.1	10.8	10.2	8.84	8.01
21	6.99	8.27	11.2	12.2	11.95	11.7	12.8	11.5	10.1	9.14	8.06	7.24
22	6.56	7.72	10.7	11.9	11.94	11.6	12.8	10.8	9.68	8.95	7.64	6.8
23	6.4	7.37	10.2	11.6	11.89	11.6	12.8	10.5	9.35	8.66	7.26	6.45

In this project an analytical study for the gathered theoretical dataset of the two parameters has been conducted to examine the probability of getting a mutual correlation between the HPF & OPMUF parameters.

In order to investigate the correlation between the selected parameters, the study has been made for two parts (periods of times). The first one was made for the **monthly** median values of the HPF and OPMUF parameters for the 24 hours of 12 months.

Figure (3): shows a sample of the scatter plot between the HPF & OPMUF values for the link (Baghdad-Tehran).

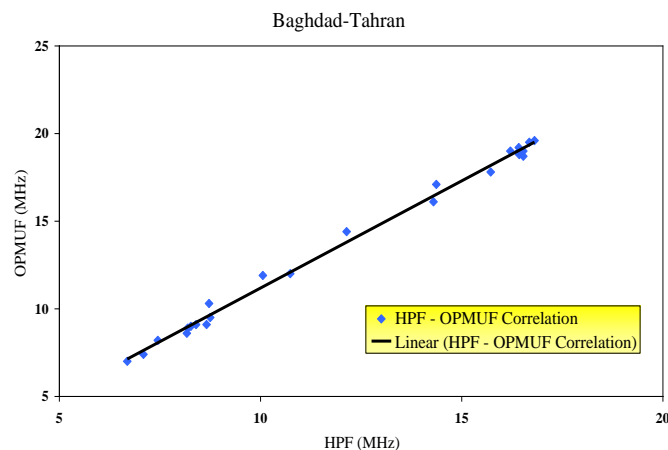


Fig. 3. Illustrates sample of monthly correlation between HPF& OPMUF.

The second part was made to investigate the correlation between the two parameters between Baghdad and other receiving stations for the **annual** variation of all months of the year 2000. Figure (4) presents sample of the annual correlation for the link (Baghdad - Ar'ar).

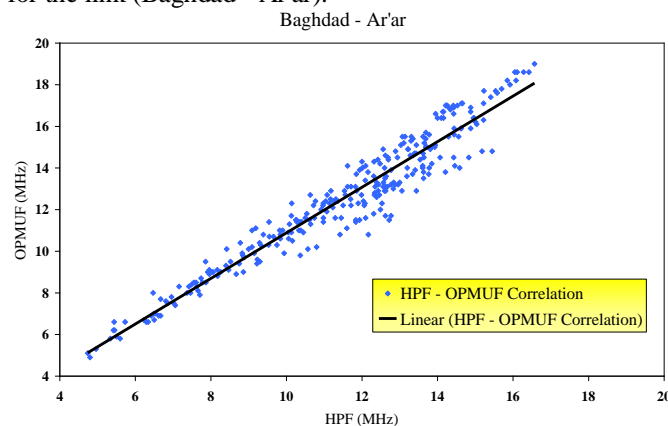


Fig. 4. Shows sample of the annual correlation between HPF & OPMUF.

It's clear from the scatter plot of the monthly and annual behavior tests between (HPF & OPMUF) parameters that shown in figures (3) & (4), the correlation is simple and can be expressed as a linear regression correlation, so the suggested mutual correlation equation between the studied parameters can be presented by the following simple equation:-

$$OPMUF = \sum_{n=0}^{n=1} a_n (HPF)^n$$

Table (4) show samples of the coefficient values ( $a_0$  &  $a_1$ ) that resulted from the analytical test of the monthly variation between the HPF and OPMUF parameters for 12 months and different links.

