Univ. Coll. Ann. Rev.
Vol 17 (1992).

SOLAR ACTIVITY -SUNSPOT NUMBER- EFFECT ON HIGH FREQUENCY ELECTROMAGNETIC WAVE PROPAGATION

A. M. SWIDAN
Faculty of Women, Ain Shams University
Heliopolis Cairo Egypt

SUMMARY

In this paper a brief description of the different types of the ionized layers, their altitude, density of free electrons is presented. The physical survey of the sun, its solar activity, sunspot cycle variations are mentioned. The propagation of the electromagnetic signal in the ionized atmosphere and maximum usable and critical frequencies are discussed. A global programme is prepared for selecting the optimum frequencies in order to propagate a high frequency electromagnetic wave (HF) and the various parameters which affect them. It is found that there are certain optimum frequencies are necessary which depend on solar activity, time, day, month and the propagated distance. It is to be noticed that during the next years (93-1998) we are in the falling period of the solar activity, i.e. bad high frequency propagation which needs more transmitter output power.

INTRODUCTION

Despite the spectacular development of satellite transmission, a large number of long-distance radio links still make use of the reflective properties of the ionosphere. The phenomenon of long-distance wave propagation by reflection is exploited both in telecommunications and short-wave radio broadcasting. In telecommunications these ionospheric links require only a simple, low cost infrastructure for transmissions with a low data transmission rate. They are widely used for communication with mobile receivers: aeroplanes, ships or land vehicles.

For short-wave radio (High Frequency electromagnetic wave), this type of propagation makes it possible to broadcast over extensive geographical areas and to a very large number of listeners, sometimes up to several thousand kilometers apart. It is an effective means to transmit undeformed and uncensored information rapidly and simultaneously to a very wide audience.

The effective use of ionospheric links is hampered by the very large variations in propagation conditions over time and space. Reliable forecasts must be established, based on a complete knowledge of the characteristics of the medium crossed and of the propagation laws. The ionosphere is the ionized region of the atmosphere situated in the area between 50 and 200 km above the Earth's surface. It is a zone comprised of neutral molecules, ionized molecules and free electrons, present in different proportions according to altitude. The main ionization sources are ultra-violet, X and particle radiation from the sun and meteor trails. These ionization processes are counterbalanced by opposing phenomena such as the recombination of negative and positive particles, the attachment of electrons to atoms or neutral molecules. The electron density in the upper atmosphere results from the equilibrium between these various processes.

Starting at ground level a certain number of layers can be defined according to their altitude and their density of free electrons per m^3.

D-Layer between 50 and 90 km: the electron density of the D-layer is low ($N=1$ to $2*10^9$ electrons per m^3) and varies considerably throughout the day. It reaches a maximum just after the local solar midday. After sunset, ionization falls rapidly and two to three hours later the layer can be considered transparent for HF. We thus have a D-layer which appears only in the daytime and which is characterized more by its absorbent than by its reflective effects. This absorption increases as the [illegible] energy loss) is due to shocks between the air molecules and the free electrons.

E-layer between 90 and 130 km: the maximum electron density in this region is at an altitude of around 110 km with $N=1$ to $2*10^{11}$ electrons per m^3. The ionization of the E-region is mainly photoelectric (Ultra-violet) so this layer is only significant in the daytime, with a maximum around midday. At night, ionization is low.

Sporadic E-layer: Over short periods (less than one hour) "clouds" of electrons in high concentrations may occur at an altitude corresponding to the normal E-layer. These clouds spread through the ionosphere via the poles and disappear before reaching the equator. Their electron density may be as high as 10^{12} . This layer becomes reflective for waves which cross through the normal E-layer. Though the layer's presence is irregular and unpredictable, reflection on the sporadic E-layer can be used with a 20 to 70 % probability of success to establish links of times of day, times of the year and in places where they would be impossible with the normal layers. The ionization of this irregular, patchy and generally thin layer appears to be caused by meteorites.

F-layer above 130 km : this is the ionospheric region most widely used for ionospheric links. In winter : (large zenithal angle) there is an F-layer with high electron density (10^{12} electrons per m^3). It is situated at an altitude of between 200 and 300 km. At night the electron concentration drops. In summer: by day the F-layer splits into two layers, a lower one called F1 and an upper one called F2 (the split occurs when the zenithal angle reaches around 45°). The F1-layer is due mainly to ultra-violet ionization. Its properties are similar to those of the F-layer (when the two layers are combined).

