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HF fixed radiocommunications systems

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1 Introduction

HF system emissions can be categorized as adaptive and non-adaptive. Non-adaptive systems depend on operator training and skill level to assess propagation variables and interference to find a clear, reliable channel. Adaptive systems automate this process. Although adaptive systems have many advantages, including decreased operator training, non-adaptive systems will continue to be operated in the foreseeable future. There is potential for interference between these two types of systems. The emission characteristics of adaptive and non-adaptive systems require separate sets of characteristics data to enable accurate electromagnetic compatibility analysis in a given environment.

Modern communications in the HF band also have specific attributes that make a viable solution for many emergency response requirements. HF systems and networks provide a highly versatile means of communications to a broad base of users engaged in public protection and humanitarian efforts. Such systems can also bring inexpensive and reliable equipment to remote and lightly populated areas.

In the event of the collapse of normal telecommunication operation due to natural disasters (e.g. earthquakes) and other emergencies, MF/HF systems could be established in a very short period of time to provide the emergency links required, in the first phase of the alarm or during the coordination of the relief operation.

2 Non-adaptive systems**2.1 Introduction**

In the manual non-adaptive operational procedure, the operator must adjust the parameters of the system for maximum performance by monitoring the conditions of the ionosphere, tracking the variable propagation conditions, and selecting the operating conditions (i.e. primarily the frequency) that will allow the signal to propagate best.

There is extreme variability and unpredictability, in the short term, of the HF propagation environment. Propagation in this band is primarily by the sky-wave mode, utilizing refraction of radio waves from the ionosphere, or in some cases by the surface-wave mode.

2.2 Propagation

The ionosphere, and radiowave propagation using it, are described in the ITU-R Handbook – “The ionosphere and its effects on radiowave propagation” – and in relevant Recommendations in the ITU-R P-Series (ITU-R P.368, ITU-R P.369, ITU-R P.371, ITU-R P.434, ITU-R P.531, ITU-R P.532, ITU-R P.533, ITU-R P.534, ITU-R P.535). Some additional information may be found in the ITU-R Handbooks – “HF broadcasting system design” and “Frequency adaptive communications systems and networks in the MF/HF bands”.

In brief, the ionosphere is formed in the Earth’s upper atmosphere, at heights above about 80 km, by the effects of ionizing radiation from the sun. The height and density of the ionization depend upon

the incoming radiation, the atmospheric constituents and their variation with height, etc. the Earth's magnetic field and the circulation of the upper atmosphere. The incoming solar radiation generally varies with the solar activity cycle, which has a period of approximately 11 years duration, as seen for example in the number of spots on the Sun's surface.

The incoming radiation ionizes a part of the upper atmospheric gases and the resulting free electrons form the ionosphere, which has the property of refracting or reflecting radio waves. In the lower parts of the ionosphere the free electrons have a limited life-time before recombining, and the density of ionization varies approximately with the elevation angle of the sun. These lower parts of the ionosphere are called the D and E regions or layers. Higher in the ionosphere, in the F region, electrons have a longer life-time and the ionization density is also strongly affected by winds and by the presence of the Earth's magnetic field.

The maximum frequency, which can be reflected vertically from an ionospheric layer depends on the ionization density and is called the critical frequency. The ionization density, and thus the critical frequency, depends on the geographical location and solar angle, and is subject to hour to hour, day to day and seasonal variability due to changes in the solar radiation, the solar-terrestrial environment, the upper atmospheric winds and the Earth's magnetic field. The lower parts of the ionosphere also attenuate radio signals, while interaction with the Earth's magnetic field also changes the signal polarization.

Terrestrial propagation may be considered as oblique incidence reflection from the ionospheric layers and additional propagation modes may have multiple reflections from the ionosphere and the Earth's surface. The maximum frequency of propagation for each mode depends on the critical frequency and on the elevation angle at the reflecting layer. Thus in general the received signal will comprise several modes, each with a different and variable strength; time of arrival and polarization.

These longer term variations in propagation conditions, from hour to hour, day to day, with season and with the solar cycle are predictable on a statistical basis. Prediction methods are available using Recommendation ITU-R P.533 or a variety of other methods.

Such long-term prediction methods cannot give a precise estimate of the best frequency to be used at a specific date and time on a specific radio path. Traditionally it has been the practice to use a frequency somewhat below the predicted maximum usable frequency (MUF), so as to ensure that a satisfactory signal would be received on most days of the month. A planned schedule of frequency changes through the day would be prepared for each month, so as to maintain usable communications. The radio operator managing the circuit would use these frequency schedules, together with his experience and actual conditions on the day, and select the best frequency from the limited set available, thus managing the circuit operation on a minute-to-minute basis.

The long-term predictions also give information on the active propagation modes and the elevation angles required for the antenna radiation.

The ground wave propagation mode is stable and predictable. It is described in Recommendation ITU-R P.368 and a prediction method is available in [software on the ITU-R website](#). At HF, the mode is only significant at ranges of up to several hundred kilometres over sea, and to substantially shorter ranges over land, in the lower part of the frequency range. Nevertheless, in appropriate circumstances the mode may be important.

Circuit operation is subject to these propagation modes, to the longer term ionospheric variations, to intensity and polarization fading. However, there are other short term and largely unpredictable factors, which are important.

