RECOMMENDATION ITU-R F.1110-2

ADAPTIVE RADIO SYSTEMS FOR FREQUENCIES BELOW ABOUT 30 MHZ

(Question ITU-R 147/9)

(1994-1995-1997)

The ITU Radiocommunication Assembly,

considering

a) that HF sky-wave links allow communication over large distances;

b) that, up to now, natural ionospheric variations and interference resulting from spectral congestion and propagation anomalies have made HF links difficult to operate and demanded highly skilled operators;

c) that technological progress in recent years has led to the development of adaptive systems which can be used to automate HF links and enhance their quality;

d) that adaptive systems make it possible:

– to achieve a higher quality of service by combining an ability to exploit modern radio-frequency technology with advanced real-time control software; the result is a system which is reliable, robust, cost-effective and easy to use;

– to establish extensive HF networks with flexible, less hierarchical architecture;

– to reduce transmission times thereby:

  – securing more efficient use of the spectrum,

  – reducing the interference between users,

  – providing the ability to increase traffic density;

e) that recent research has produced adaptive automatic link establishment (ALE) systems,

recommends

1 that adaptive HF systems should have the general characteristics given in Annex 1;

2 that the assignment of frequencies to such systems should follow the principles set out in Annex 2.

NOTE 1 – Different adaptive systems are described in Annexes 3-9.

ANNEX 1

General characteristics of HF adaptive systems

1 Introduction

Whatever the type of service to be provided:

– telephony,

– telegraphy,

– picture transmission,

– data transmission,

an HF link is characterized by the following phases:

– watch-keeping,
– calling,
– establishment of link,
– traffic handling,
– disconnection,
– return to watch-keeping.

An adaptive system automates this process, dispenses with the need for a skilled operator and improves the quality of service and the efficiency of the link.

It may be used:

– for point-to-point links,
– for a network, with selective calling procedure, carried out by the control station, which may be:
  – general (all stations),
  – group (several stations),
  – individual (a single station with which a point-to-point link is established).

All the user has to do is to operate the peripheral equipment corresponding to the type of service indicated in the call sequence (telephone, teleprinter, picture transmission equipment, data terminal), there being no need whatever for him to intervene in connection with the establishment, control and interruption of the radio connections.

Basically, an adaptive system has a triple function:

– automatic selection of the frequency to be used;
– automatic operation as regards calling, establishing the communication (with possible switch-over to the peripheral equipment needed for the type of service to be provided), and disconnecting;
– adaptivity during the communication so as to optimize at all times the quality of service according to the ionospheric conditions and spectrum congestion.

2 Automatic selection of the frequency to be used

The selection of the frequency to be used should utilize some or all of the following information:

– list of assigned frequencies;
– a stored ionospheric prediction schedule for predicting link quality at different frequencies as a function of the time, the season and the year;
– data on the quality of previous links, which may reduce the ALE time if the ionospheric duct is sufficiently stationary (short-term) or sufficiently reproducible during the same time interval on successive days;
– passive real-time analysis of channels in order to sort out free channels from channels suffering interference (reducing spectrum congestion) (see Note 1);
– possibly, information provided by another device, e.g. ionospheric-sounding system.

On the basis of all this information, a preferential list can be drawn up, when required, of the frequencies to be used for a given link.

NOTE 1 – Channels using LINCOMPEX transmissions shall be determined by demodulation and detection of the LINCOMPEX control tone and cannot be considered as free channels.

3 Automatic calling, link establishment and disconnection

3.1 Common calling/traffic channels

The calling sequence should contain the following information provided by the user:

– identification of calling station,

– identification of called station,

– type of service,

– possibly, mode of operation (simplex, half-duplex, duplex) for the fairly rare cases in which this is not imposed by the link and where there is not a one-to-one correspondence between the mode of operation and the type of service.

The calling sequence is carried out on the frequency classified as No. 1 by the frequency selection unit.

This frequency is retained for the link if:

– a reply is received from the called station;

– this reply indicates that the measured quality of the link in the calling-called direction is sufficient to provide the required service (the quality might be sufficient for establishing the link, which is always done at a low bit rate, but it might be insufficient for a service requiring a higher quality, for example analogue telephony or high bit rate transmission);

– the measured quality of the link in the called-calling direction is sufficient to provide the required service.