The ionization of the F2-layer is caused by ultra violet and particle radiation. The degree of ionization, between the day-night cycle, is related to solar activity (11 year cycle). Unlike F1, which has a stable electron density, F2 has two maxima (the first just before midday and the second just before sunset) and a very low minimum just before sunrise (dawn crevasse). F2 ionization is very high (10^{12} to 10^{13})

THE SUN AND ITS ACTIVITY

The Sun is classified by astronomers and is thought to be about 5 thousand million years old. The Sun is made up of roughly 75 percent Hydrogen and 25 percent Helium. Its diameter is about 1,400,000 km, and over 1 million planets the size of Earth could fit inside it. The distance between the Sun and the Earth is roughly 150 million km, and the light emitted from it takes just over 8 minutes to travel the distance. The Sun's surface gravity is known to be 27 times stronger than Earth's, and the Sun takes about 26 days to rotate at its equator, but its polar regions take around 33 days.

The Sun is a large thermonuclear reactor burning away in the sky. Current models of it say that it is made up of 3 regions: the core, where the temperature is thought to be about 15 million degrees celsius, and is where the thermonuclear reaction takes place; the radiative zone, where the temperature slowly decreases down to about 1 million degrees celsius. X- ray and gamma radiation from the core is carried through this region out to the Sun's outer layer, the convection zone. This zone is thought to range from a million to 6 thousand degrees celsius, and is a very turbulent region.

The photosphere is the lowest layer that we can see, and it is a very turbulent region which is thought to be 500 km deep, with a temperature of around 6 thousand degrees celsius. The photosphere appears to have a boiling granular structure, and each grain is typically 1000 km in diameter. Sunspots are formed in the photosphere. They are cooler regions that are caused by stronger magnetic fields breaking through the surface. A typical spot has a dark centre called the umbra, surrounded by a lighter region called the penumbra. Sunspots also usually appear in groups, and the boundary between them and the photosphere is quite irregular in shape.

The Sun's lower atmosphere is called the chromosphere, and is about 3,000 km. deep, with a temperature of approximately 4,300 degrees celsius. The chromosphere can be seen as a red ring around the Sun just before and after totality during a solar eclipse.

In this region irregular bright areas appear called plage. (Plage is the french word for beach). Sunspots are always accompanied by surrounding plage areas, however plage regions can occur without sunspots. Plage regions are where solar flares erupt from, which in turn can cause a short wave fadeout or a geomagnetic storm.

THE SUNSPOT-CYCLE VARIATIONS IN HIGH FREQUENCY (SHORT-WAVE) SIGNAL STRENGTH

Astronomers have observed that solar activity varies periodically. Variations in solar activity manifest themselves in the varying number and size of sunspots, faculae (sometimes called torches), prominences, and flocculi, and changes in the intensity of solar radio emissions. It is customary to evaluate solar activity in terms of the sunspot (Wolf) number.

The manner in which the sunspot number varies can be visualized from Fig.(1) which shows changes in the sunspot number between the years 1750 and 1964. During the intervening period, the minimum sunspot number was 0.0 (in 1810), and the maximum number was 190.2 (in 1957). The shape of the curve bears out that solar activity is not a strictly repetitive process. Yet, in the two hundred years covered by the plot, solar activity had an average period of about 11.3 years with a deviation of plus or minus four years from this average.

Variations in solar activity are accompanied by changes in the strength of the short ultra-violet radiation (shorter than 2200 Angstrom units), X-ray, radio emission, and corpuscular streams, that is, in the types of radiation that are completely absorbed by the upper atmosphere and have no chance of reaching the earth's surface.

An increase in solar activity raises the electron density in all layers of the ionosphere. This rise is most pronounced in the outer reaches of the atmosphere, that is, the F2 layer, and is least noticeable in the E region. Reliable data on the D region are lacking .

Measurements had been done in the period between 1933 and 1937 when the sunspot number varied between 5.9 and 114.4, Fig.(1). The measurements showed that the higher frequencies experience a lower attenuation in the D and E regions, therefore the advisability of using higher frequencies is obvious. This means that during the incidence of increased solar activity the "night-time","twilight" and "day-time" frequency bands should be shifted in the direction of higher frequencies. There is also an overall improvement in short-wave propagation owing to a greater ionization of the upper atmosphere.

MAXIMUM USABLE AND CRITICAL FREQUENCIES

The propagation of the electromagnetic waves (radio waves) in the ionized atmosphere, follow curved paths because this ionized atmosphere is inhomogeneous. Given certain conditions, these waves can be fully reflected from the ionosphere and come back to the Earth. If the maximum electron density, for the ionized layer at given hight h, Fig.(2), is fixed, the ray can be made to return to Earth by suitably arranging its angle of incidence to the ionosphere.

