HF spectral occupancy over the eastern Mediterranean

Haris Haralambous, Md Golam Mostafa

Department of Electrical Engineering, Frederick University,
7 Filokyprou St, Palouriotissa, Nicosia, 1036, Cyprus

ABSTRACT

A dedicated measurement system has been operating in Cyprus for more than two years facilitating the effective measurement and analysis of HF spectral occupancy over the eastern Mediterranean. The ultimate aim of these systematic measurements is to compile an adequate dataset that will enable an investigation into the parameters that define the variability of HF spectral occupancy. In this paper aspects of the diurnal, seasonal and annual variability of HF spectral occupancy within the individual frequency bands allocated by the ITU to separate radio services during the maximum phase of the current solar cycle are presented.

1. INTRODUCTION

The HF channel is characterized by diurnal, seasonal and long-term variability in addition to unpredictable behaviour due to space weather effects (e.g. solar flares and geomagnetic storms), which at times reduce the useful frequency range of the HF spectrum. Furthermore, it is subjected to ionospheric phenomena causing a variety of propagation impairments such as multipath, Doppler spread and deep fading. However the most important limitation is interference from other users which reduces the usable frequency spectrum particularly at night due to lack of ionospheric propagation support at higher HF frequencies. Under such circumstances, it is important to find portions in the frequency band with an acceptable interference level as the utilization of the HF spectrum on a global basis results in spectral congestion. Therefore, the measurement, analysis, modelling and prediction of HF spectral occupancy is very important in order to efficiently use the HF spectrum for successful communications.

2. HF SPECTRAL OCCUPANCY STUDIES

Many researchers have sought to characterise the HF spectrum. Past researchers (Spaulding and Hagn, 1977; Stehle and Hagn, 1991) proposed an early definition of occupancy and has made occupancy observations at HF. Other studies reported in (Goutelard et al., 1991; Lemmon et al., 1989; Gott et al., 1997) HF spectral occupancy measurements in Europe since 1982, and given examples of models for the allocation congestion.

The systematic investigation of spectral occupancy over northern Europe started in at UMIST in 1981 and involved only solstice measurements (Dutta et al., 1982). The project gradually expanded to include Baldock (UK), Linkoping (Sweden), Munich (Germany), Kiruna (Sweden). This has resulted in an extensive database of spectral occupancy measurements made at four sites over a complete sunspot cycle which were reported in a number of papers (Economou et al., 2005; Haralambous et al., 2009) and mathematical models for spectral occupancy have been developed. The UMIST work on HF occupancy began with an investigation of aeromobile channels. Subsequently, the occupancy measurements were extended, first to fixed and mobile channels, and then to the entire HF spectrum. Work at this time included the establishment of an appropriate definition of occupancy, and experimental and theoretical investigations into the correlation of occupancy with range.

To the best of our knowledge, an in-depth study of HF channel occupancy and interference for the Eastern Mediterranean region has not been performed so far. Recently, a dedicated measurement system has been established to provide effective measurement and analysis of HF spectral occupancy in Cyprus (Haralambous et al., 2009). The system is capable of systematic measurement of occupancy over the HF spectrum systematically on an hourly basis. A substantial amount of occupancy data has been accumulated since 2012, which is available for analysis and modelling the HF spectral occupancy over Cyprus and eastern Mediterranean region.

3. MEASUREMENT SYSTEM AND OCCUPANCY CALCULATION

In the case of Cyprus the occupancy measurement of the HF spectrum has been conducted systematically during the last two years of system operation on an hourly basis. Since the interference characteristics differ significantly between ITU defined user allocations it is important that occupancy is evaluated for specific user type frequency allocations rather than for arbitrary frequency ranges. This is because different user types employ different transmission powers, bandwidths, modulation schemes and operating procedures.

