The HF spectrum (3 MHz to 30 MHz) is capable of long-range communication with modest transmitter powers by the ionospheric reflection of low-angle sky waves. It is also used for short-range communication by ground wave or by the ionospheric reflection of high-angle sky waves, the latter technique being important in mountainous or forest terrain. Examples of HF users are international broadcasters, land-based fixed and mobile, maritime mobile and aero-mobile operators. To enable organized use of the spectrum, the International Telecommunication Union defines a number of frequency allocations across the spectrum for each type of user.

The main problems of the HF channel arise from time-varying multipath propagation, atmospheric and galactic noise and interference from other HF users. Propagation and noise have been extensively studied and documented. But interference from other users, although often very severe due to the typically high congestion of the spectrum, has received little attention.

The aim of the international measurement program is to provide occupancy data for the entire HF spectrum. This may be used in conjunction with frequency predictions to advise operators on the typical occupancy they may encounter and show how this occupancy depends on relevant parameters. Such information may also be useful to communication system designers, to HF ground wave users (who may then choose operating frequencies to avoid severe sky wave interference), and to study groups who are concerned with the determination of international frequency assignments.

Several automatic occupancy measurement systems are currently in operation in Europe (FIG 1). The sites range from Kiruna in northern Sweden (inside the Arctic circle) to Munich in southern Germany. The systems use Test Receivers ESH3, Active Rod Antennas HE010 and Active Turnstile Antennas HE004, all from Rohde & Schwarz (FIGs 2 and 3). These antennas give occupancy measurements for signals received at low and high angles of elevation. Each system is connected to the telephone network to enable control and retrieval of measured data.

Occupancy is measured across each ITU-defined HF frequency allocation at each measurement site [1]. The test receiver is stepped in frequency through each allocation, typically spending 1 s at each increment. The fraction of the increments for which the receiver IF output signal exceeds a defined threshold level defines the congestion value for that allocation. This procedure is shown in FIG 4, which indicates the measurement of congestion for the fixed and ground mobile frequency allocation 10.15 MHz to 10.60 MHz. Congestion values are measured for threshold...
Mathematical models are currently being fitted to the experimental congestion values [2] and examples of such models have been published [1,3,4]. The modelled value of congestion $Q_k$ for ITU frequency allocation $k$ is given by

$$Q_k = \frac{e^{y_k}}{1 + e^{y_k}}$$

where $y_k$ is the model index function incorporating parameters on which occupancy depends. Measured congestion values are probabilities ranging from 0 to 1, and the above logit transformation ensures that the modelled values do not fall outside this range.

Measurements in the UK have been made since 1982. As a simple example, the earliest model for the entire HF spectrum was for UK summer solstice, for which the index function has the following form [1]:

$$y_k = A_k + (B_0 + B_1 f_k + B_2 f_k^2) 20 \log \psi + (C_0 + C_1 f_k + C_2 f_k^2) \text{sunspots}$$

$A_k$ has 95 values corresponding to the 95 ITU frequency allocations, $f_k$ is the allocation center frequency, $\psi$ is the field-strength threshold, and sunspots are the 12-month running mean of the monthly mean international sunspot number. For this example the measurement bandwidth was fixed at 1 kHz, and only the rod antenna was used. The model was initially based on 5500 values of congestion measured over the period 1982 to 1995. When measured and fitted values were compared, 54% of the measured values were given by the model to an inaccuracy of ±0.01, 87% to an inaccuracy of ±0.05 and 96% to an inaccuracy of ±0.1, where congestion values are in the range 0 to 1.

To demonstrate the ability to predict future values of congestion, the project team used a model developed from summer solstice data obtained from 1982 to 1992 to predict occupancy at the summer solstice for the years 1993, 1994 and 1995. The predicted values were then compared with measured ones. For example, for the 1995 predictions 79% of the predicted values were within ±0.05 of the measured values. When the model was subsequently fitted using measured values up to 1995, the model gave 83% of fitted values within ±0.05 of the measured values. Thus the predicted values were nearly as accurate as the modelled ones. This indicates that the model specification had not altered significantly by the inclusion of the 1993 to 1995 data, which shows that the utilization of the HF spectrum had not altered significantly in a systematic way over these years. It may be noted
that the predicted values of congestion are based on predicted sunspot numbers.

Since 1993, frequent measurements have been undertaken at Baldock, Linköping and Munich, and comprehensive models for low-angle and high-angle HF occupancy are being developed for northern Europe. These recent model index functions include the parameters field-strength threshold, frequency, time of day, week of year, bandwidth, sunspot number and geographical location [3]. Up to 300,000 measured congestion values are currently being fitted in the modelling procedures, and an example of modelled occupancy contours is shown in FIG 5. These contours are for the fixed and ground mobile frequency allocation 7.3 MHz to 7.8 MHz, midnight, summer 1995, for a threshold level of 1 µV/m and a bandwidth of 1 kHz.

A measurement system at Cobbett Hill near Farnborough in the UK has been operational since 1995 to determine the variation of HF occupancy with azimuth. Twenty travelling-wave Vee antennas are used to systematically monitor occupancy for twenty different azimuths, and these results are also being modelled [4]. The measurement system at Kiruna became operational in 1997 and no modelling has yet been attempted for this site. It will be of interest to see if the high latitude of Kiruna gives rise to very different occupancy characteristics when compared to results from the other European sites.

It is hoped that the project may continue until high sunspot numbers are encountered, so that a wide range of sunspot numbers may be included in the models currently being developed.

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