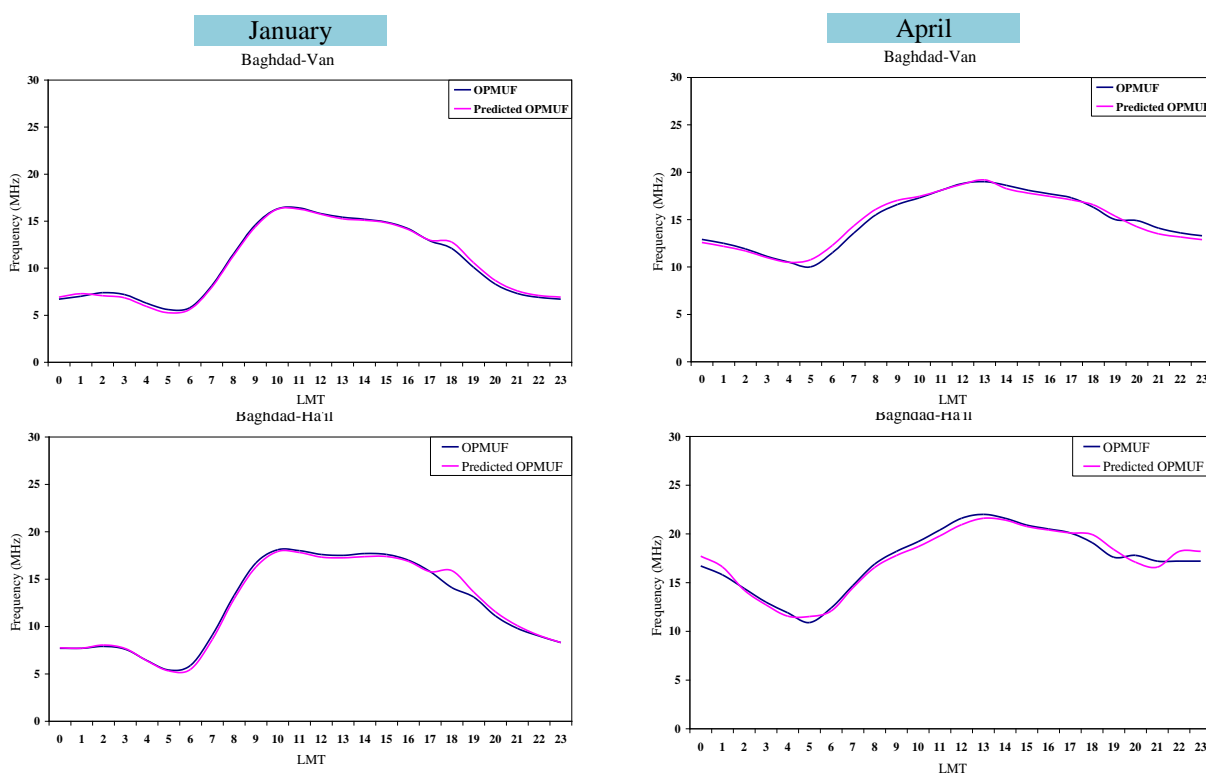
Table 4 Correlation coefficients for the monthly analytical test.