Because of the spherical Earth, there is an upper limit to the angle of incidence that can be used. As follows from Fig.(2), even for a ray tangent to Earth's surface (at point A) the maximum angle of incidence is given by:

$$\sin \varphi_{0\,max} = a/(a+h) \qquad (1)$$

Because of this limit, not all radio waves can be reflected from the ionosphere - some will pass through it under certain conditions. Referring to Fig.(3), the relationship between the angle of elevation β , the electron density N, the ionosphere height h and the maximum usable frequency is as follows:

$$F_{max} = \sqrt{\frac{80.8\ N(1+2h/a)}{\sin^2\beta + 2h/a}} \quad Hz \qquad (2)$$

a is the Earth radius ($a=6.37\times10^6$ m)

N is the electron density in cubic meter.

From Eqn.(2), for fixed angle of elevation, β, a greater electron density is required to reflect a higher frequency. For fixed electron density, a smaller elevation angle allows higher frequency for reflection. When the elevation angle is zero, the maximum usable frequency will be maximum (horizontal radiation):

$$F_{max\,0} = \sqrt{\frac{80.8\ N(a+2h)}{2h}} \quad Hz \qquad (3)$$

when the elevation angle is 90^o , i.e. for a ray radiated vertically upwards:

$$F_{max} = F_c = \sqrt{80.8\ N} \quad Hz \qquad (4)$$

where F_c is the critical frequency. This is a maximum frequency for which a wave radiated vertically upwards can be returned to Earth by the ionosphere. From Eqns.(3 & 4), it follows that the maximum usable frequency is $\sqrt{(a+2h)/2h}$ times the critical frequency. At h = 200 km the ratio of max. frequency to critical frequency is 4.1. From Eqn. (2) it follows that a wave will be reflected if and only if the frequency of the wave does not exceed the maximum frequency. Otherwise, the wave will pass through the ionosphere.

CALCULATIONS AND RESULTS

In order to transmit a programme carried by an electromagnetic short wave from certain point to certain area, it is important to search for an optimum frequency in the short wave band (3-30 MHZ) for this transmission. This optimum frequency depends on many factors: transmitting and receiving coordinates, month, day, time and the sunspot values. A global programme is prepared for selecting the optimum frequencies as discussed above. Four months (January, April, July and October), are chosen to cover the four seasons. Three different sunspot numbers are used in the calculations (namely 10, 100 , and 160) as a low, medium , and high values. The optimum frequencies are checked at different distances 250, 500, 1000, 2000, and 3000 km. The broadcasting transmitter is supposed to be in Cairo and the direction of transmission in the east direction towards the Gulf and Asian countries.

The curves in Fig.(4) are the results of these calculations. As noticed from these curves that the time is in GMT (Grinech Mean Time)is laid off along the X-axis, as abscissa. Cairo local time is GMT + 2 hours. The frequency is laid off as ordinate. From Fig.(4) the following phenomena are noticed:

1. The optimum usable frequency, which secures the least attenuation for radio waves in the ionosphere, increases as the sunspot number increases. Also the rate of increasing is proportional to the propagated distance. As mentioned before, the higher frequencies experience a lower attenuation, therefore during the incidence of increased solor activity, the frequency bands should be shifted in the direction of higher frequencies. In this case, there is an overall improvement in short-wave propagation owing to a greater ionization of the upper atmosphere.
2. The maximum optimum usable frequencies increase as the sunspot number increases and also increase by increasing the propagated distance, Figs.(5 & 6).
3. Generally the optimum usable frequency is low at night and rises to the maximum values at noon as shown in Fig.(4). This phenomenon is redrawn in Fig.(7) which shows that the values of optimum frequencies at times 6,10,12 GMT (daytime) is very high as compared to times 18,0 GMT (nighttime).
4. The maximum optimum usable frequency varies according to the season. During autumn and winter, this maximum is at times 9 and 10 GMT. During spring and summer the maximum is shifted to about time 14 GMT, Fig.(7).

CONCLUSION

It is concluded that it is better to use higher frequencies, in the short wave band (HF), because the higher frequencies experience a lower attenuation. Increasing the solar activity, there will be possibility to shift the HF frequency bands in the direction of higher frequencies, which means better propagation. Also it is noticed that for long propagation distances, the optimum frequency is high as compared to the short distances.

The optumum frequency used during daytime is high than the one used during the nighttime.

Since we are in the falling cycle (93 to 1998), with respect to the solar activity, we are expecting to have, in general, a lower received signal to noise ratio as compared with the last four years. Therefore it is important to use a higher transmitter output power and higher antenna gain.