In the lower part of the ionosphere, at about 100 km, additional ionization may occur, in a manner which cannot be adequately predicted, due to meteorological factors and trace elements, and due to

other mechanisms at both high and equatorial latitudes. This “sporadic-E” ionization may have a major impact on radiowave propagation and may provide an additional propagation mode.

There are also important contributions to the incoming radiation from eruptions on the Sun’s surface, often seen as solar flares, which release ultra violet and X-rays, high energy particles and a plasma of medium energy particles which may then propagate in the solar wind, through the solar terrestrial environment, to reach the Earth. When these radiations reach the vicinity of the Earth they directly cause additional ionization. They also interact with the Earth’s magnetic field, depositing ionization into the polar regions, changing the temperature of the neutral gases in the upper atmosphere, changing the wind system and the distribution of ionization. These events are described as geomagnetic and ionospheric storms and may have a major impact on HF propagation. They cannot be forecast long in advance, and the effects cannot be accurately forecast even a few hours ahead. The skill of a circuit operator may be able to enable some continued operation during a storm, but he would have to work on a trial and error basis as experience of such events would be limited. One technique of value at high latitudes, where storm effects are most pronounced, is path diversity, using alternative radio paths to avoid the most disturbed areas but this requires rapidly available information at a network level.

Modern HF communications are now required to deliver increased data rates with wider bandwidth systems. The performance of these systems will depend on the multipath delay spread of the active propagation modes at that time, which are due to propagation from the various layers, etc. The ionization is also moving due to the atmospheric winds so that each mode will have a different frequency shift due to Doppler effects. At equatorial latitudes, near the magnetic equator, the ionospheric layers may break up after sunset into a diffuse region from which signals are scattered with large time and frequency spreads. At high latitudes, the ionospheric layers may be broken up due to ionospheric storms, again resulting in signal scattering with large time and frequency spreads.

For those systems where ground wave propagation is used and long range communications via the ionosphere is not required, frequencies should be selected which take advantage of propagation conditions to limit unwanted propagation. Means of achieving this include the selection, during daylight hours, of frequencies below the lowest usable frequency (LUF) of the propagation modes available and the selection, at night, of frequencies above the MUF for long paths for the antenna being used. Note that the LUF is dependent on solar cycle, increasing with higher solar cycle indices. Caution should be exercised when using frequencies above the MUF at night in tropical regions as long-distance “chordal”, or trans-equatorial propagation may be stimulated. Transmitters and receivers should also have broadband or fast tuning capabilities, again extending across the frequency range for the adaptive operation.

3 Adaptive systems

3.1 Introduction

An adaptive MF/HF system is one which automatically (i.e. without the need for intervention by a radio operator) carries out the functions of establishing radiocommunications links and exchanging of information in a manner that copes with the variations and the high probability of interference inherent to MF/HF frequency bands propagating through the ionosphere. In addition, adaptive systems are able to monitor spectrum occupancy in a regular manner, and select operating frequencies so as to avoid causing interference to other users more effectively than many non-adaptive systems now in operation.

3.2 Operational characteristics

The salient features of the adaptive MF and HF systems are:

- *Decreased Operator Training:* The adaptive systems will establish, maintain and disconnect the MF and HF link without the need for an operator to interact technically. This alleviates the requirement for using trained radio personnel.
- *Increased reliability:* The percentage of time in which the adaptive systems will provide a high quality service is much higher than traditional fixed frequency systems. This is ensured by the use of adaptive frequency selection, automatic repetition on request (ARQ) and adaptive selection of the most appropriate modulation waveforms.
- *Flexibility:* An adaptive system continuously analyses and updates link quality assessment information making it possible to select the most suitable traffic frequency and modulation for each particular time instant. This adaptive behaviour minimizes the time periods in which stations cannot communicate, and also increases the opportunities for use of reduced power, in both the fixed and mobile services.

MF and HF radio has been used for decades for long-distance communications. MF and HF radiocommunication has a number of positive characteristics that can be enhanced – and drawbacks that can be minimized – through the use of automatic and adaptive techniques. The positive attributes for communication in the HF band include cost-effective long-distance transmission. The negative aspects include: labour-intensive operation, variable propagation, modest overall reliability and limited data bandwidth. Communicating in the HF radio band requires the optimization of conditions to make it reasonably reliable. The reliability of HF radio transmissions is dependent on a large number of factors such as:

- operating frequency;
 - a) the degree and distribution of ionization of the ionosphere;
 - b) the distance between stations (number of hops);
- operating power;
- modulation;
- SNR requirement;
- signalling overhead procedures (i.e. error checking, handshaking, etc.).

In the manual operational procedure which has been used until recent years to optimize HF radiocommunication, the operator must adjust the parameters of the system for maximum performance by monitoring the conditions of the ionosphere, tracking the variable propagation conditions, and selecting the operating conditions (i.e. primarily the frequency) that will allow the signal to propagate best. Because of the intensive labour, experience and skill required, HF and MF radiocommunication is an easily recognized target for justifying automation and the use of adaptive techniques. Present day automation techniques reduce the burden on the operator by adding subsystems for frequency management, link establishment, link maintenance, etc. These techniques can be used to reduce the skill-level demands and duty requirements of the radio operator or communicator. Typically, automation can be added to make the radio appear to be “push-to-talk on the best channel”, while actually the radio is a multichannel communication device performing many underlying functions.

3.2.1 General description

The following describes a common set of functions that are embedded in most of the various types of systems that have been developed. “Common” in this respect does not necessarily mean that they have been implemented in the same way thus enabling intercommunication. It only means that the