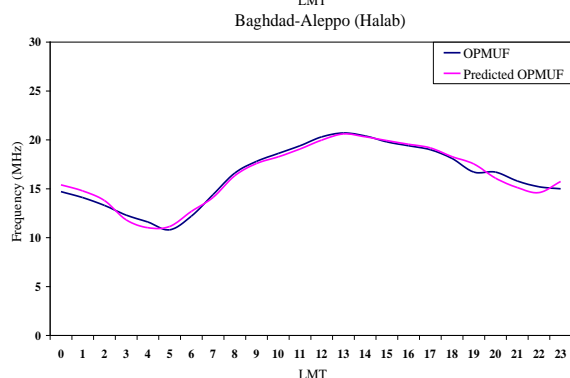
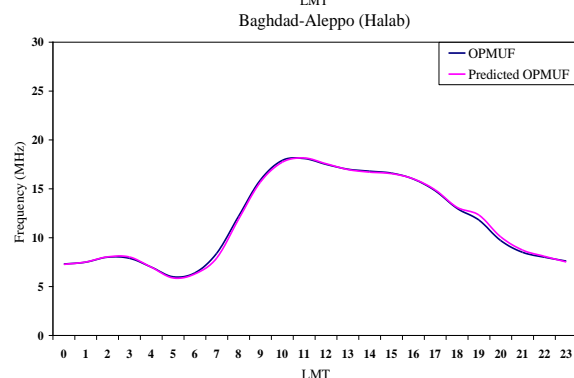
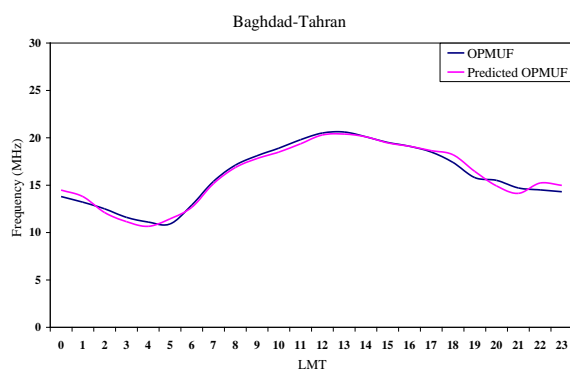
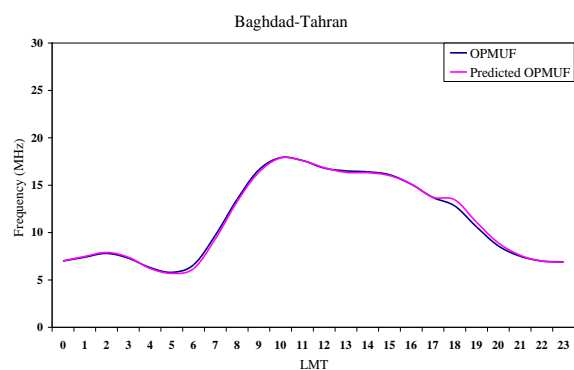
Baghdad-Van				
Month	$a_0$	$a_1$	$R^2$	MSE
Jan	- 0.3962	1.1417	0.9949	0.2
Feb	- 0.0471	1.1624	0.9907	
Mar	0.8349	1.0357	0.9879	
Apr	0.6696	1.0498	0.9766	
May	1.0017	0.9746	0.9305	
Jun	5.2328	0.5796	0.6365	
Jul	5.0213	0.5805	0.6142	
Aug	4.0047	0.6797	0.8395	
Sep	0.9789	1.0057	0.9826	
Oct	0.4478	1.0336	0.9907	
Nov	0.7379	1.0616	0.9944	
Dec	0.0142	1.1553	0.9954	

Baghdad- Aleppo (Halab)				
Month	$a_0$	$a_1$	$R^2$	MSE
Jan	- 1.0692	1.1437	0.9978	0.19
Feb	-1.1176	1.2217	0.9939	
Mar	-1.2348	1.1833	0.9898	
Apr	-2.1006	1.2383	0.9752	
May	-1.9623	1.1894	0.903	
Jun	2.9811	0.789	0.7638	
Jul	2.4007	0.7952	0.7588	
Aug	2.8833	0.7998	0.8851	
Sep	-1.4627	1.2061	0.9782	
Oct	-0.1433	1.0603	0.9901	
Nov	-0.7895	1.1991	0.9967	
Dec	-0.9311	1.2114	0.9938	

Baghdad- Tehran				
Month	$a_0$	$a_1$	$R^2$	MSE
Jan	0.8092	0.8815	0.9971	0.17
Feb	0.9131	0.8136	0.9949	
Mar	1.0532	0.8437	0.9881	
Apr	1.5192	0.8156	0.9776	
May	2.5331	0.7754	0.9245	
Jun	-0.9997	1.0619	0.7988	
Jul	-0.0973	1.0421	0.7726	
Aug	-2.0522	1.1405	0.9194	
Sep	1.2731	0.8235	0.9838	
Oct	0.3031	0.93	0.9953	
Nov	0.6852	0.8328	0.9358	
Dec	0.9709	0.808	0.9947	