REFERENCES

1. Swidan A. M.," Medium Wave Propagation in Middle East ", International Union Of Radio Science, ISSSE 92, Paris, 1992.
2. Dolukhanov M. , "Propagation of Radio waves", Mir Publishers, Moscow, 1971.
3. CCIR, " Statistical Distribution in Radio Wave Propagation", Report AA/5 (MOD F), 1986.
4. CCIR, "Ionospheric Properties", Propagation in Ionized Media, Vol. VI, Report 725, 1990.
5. Hanbaba R.," Les Previsions de Propagation Ionospherique des Ondes Radioelectriques",Centre National d'Etudes des Telecommunications CNET, 1988.
6. [illegible] Radioelectriques dans L'Environnement Terrestre", Centre National d'Etudes des Telecommunications CNET, 1990.
7. National Telecommunication and Information Administration Institute for Telecommunication Sciences, " Estimating the Performance of Telecommunication Systems Using the Ionospheric Transmission Channel - Ionospheric Communications Analysis", 1978.
8. TCI, " Broadcast Antennas, LF to HF Bands, Powers to 500 KW Communications Antennas, Fixed and Tactical", Technology for Communications International, 1987.
9. CCIR, " Propagation in Ionized Media", Recommendations and Reports of the CCIR, Volume VI, 1986.
10. EBU, " EBU Guiding Principles for WARC-92 regarding High Frequency Broadcasting", European Broadcasting Union", 1992.

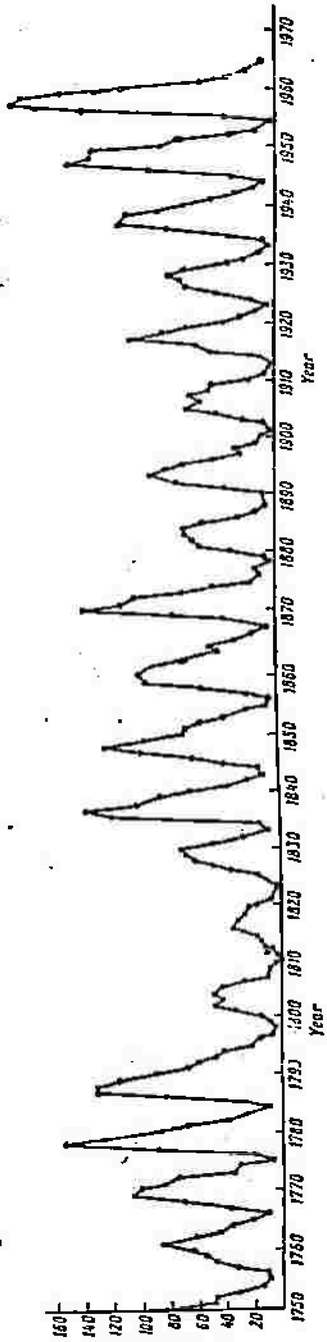

Fig. (1). Variations in the relative sunspot number between 1750 and 1964.