In principle the measurement procedure that was adopted was similar to that applied by other systems in the past (Gott et al., 1982). A typical monitoring routine involved the measurement of occupancy across all ITU defined frequency allocations at the same specific field strength threshold levels, within a period of an hour. The rms signal output of the resolution filter during the measurement interval was recorded and stored for further processing. The occupancy for each allocation was calculated as the percentage of 1 kHz channels within the allocation for which the rms signal level exceeded a certain threshold level and was determined by offline processing (Figure 1). The number of channels evaluated was in accordance to the width of the allocation, a fact which did not significantly affect the calculation of occupancy. A value of zero represents an empty band and a value of one a fully congested band at that particular threshold level. This defines the congestion Q for that allocation, for the corresponding threshold level. A single congestion value represents an ITU frequency user allocation occupancy; thus the same congestion level will apply to contiguous 1 kHz channels within an allocation. The decision thresholds were selected such that the probability of a noise sample exceeding the specified threshold was kept low. The vertical polarization of the R&S HE016 antenna element was connected to the antenna input of the R&S EM510 digital wideband receiver and occupancy across each ITU defined frequency allocation was measured for signals received at low elevation angles. The measurement receiver was operated with an appropriate receiver measurement interval (100 ms) so that the whole HF band can be monitored in less than an hour.

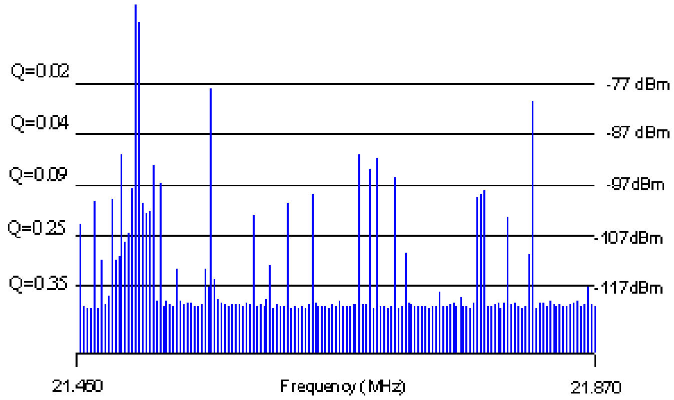

Figure 1. Congestion measurement within an ITU allocation.

4. OCCUPANCY CHARACTERISTICS

The diurnal variation of the upper and lower limit of the available frequency window over which ionospheric propagation is supported determine the HF spectrum usage. As demonstrated in the diurnal profile of the HF spectrum occupancy (at a threshold of 20dBμV/m) in Figure 2 the behaviour is very similar for the three consecutive days in question. Around noon, the available window of operating frequencies is in the middle of the HF spectrum, whereas at night it shifts to the lower portion of the spectrum. This is due to the lack of ionospheric propagation support at higher frequencies which limits the number of potential users that can operate. The high congestion problem at night is intensified due to the absence of ionospheric D-layer absorption allowing signals to travel longer distances thus causing greater co-channel interference. These factors facilitate the exploitation of a limited portion of the HF band which subsequently increase the level of occupancy within the available allocations. This problem is especially acute since the usable operating frequency window may be further limited during low solar activity periods (although the duration of this project coincided with the high solar activity phase of a relatively low activity cycle). Spectral overlap causes high levels of occupancy at these times.

Allocations in the lower portion of the band exhibit different characteristics to those residing in the upper portion of the band. In the lower portion of the HF band occupancy peaks during the night. The variation in occupancy observed in allocations residing in the lower portion of the HF band can be attributed to diurnal variation of circuit LUF (Lowest Usable Frequency). Conversely, in the upper portion of the HF band a complete reversal of diurnal variation is observed which again shows significant diurnal variation, but in this case occupancy maximizes during dayime.

The seasonal behaviour in the diurnal variation is evident in Figure 3, with higher occupancy on average during winter months at the lower part of the spectrum. As a general principle during years of low solar activity, the lower frequencies are expected to be utilised more, while during years of high solar activity the higher frequencies are also used. This is demonstrated in Figure 4 where the measured occupancy is plotted for 25.670- 26.100 MHz. in the upper part of the spectrum. This frequency range is referred to as the 26 MHz broadcasting band and is traditionally used for long distance transmission during high activity periods of the solar cycle, because of the need of increased ionospheric ionization of this type of propagation.