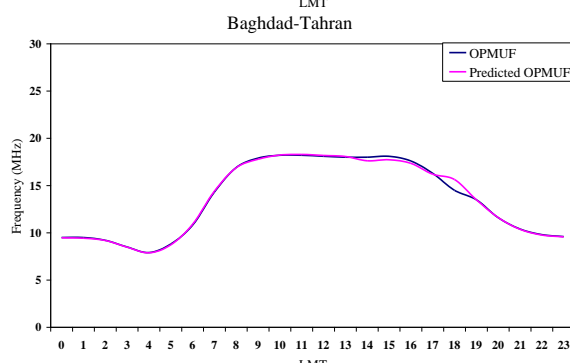
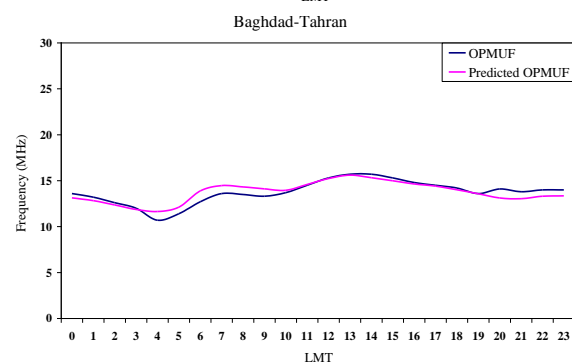
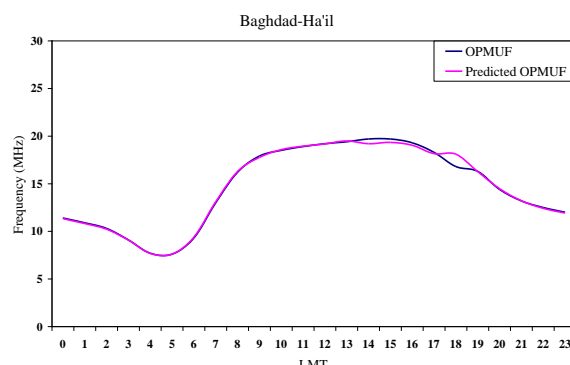
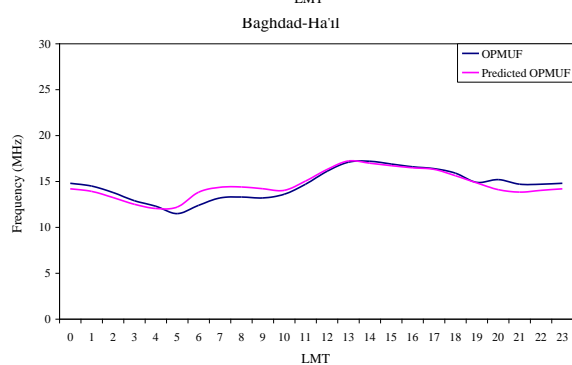
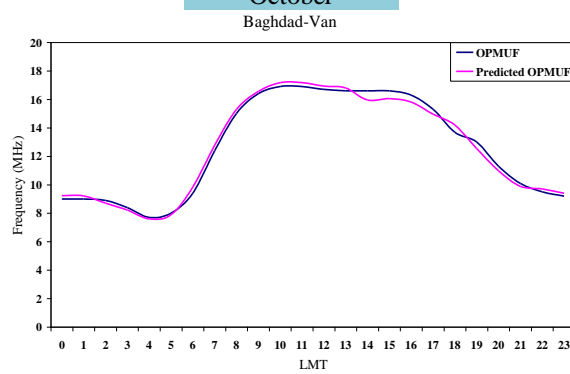
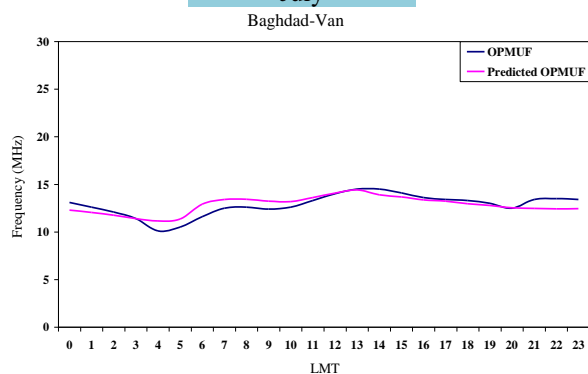
Samples of the predicted monthly values of the OPMUF parameter that have been calculated using the suggested formula (Predicted OPMUF) and the theoretical monthly values obtained from the execution of the international model (REC533) are presented in Figure (5) for different months and different sites.