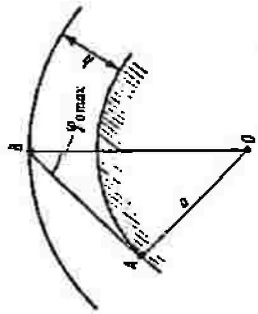

Fig. (2) Maximum angle of incidence at the entrance to the ionosphere

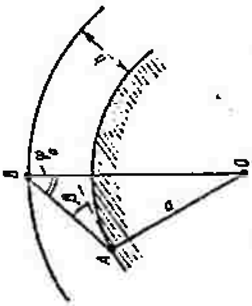

Fig. (3) Relationship between angles of elevation and incidence

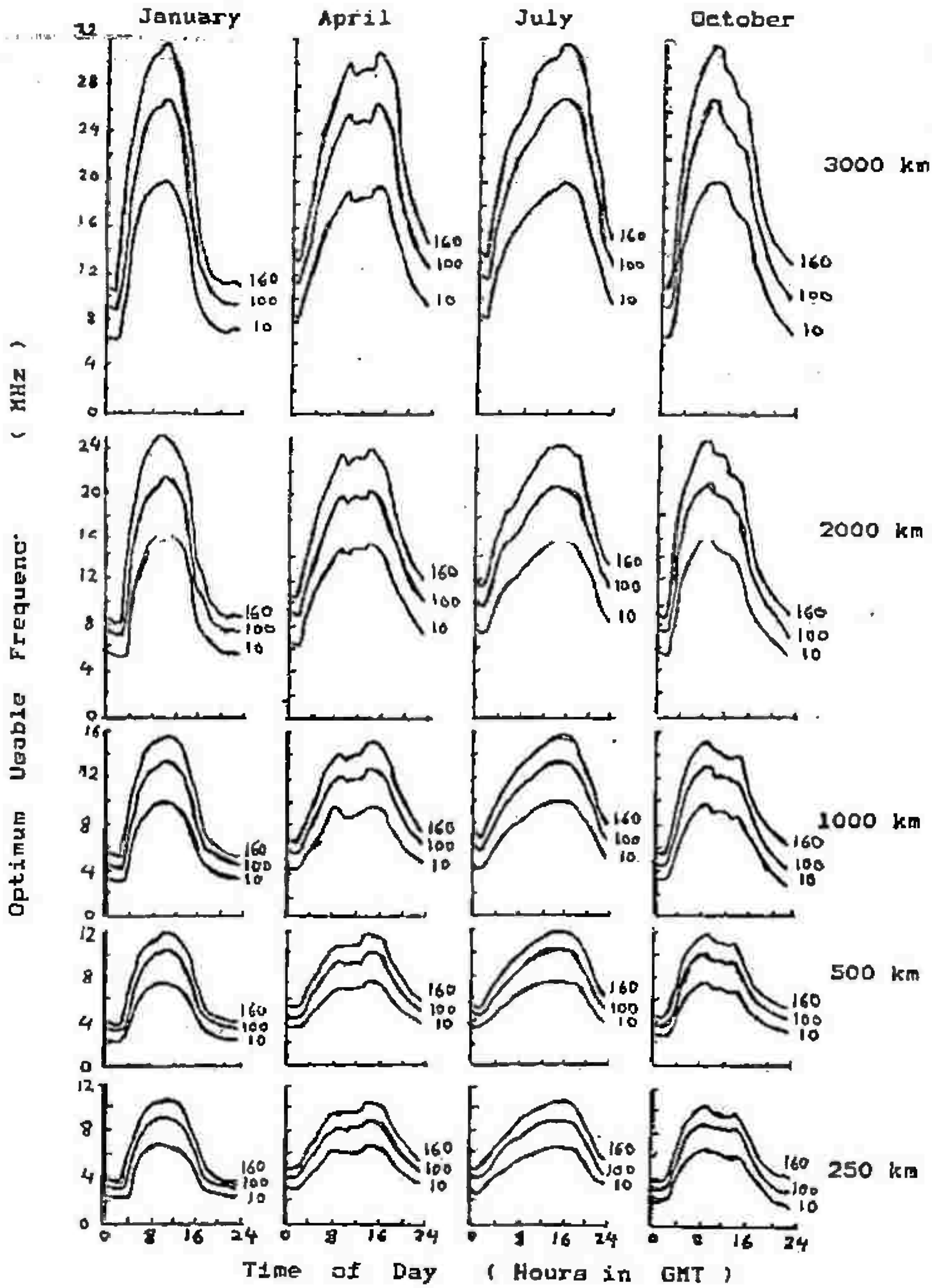

Fig. (4) Daily Optimum Usable Frequency for Sunspot Numbers 10, 100, and 160 at Distances 250, 500, 1000, 2000, and 3000 km in the Four Seasons.

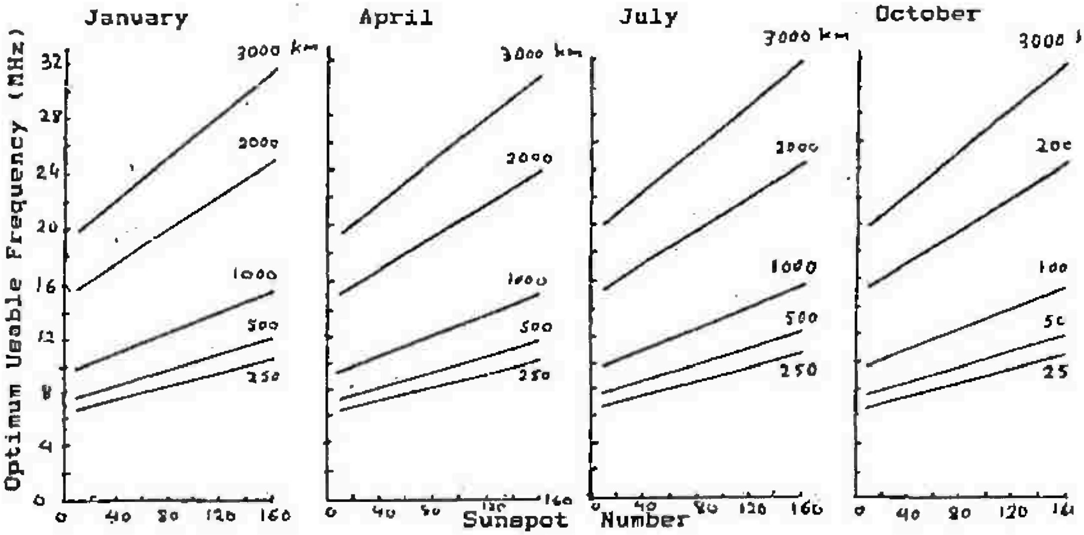

Fig.(5) Maximum Optimum Usable Frequency against Sunspot Numbers at Distances 250, 500, 1000, 2000, and 3000 km in the Four Seasons.