A call on the frequency classified as No. 2 will be reinitiated if one of the above three conditions is not met.

As soon as an adequate frequency has been found, the system switches over automatically to the peripheral equipment corresponding to the type of service to be provided.

After disconnection, stations return to the watch-keeping mode.

NOTE 1 – By frequency classified as No. 1, No. 2, …, the following is meant:

– one single frequency for simplex operation,

– a pair of frequencies for half-duplex and duplex operation.

It is highly advisable to employ procedures allowing independent selection of the frequencies for each direction of the link in the following cases:

– presence of local interference,

– when the same frequencies are not available at the two ends of the link.

3.2 Separate calling and traffic channels

For networks or systems where the traffic density or number of stations is large, the use of separate calling and traffic channels may be preferred. In such cases the call establishment will generally follow the pattern of § 3.1, except that the initial contact is made on one of a set of calling channels, which are monitored by all stations when watch-keeping. After this, a combination of passive channel assessment and active channel sounding is used to determine the most suitable traffic frequency.

4 Adaptivity during a communication

Due to its adaptivity, the system automatically maintains the quality of an HF transmission during a communication by varying the main transmission parameters in accordance with the changing state of the channel.

These parameters are, for example:

– radio equipment:

  – transmission power,

  – frequency,

  – choice of single sideband (SSB) (upper band – lower band);

– telegraph peripheral equipment or data terminal and their associated modems:
  – bit rate,
  – type of coding,
  – shift excursion,
  – value of sub-carrier.

In setting up an adaptive process, it is necessary to:

– determine a measurable criterion representative of the quality of the link for a given type of service (for example, number of repetitions for an automatic repeat request (ARQ) telegraph link – error rate for a digital transmission measurement of *S*/*N* ratio-jitter);
– decide on a value for this criterion below which the quality is regarded as inadequate (threshold value);
– arrange for constant measurements of the value of this criterion during the communication process;
– if this value drops below the threshold set for a specific time, vary one (or more) of the link parameters so as to obtain the required quality again.

This clearly presupposes that these parameters are programmable and that the various discrete values adopted may be modified by telecommand.

When the parameters are modified, the two terminals concerned have to be informed by a special signal that an adaptive process is in progress.

NOTE 1 – In analogue telephony, the criterion which is representative of the link quality can only be subjective; the user must therefore be able to take the decision to change the parameter. For example, a "restart" command activated by a user who is not receiving properly might tell the system that the adaptivity procedure needs to be triggered.

ANNEX 2

Frequency assignments

1 Recall on a maximum usable frequency (MUF) and a lowest usable frequency (LUF)

At any particular time, a sky-wave path is available on channels in a window below the MUF and above the LUF. The MUF is defined by the prevailing ionospheric conditions but the LUF is set by a combination of path loss and equipment parameters such as transmitter power, noise figures and antenna gain. In practice, many of the channels in this window will be blocked by interference from other users.

MUF can be predicted on a long-term average basis. The variations in MUF can be ± 30% day-to-day and in disturbed conditions the MUF can be less than 50% of the predicted value.

LUF is typically, for commercial systems, about half the MUF, but this also can vary considerably. Under "normal" conditions, the window varies predictably as follows:

– daytime MUF is higher than night-time MUF,
– winter MUFs vary more than summer MUFs,
– short path links, less than 1 000 km, normally use frequencies below 15 MHz,
– long path links, more than 1 000 km, normally use frequencies above 5 MHz,
– MUFs are higher when the sunspot number is high.

2 Frequency assignments for a link

When requesting frequency assignments for a high frequency link required to operate reliably at all times, it is desirable to plan for frequencies which are spread evenly (geometrical progression) across the required band. For example a short path link might theoretically be catered for by an assignment of four frequencies with a 1.9x relationship as follows:

2.0 3.8 7.2 13.7 MHz

To ensure reliable continuity of service through disturbed conditions a larger complement of frequencies would ideally be required, e.g. eight frequencies with a 1.3x relationship as follows:

2.0 2.6 3.4 4.4 5.7 7.4 9.6 12.5 MHz

A long path link might use a similar relationship in the upper part of the band as follows:

4.4 5.7 7.4 9.6 12.5 16.3 21.2 27.6 MHz

This would put three channel assignments in the usual 50% wide window and thus allow for a significant narrowing due to disturbances.