July

October





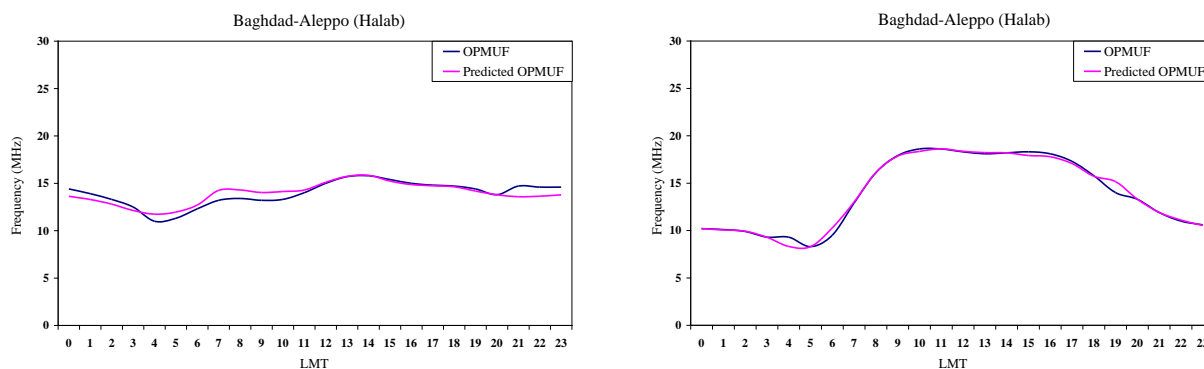


Fig. 5. Show samples of monthly theoretical & predicted OPMUF.

Table (5) shows the annual correlation coefficients for the mean value of the annual variation between the HPF & OPMUF parameters for the thirty five selected sites (receiving stations).

Table 5 Show annual correlated coefficients for the selected receiving locations.

Station Name	$a_0$	$a_1$	$R^2$
Al-Abilah	- 0.6865	1.1053	0.937
Al-Aqabah	- 0.8511	1.1106	0.9327
Aleppo (Halab)	- 0.5208	1.1058	0.9349
Al-Hazakah	- 0.1409	1.0946	0.933
Al-Jawf	- 0.2558	1.0976	0.9338
Al-Jufur	- 0.2793	1.1003	0.9295
Al-Qatif	- 0.7364	1.105	0.9373
Al-Raqqah	- 0.3329	1.1054	0.9339
Amman	- 0.6441	1.1083	0.9337
Ar'ar	- 0.0686	1.0948	0.9348
Ba'ar	- 0.6458	1.1114	0.9344
Buraydah	- 0.5496	1.1046	0.9389
Dayr Alzawr	- 0.0787	1.0927	0.9334
Demascuse	- 0.5647	1.107	0.9341
Diyarbakir	0.833	1.002	0.9195
Erzurum	0.7473	1.0033	0.9225
Ha'il	- 0.4437	1.1038	0.9377
Hamadan	- 0.061	1.0938	0.9349
Hamah	-0.5432	1.1077	0.9353
Isfahan	- 0.4176	1.1019	0.9402
Izmir	0.3301	1.0248	0.917
Karmanshah	0.1157	1.0803	0.9329
Kharma	- 0.6889	1.105	0.9361
Kuwait	- 0.3546	1.1044	0.94
Macca	- 1.6073	1.1295	0.934
Mahabad	1.0749	0.973	0.915
Malatya	0.8571	0.9956	0.9204
Masjed Sul.	- 0.1688	1.0973	0.9369
Riyadh	- 0.8865	1.1105	0.9402
Shiraz	- 0.6563	1.1051	0.9419
Tabriz	0.8955	0.9976	0.9218
Tabuk	- 0.8896	1.1164	0.9346
Tadmur	- 0.3625	1.1064	0.9337
Tehran	-0.4619	1.103	0.9412
Tayma'a	- 0.7875	1.1159	0.9364
Van	0.8903	0.9976	0.9217
Zanjan	0.9443	0.995	0.9221

Figure (6), show samples of the variation (fitting) between the calculated values of the annual predicted OPMUF that have been determined using the suggested formula and the annual theoretical OPMUF values that have been calculated using the REC533 international model.