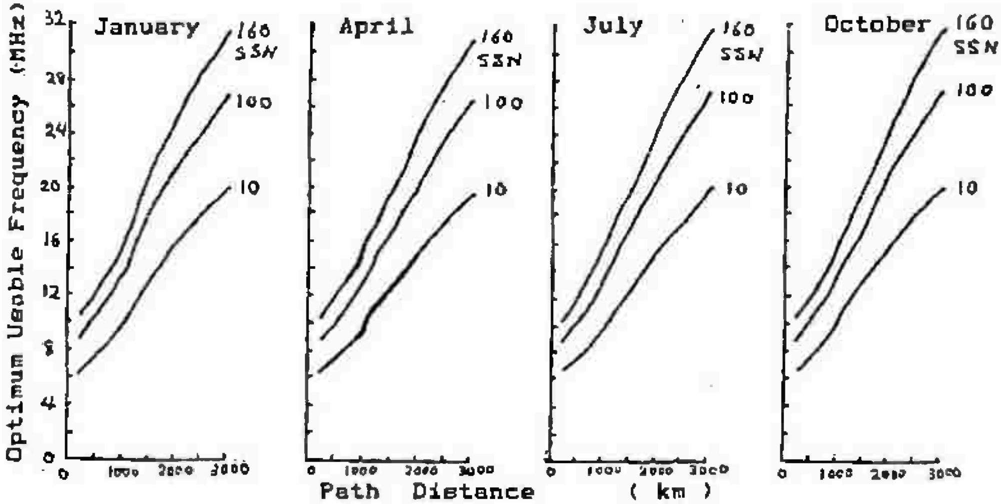

Fig.(6) Maximum Optimum Usable Frequency against Path Distances at Sunspot Numbers 10, 100, and 160 in the Four Seasons.