The above frequencies are, of course, only examples and actual assignments would depend on the circumstances. Of more importance is the probability that the single frequencies in a set may be unusable due to interference so that, for maximum availability, it would be necessary to have a choice of several channels at each point in the band.

3 Frequency assignments for adaptive systems

An adaptive system could be used simply to scan through a set of assigned channels and select the best; whilst this would aid the operator, it does not offer any improvement in spectrum utilization.

A more effective means of spectrum utilization may be to group the frequency assignments of a number of circuits together and to operate these jointly as a network, using the combined pool of frequencies as a resource assigned on demand.

In general there is a relationship between network size, traffic density and the channels required. For example:

– a particular number of propagating channels can support a specified level of traffic in a network of so many stations; or

– a network of so many stations, with a specified level of traffic requires a particular number of channels in the propagating window.

In simple terms, when it is necessary to cater for more than one call at a time (i.e. in a network) the number of required channels is multiplied by the maximum number of simultaneous calls. If insufficient channels are available then some calls will have to be queued.

Any restrictions on the number of channels available will therefore have a bearing on the traffic handling efficiency of the system.

The concept of shared channels is complicated by the need for adaptive systems to use a spread of frequencies across the HF band for:

– traffic,

– network management,

– channel evaluation.

If mutual interference between systems is to be minimized, then design standards for HF adaptive systems using the common pool of channels need to be established.

ANNEX 3

Microprocessor controlled automatic HF system for voice and telex traffic

1 Introduction

A microprocessor controlled automatic HF radio system has been developed to handle SSB voice and the frequency-shift keying (FSK) telex traffic.

The system includes the following automatic functions:

– real-time frequency evaluation and selection,

– automatic link set-up with SELCAL,

– ARQ with special order channel facility,

– link quality monitoring, automatic frequency change when necessary.

2 Frequency allocation and real-time channel evaluation (RTCE)

The system passively evaluates the noise and interference levels in each of six channels in a 3 kHz assignment in each band. The appropriate band is selected by propagation predictions under microprocessor control. The best channel in the predicted optimum band is then the first choice for ± 85 Hz shift FSK communication.

3 Operator interaction

Message handling is undertaken by unskilled operators using a simply controlled paper tape reader. The system management is under the control of the microprocessor. If required, voice communication is immediately available using the full 3 kHz bandwidth, in which case the telegraph traffic is temporarily interrupted.

4 Network data input

The system data (frequencies, SELCALs, etc.) are entered into the computer via a keyboard or by paper tape, or even via the HF link.

5 Link establishment

When establishing a link, the system uses the best frequency available, taking into account both propagation conditions and interference.

A propagation forecast, updated by experience, is used to rank the bands from best to worst for various periods of the day. Communication is established by sequentially scanning the assigned channels until the appropriate transmission is recognized.

6 Link supervision

ARQ error correction is used which is a semi-duplex version that transmits information in both directions when there are no errors. The character error rate is better than 1 in 10^6. Alternatively, a combination FEC (single error correction) and ARQ (multiple error retransmission request mode) can be used.

A special order mode is available to transmit radio-system commands and data between stations without compromising the integrity of the ordinary telex information. This important feature enables the system to perform complex control functions – actually a necessity in an "intelligent", automatic system.

The ARQ repetition frequency is monitored and when the link is too bad, the system tries to find a better channel in the same band in the disturbed direction. If it does, the receiving station orders the transmitting station to change to the new channel and traffic continues. If for some reason there is no better channel, other bands will be tried until a useful channel is found or some other station wants to break in. This is all automatic and only delays messages, without affecting the printed copy. The system can find short-lived, hard-to-predict ionospheric features such as sporadic-E layers and use them when needed.