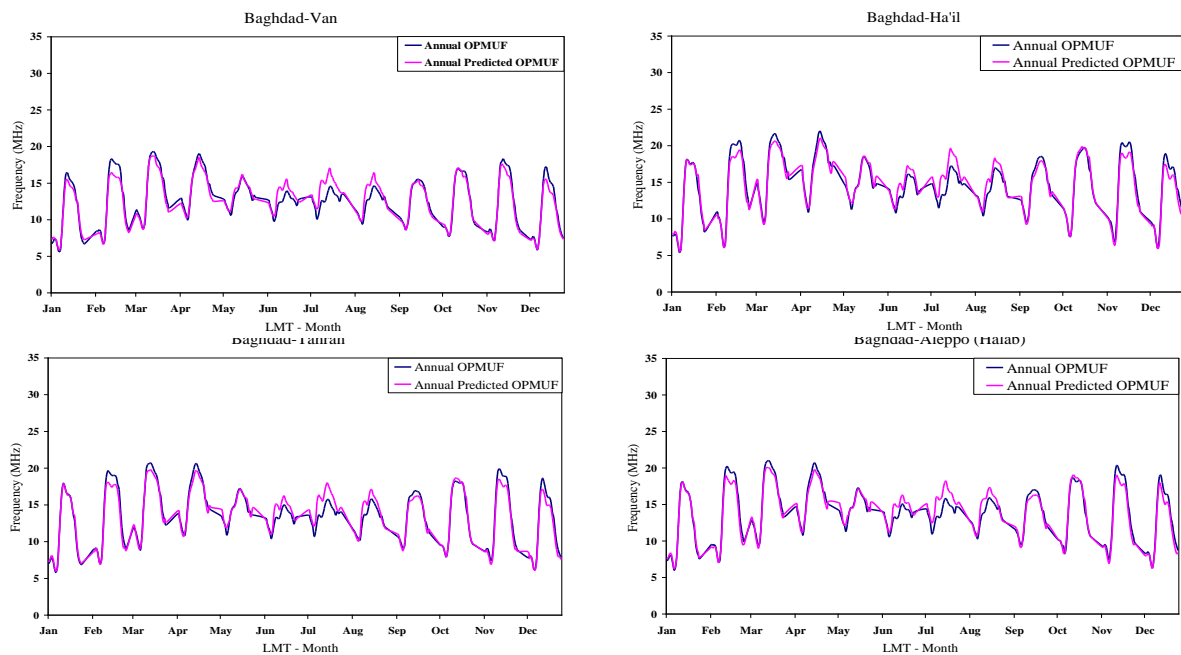


Fig. 6. Show samples of annual theoretical & predicted OPMUF.

## V. Discussion & Conclusions

It's obvious from the analytical study that have been made for the dataset of the HPF and OPMUF parameters that the two parameters have the same behavior and consequently the correlation relationship can be conducted between them. The monthly and annual tests of the correlation between the two parameters "figures (3) & (4)" show that the mutual correlation is simple and can be represented by a simple linear regression equation. The correlation coefficients that shown in tables (4), shows that the suggested equation can give a good fitting between the two parameters standing on the values of the ( $R^2$ ) and the MSE which were within the accepted range. Figure (5), shows a monthly variation of the correlation between the theoretical and predicted OPMUF values for the months (January, April, July, and October) for the link (Baghdad – Van). The shapes show a good fitting between the two curves for the months (Jan., April, and Oct.) and a little variant in (July) that may due to the high solar activity during the summer time. Figure (6), shows an annual variation of the correlation between the theoretical and predicted OPMUF. The presented figures show that the correlation between the two parameters is good, so it gives generally mean square error (MSE) equal to (0.9102). According to the above discussion, we can conclude the following:

1. The behavior of the two parameters is the same, so the relationship is simple and the mutual correlation can be conducted.
2. The analytical study has been made for monthly and annual tests, in order to investigate the accurate correlation between the two parameters for different months and different directions to cover the studied region.
3. The suggested equation was simple (simple regression equation) gave a good results comparing with the theoretical data obtained from the execution of the two latest modern HF international communications models.

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