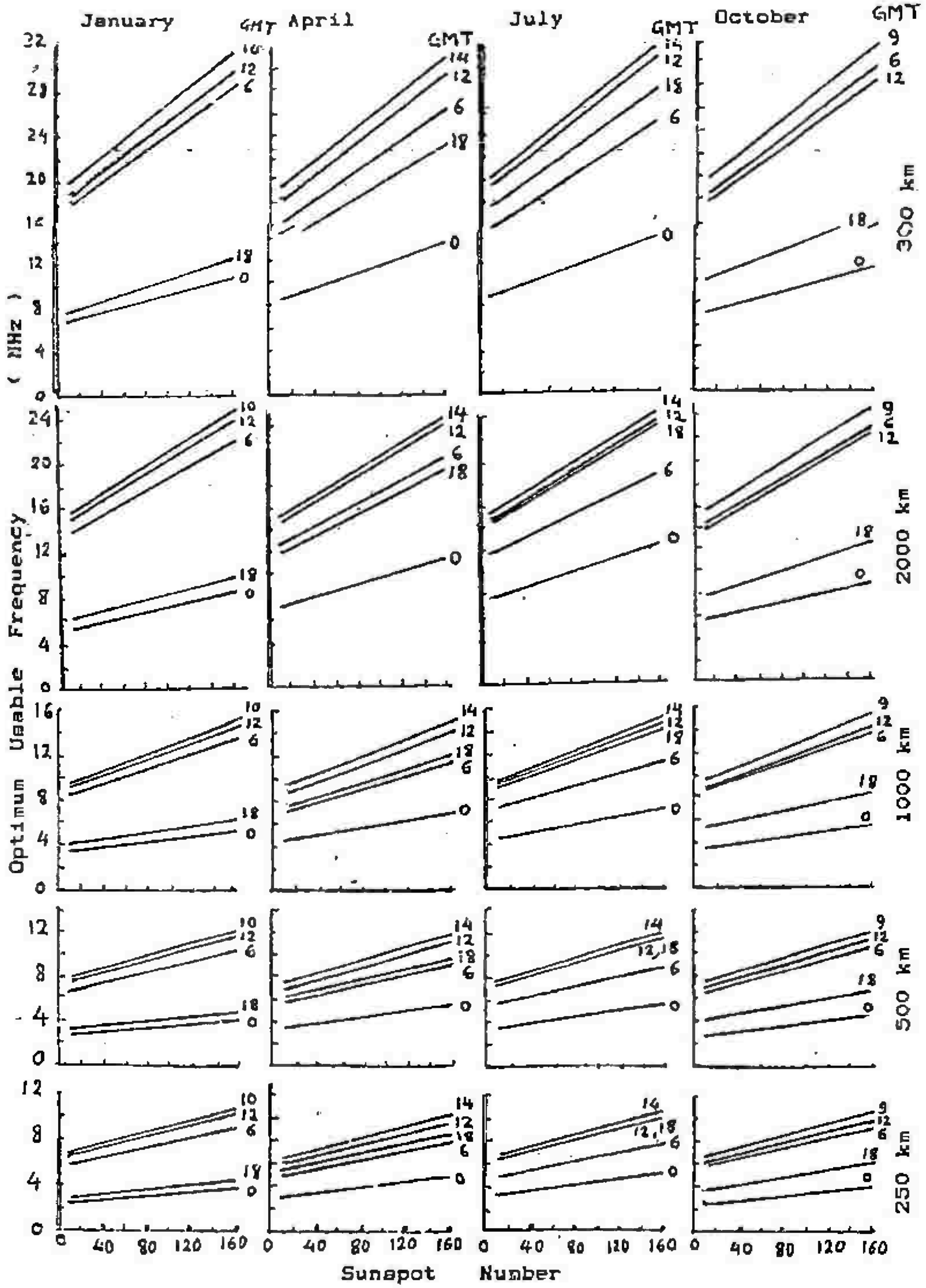

Fig.(7) Optimum Usable Frequency against Sunspot Numbers for Distances 250, 500, 1000, 2000, and 3000 km at different day hours in the Four Seasons.

Univ. Coll. Ann. Rev.
Vol 17 (1992).

تأثير النشاط الشمسى (البقع الشمسية) على انتشار الموجات الكهرومغناطيسية عالية التردد

على الرغم من التقدم الكبير فى مجال الاقمار الصناعية واستخداماتها فى الاتصالات ونقل المعلومات والابحاث الفضائية والطبيعية الا أنه مازالت الطبقات العليا المتأينة تمثل الوسيلة الفعالة والمنتشرة فى هذه المجالات، وتعتبر من حيث التكاليف المالية والإنشائية أرخص بكثير من الأقمار الصناعية.

وان الكثافة الالكترونية لهذه الطبقات المتأينة تتأثر بصورة مباشرة وفعالة بالنشاط الشمسى (البقع الشمسية والشهب والنيازك). وما ينشأ عنه من أشعة فوق بنفسجية وجسيمات مشعة وأشعة سينيه (إكس).

ويعتقد الفلكيون أن عمر الشمس يقدر بحوالى ٥٠٠٠ مليون سنة وتتكون من الهيدروجين والهليوم بنسبة ٣ : ١ ويعتبر حجم الشمس ضعف حجم الأرض مليون مرة وتكون بمثابة مفاعل نووى حرارى يحترق فى الفضاء وتنقسم الشمس إلى ثلاث طبقات وتعتبر الطبقة الخارجية منطقة غير مستقرة تصل درجة حرارتها إلى ٦٠٠٠ درجة مئوية وهى فى غليان مستمر وذات مجالات مغناطيسية فائقة ، وتتكون على هذه الطبقة الخارجية للشمس البقع الشمسية وهى عبارة عن بقع مظلمة محاطة بمنطقة مضيئة حيث تتجمع فى مجموعات متباعدة بطرق غير منتظمه وهذا ما يسمى بالنشاط الشمسى وعدد هذه البقع الشمسية وحجمها يتغير تغيرا دوريا حيث لوحظ أن هذه الدورة تتكرر كل ١١,٣ سنة حيث يمكن ان يزداد عددها حتى يصل إلى ١٩٠ ويقل إلى أن تتلاشى تماما.

وهذا النشاط الشمسى وما ينشأ عنه من أشعة فوق بنفسجية وأشعة سينية – كما ذكر – يؤثر فى كثافة الالكترونات فى الطبقات المتأينة وهذه الطبقات تقوم بعكس الموجات الكهرومغناطيسية عالية التردد (قصيرة الطول الموجى) الساقطة عليها من أجهزة الارسال الارضية فتعكسها إلى اماكن بعيدة على الكرة الارضية تقاس بالآف الكيلو مترات بحيث يمكن استقبال المعلومات المحمله على هذه الموجات خلال أجهزة الاستقبال . وتؤثر الكثافة الالكترونية للطبقات المتأينة والتى تتناسب طرديا مع عدد البقع الشمسية على فاعلية انعكاس الموجات الكهرومغناطيسية بحيث تزداد قوة انتشارها مع زيادة الكثافة الالكترونية. وهذه الطبقات المتأينة تحتوى على جزئيات متعادلة وايونات والكترونات حرة بنسب مختلفة حسب بعدها عن سطح الارض وفى هذه الطبقات يحدث تفاعلات عكسية وهى اتحاد الجسيمات السالبة والموجبة الشحنة واندماج الالكترونات مع الذرات والجزيئات،وعليه تتحدد الكثافة الالكترونية لهذه الطبقات نتيجة للإتزان بين هذه التفاعلات المختلفة، ولذلك نجد أن الكثافة الالكترونية لهذه الطبقات المتأينة تتغير بتغير فصول السنة وتتابع الليل والنهار وذلك بسبب تغير عدد البقع الشمسية.