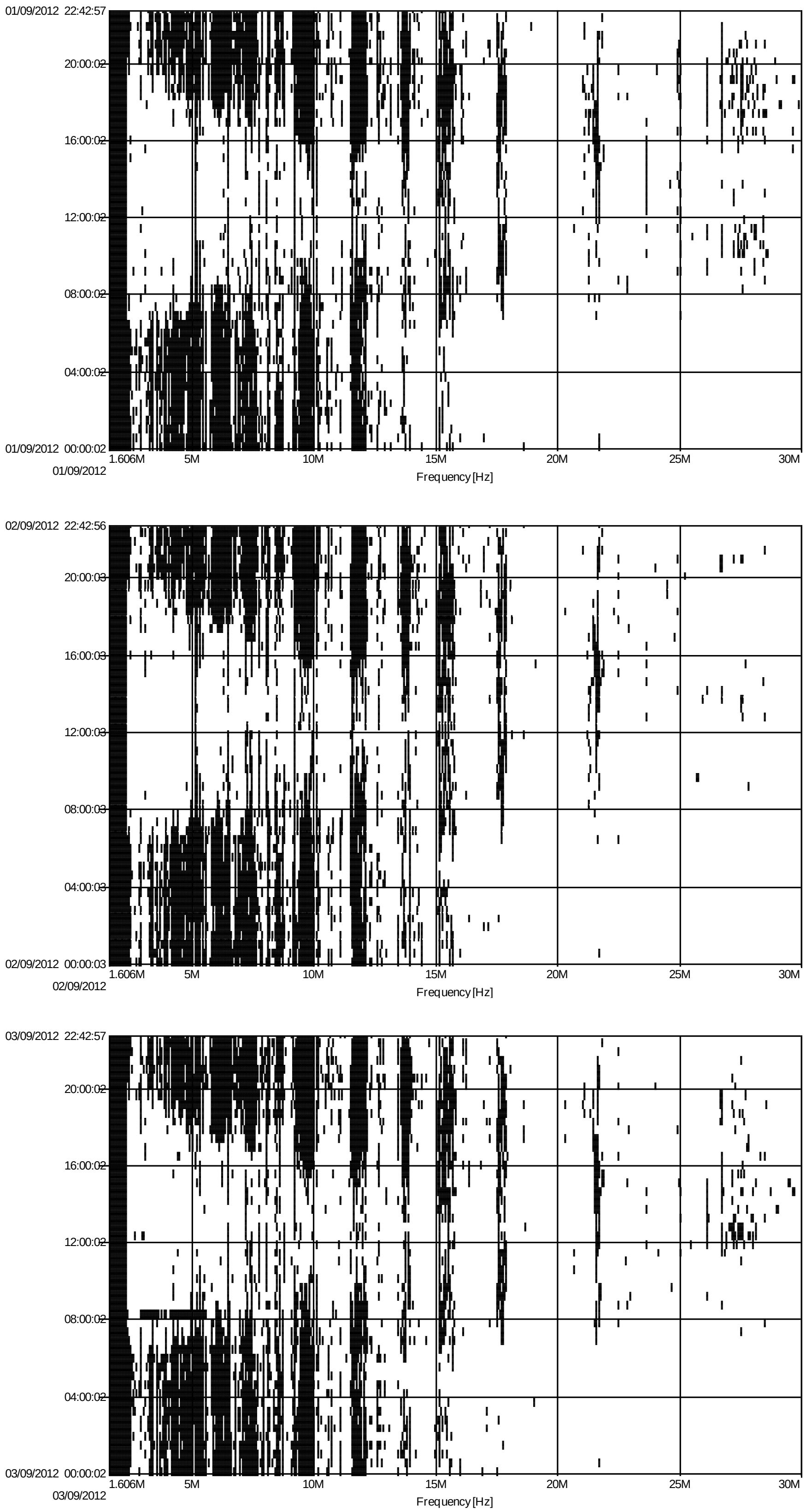

Figure 2. Three consecutive diurnal plots of HF spectral occupancy at a threshold of 20dBμV/m.