ولإرسال معلومات معينة يتم توجيه الاشارات الكهرومغناطيسية الحاملة لهذه المعلومات من خلال هوائيات ومحطات ارسال ارضية فى اتجاه الطبقات المتأينة فتخترق الطبقات القريبة من الارض ذات الكثافة الالكترونية المنخفضة إلى ان تصل إلى الطبقات الاعلى ذات الكثافة الالكترونية الاكثر فتنعكس عندها انعكاسا كليا فى الاتجاه المحدد طبقا لزاوية السقوط.

ومن المعروف ان الطبقات السفلى تقاوم هذه الاشارات قبل وصولها للطبقات العاكسة مما يقلل من فاعلية انتشارها ووصولها إلى المكان المحدد ، وتزداد مقاومة هذه الطبقات مع زيادة الطول الموجى لهذه الاشارات، ولذا يفضل ان تستخدم الموجات ذات الطول الموجى القصير حتى تقل هذه المقاومة لتصل الاشارة بالقوة اللازمة

لإستقبالها. ويجب التأكد أنه اذا استخدمت موجات ذات طول موجى قصير إلى حد معين يتم اختراقها تماما لجميع الطبقات المتأينة ولاتنعكس إلى الارض.

وفى هذا البحث تم اعداد جميع البيانات والمنحنيات الخاصة بالتكوينات الفيزيائية والنشاط الشمسى والمعادلات الخاصة بالانتشار فى مجال الترددات العالية والتى تغطى جميع خطوط الطول والعرض المنتشرة على الكرة الارضية وزوايا الميل الشمسية فى الاماكن والاوقات المختلفة وعلى مدى الاثنى عشر شهرا.

وقد تم تخزين هذه المعلومات وقيم البيانات والمنحنيات فى حاسب آلى حيث تم تصميم برنامج شامل لدراسة انسب المتغيرات التى تؤثر على انتشار الموجات الكهرومغناطيسية عالية التردد والتى تنتشر من خلال انعكاساتها عبر طبقات الجو المتأينة، وذلك لإختيار التردد الامثل المستخدم فى الارسال الذى يعانى أقل مقاومة ممكنة اثناء عبورة خلال الطبقات المتأينة.

وقد شمل هذا البحث تأثير العناصر الطبيعية التالية على فاعلية الانتشار:

- عدد البقع الشمسية - تعاقب الليل والنهار والايام والشهور.
- تغير فصول السنة - مقدار مسافة الانتشار

وقد تم اختيار ثلاث قيم لعدد البقع الشمسية ١٠، ١٠٠، ١٦٠ وكذا اختيار الشهور التى تمثل الفصول الاربعة وهى يناير، ابريل، يونيه، اكتوبر وحددت المسافات التالية ٢٥٠، ٥٠٠، ١٠٠٠، ٢٠٠٠، ٣٠٠٠ كيلو مترا.

وقد اظهرت نتائج هذه الدراسة عن منحنيات كثيرة تتمثل فى العلاقات بين التردد الامثل الذى يفضل استخدامه فى ساعات محدده خلال الـ ٢٤ ساعة فى كل شهر من الاشهر السابق ذكرها عند القيم المختارة للبقع الشمسية وتكرار ذلك عند المسافات المحدده.

وقد استخلص من هذه المنحنيات النتائج الهامة التالية حيث توجد محطة ارسال التردد العالى بالقاهرة واتجاه الانتشار نحو دول الخليج العربى وشرق آسيا :

- يتناسب التردد الامثل المستخدم - والذى يعانى أقل مقاومة اثناء الانتشار - تناسبا طرديا مع عدد البقع الشمسية.
- يتناسب التردد الامثل ايضا مع مقدار مسافة الانتشار.
- تتناسب القيمة العظمى للتردد الامثل تناسبا طرديا مع عدد البقع الشمسية ومع مقدار مسافة الانتشار.
- بصفة عامة وجد ان التردد الامثل ذات قيمة منخفضة اثناء الليل مقارنة بالنهار وخاصة اثناء الظهيرة.
- تتغير القيمة العظمى للتردد الامثل بتغير فصول السنة فمثلا تتزامن القيمة العظمى فى فصلى الخريف والشتاء الساعة التاسعة والعاشرة بتوقيت جرينتش فى حين أن ذلك يحدث الساعة الرابعة عشر من فصلى الربيع والصيف علما بان التوقيت المحلى بالقاهرة يسبق توقيت جرينتش بساعتين.
- التنبؤ بانه خلال السنوات القادمة من ٩٣ - ١٩٩٨ سيكون النشاط الشمسى فى أقل قيمة مما يقلل من الكثافة الالكترونية للطبقات المتأينة طبقا لشكل رقم (١) وبالتالى تزداد مقاومة هذه الطبقات لانتشار الموجات الكهرومغناطيسية عالية التردد مما يؤكد من ضرورة زيادة قدرات اجهزة الارسال ذات التردد العالى ليتسنى استقبال هذه الموجات بوضوح.