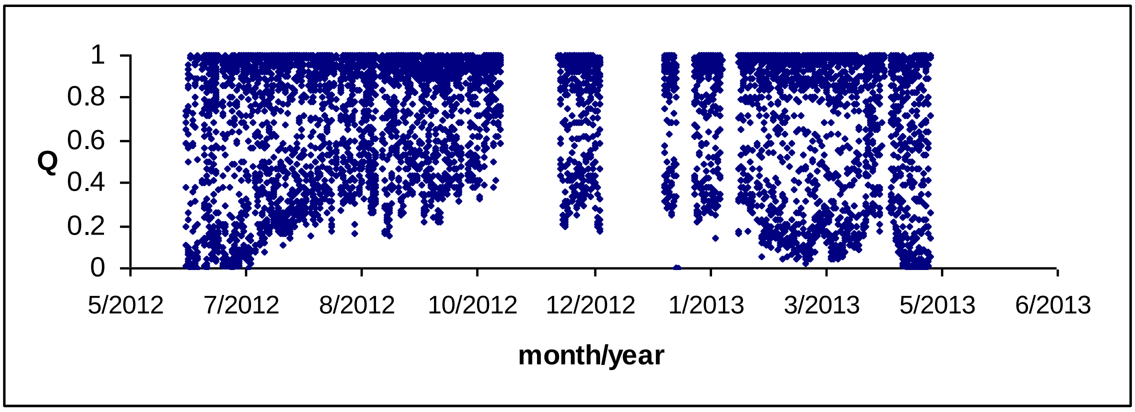

Figure 3. Seasonal variation of occupancy for 5.950 - 6.200 MHz at a threshold of 20dBµV/m.

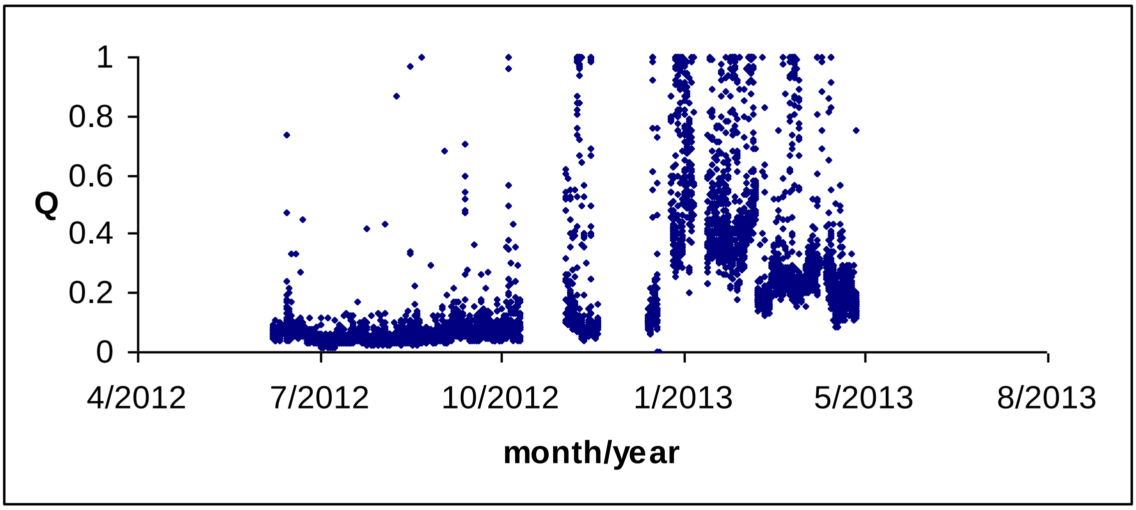

Figure 4. Seasonal variation of occupancy for 25.670- 26.100 MHz at a threshold of 20dBµV/m.

Figure 5. HF transmission conditions plot taking into account simultaneous HF spectral occupancy and NVIS ionospheric propagation conditions over Cyprus.

At present the HF occupancy measurement system operation complements the operation of a digisonde (DPS-4D) in the frame of real time monitoring of propagation predictions of MUF (Maximum Usable Frequency) to enhance HF communication system predictions over Cyprus. The simultaneous operation of the two systems is considered quite beneficial in the case of Cyprus where the near vertical incidence sky wave (NVIS) mode of propagation is the preferred mode of HF communication networks due to terrain imposed limitations. An example of the information provided by the two systems is shown in Figure 5. Different coloured bars represent the spectral occupancy of different types of user. The thin grey line represents the lower limit for NVIS propagation defined by the critical frequency of the blanketing sporadic-E layer which is often present over Cyprus particularly during summer months (Oikonomou et al., 2014). The black line represents the upper limit for NVIS propagation defined by the critical frequency of the F2 layer (foF2). By selecting a frequency as close to foF2 with minimum occupancy we can optimize the link quality.

5. FUTURE WORK

Dependence of occupancy on receiver bandwidth will also be thoroughly examined taking advantage of the wide selection of filters of the R&S EM510 receiver. This will allow for a wideband interference investigation to be undertaken motivated by the application of spread spectrum technology at HF. These studies may also provide information on the unique signal characteristics associated with these allocations, which are needed to enable design of spectrum sharing algorithms. In later stages, an effort to fit models on the HF usage dataset will be undertaken. This will enable the description of occupancy variation on various parameters such as signal frequency, solar activity, time of day and season (day of year).

6. CONCLUSION

The dedicated measurement system that has been established to provide effective measurement and analysis of HF spectral occupancy in Cyprus and the substantial dataset of occupancy data that has been accumulated, enables the extensive investigation of the dependence of HF interference characteristics on various parameters such as signal frequency, solar activity, filter bandwidth, time of day, season and signal elevation angle. Ultimately this effort aims to provide experimental data and to develop statistical, mathematical and possibly data-driven models that may be used in conjunction with frequency predictions to advise operators on typical interference occupancy levels and assist in the planning of frequency usage and management. The results and the analysis of observations from continuous monitoring of HF spectrum occupancy over Cyprus will contribute towards improved understanding of HF spectral characteristics over the Eastern Mediterranean region and especially of any systematic variations present. The subsequent occupancy studies could also reveal allocations of the HF spectrum that exhibit low utilization, and therefore assist in the identification of any long-term trends in the usage of various frequency allocations. From these studies, candidate allocations for spectrum reallocation and sharing could be identified.

REFERENCES

Dutta, S., & Gott, G.F. (1982). HF Spectral Occupancy. IEE Second International HF Conference Publication, 206, 96-100.

Economou, L.V., Haralambous, H., Pantjairos, C.A., Green, P.R., Gott, G.F., Laycock, P.J., Broms, M., & Boberg, S. (2005). Models of HF Spectral Occupancy over a Sunspot Cycle. IEE Proceedings Communications, 152(6), 980-988.

Gott, G.F., Wong, N.F., & Dutta, S. (1982). Occupancy Measurements Across the Entire HF Spectrum. Proc. of AGARD Conf. Propagation Aspects of Frequency Sharing, Interference and System Diversity.

Gott, G.F., Chan, S.K., Pantjiaros, C.A., & Laycock, P.J. (1997). High Frequency Spectral Occupancy at the Solstices. IEE Proceedings - Communications, 144(1), 24.

Goutelard, C., & Caratori, J. (1991). Time Modelling of HF Interferences. Fifth International Conference on HF Radio Systems and Techniques, 343-348.

Haralambous, H., Economout, L., Pantjiaros, C., & Christofi, L. (2009). Monitoring of HF Spectral Occupancy in Cyprus. 11th International Conference on Ionospheric Radio Systems and Techniques, 1-4.

Haralambous, H., & Papadopoulos, H. (2009). 24-Hour Neural Network Congestion Models for High-Frequency Broadcast Users. IEEE Transactions on Broadcasting, 55(1), 145-154.

Lemmon, J.J. (1989). Wideband HF Noise and Interference Modelling. Proc. MILCOM '89, 3, 846-851.

Oikonomou, C., Haralambous, H., Haldoupis, C., & Meek, C. (2014) Sporadic E Tidal Variabilities and Characteristics Observed with the Cyprus Digisonde. Journal of Atmospheric and Solar-Terrestrial Physics, 119, 173-183.

Spaulding, A.D., & Hagn, G.H. (1977). On the Definition and Estimation of Spectrum Occupancy. IEEE Trans. on Electromagnetic Compatibility, 19(3), 269-280.

Stehle, R. H., & Hagn, G. H. (1991). HF Channel Occupancy and Band Congestion: The Other-user Interference Problem. Radio Science, 26(4), 959-970.