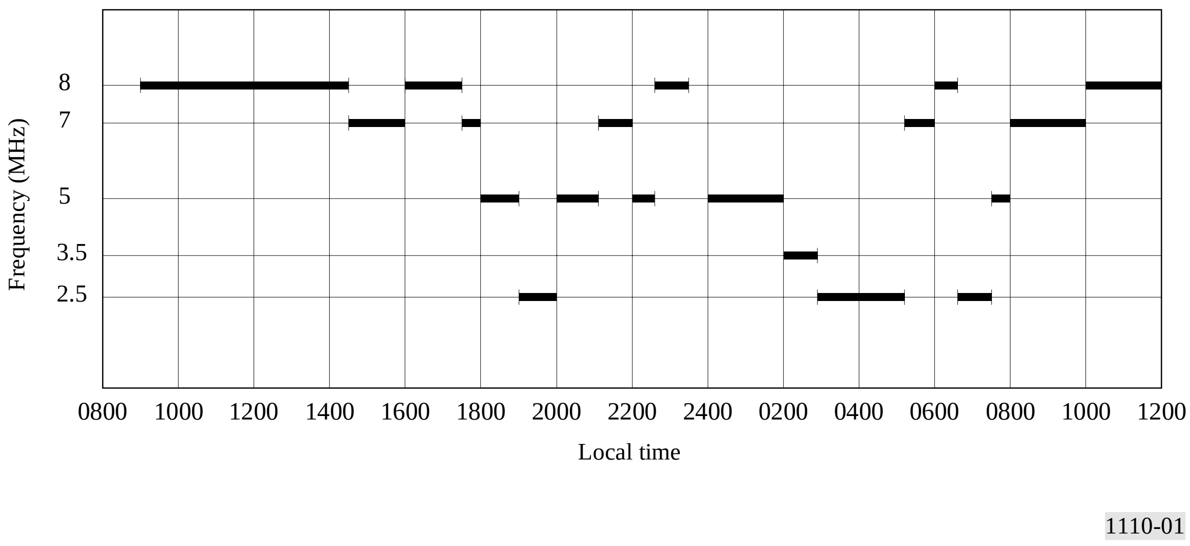
7 Tests and performance

During 1984, the system underwent tests on a trans-auroral 1 000 km link from Stockholm. Five bands of six channels were used. The effective radiated power was 100 W using a wideband antenna.

The performance was monitored using a desktop computer which collected efficiency/throughput, frequency usage and character error rate data. Figure 1 shows typical frequency usage data. The link was very difficult, as it was heavily impaired by aurora and high latitude winter ionospheric disturbances. In spite of this, the system seldom went below a 24-hour character transfer capacity of 300 000 characters, i.e. about 50% efficiency. The mean 24-hour efficiency on this circuit for most days was 70 to 80%.

FIGURE 1

An example of frequency usage



8 Comments on test results

On many occasions the system used, to good effect, frequencies much higher than the predicted F2 MUF values. This was probably due to the existence of sporadic-E ionization. An automatic HF system which can adapt to difficult and changing ionospheric conditions has been successfully demonstrated.

ANNEX 4

A small automatic radiotelephone system

1 Introduction

An automatic HF radiotelephone system developed in Canada is undergoing a field trial as an adjunct to the switched telephone network. The system has enhanced performance with the following general characteristics:

– real-time HF frequency evaluation and selection,

– access to the switched network without operator intervention,

– storage and updating of information for channel selection, billing and traffic evaluation,

– economical for deployment in remote areas,

– enhanced reliability through modern design.

2 System configuration

The network of HF stations is allocated a number of frequencies (up to eight) covering all expected propagation conditions. All HF subscribers can be accessed by or can access any subscriber within or outside of the HF network. The HF radiotelephone system described operates in a voice activated mode using the same frequency in both directions of transmission (simplex mode). This does not preclude future employment of different frequencies in the two directions of transmissions (half-duplex or full-duplex mode).

3 System description

The automatic HF station consists of an all-solid-state 100 W HF/SSB transceiver, a broadband antenna, a 75 bit/s modem and a controller/interface unit which provides the automatic functions and interface characteristics for telephone compatibility.

A three-station system deployed in Canada is depicted in Fig. 2. Two types of remote station are shown, one having a single telephone and the other interconnected to an optional small PABX switch in order to serve a larger community. Since the master station would normally be located in a larger community, it was also provided with an optional PABX switch. This switch could be eliminated if not required to service subscribers in the vicinity of the master station; its presence is not required in order to interface the HF radiotelephone to the switched network.

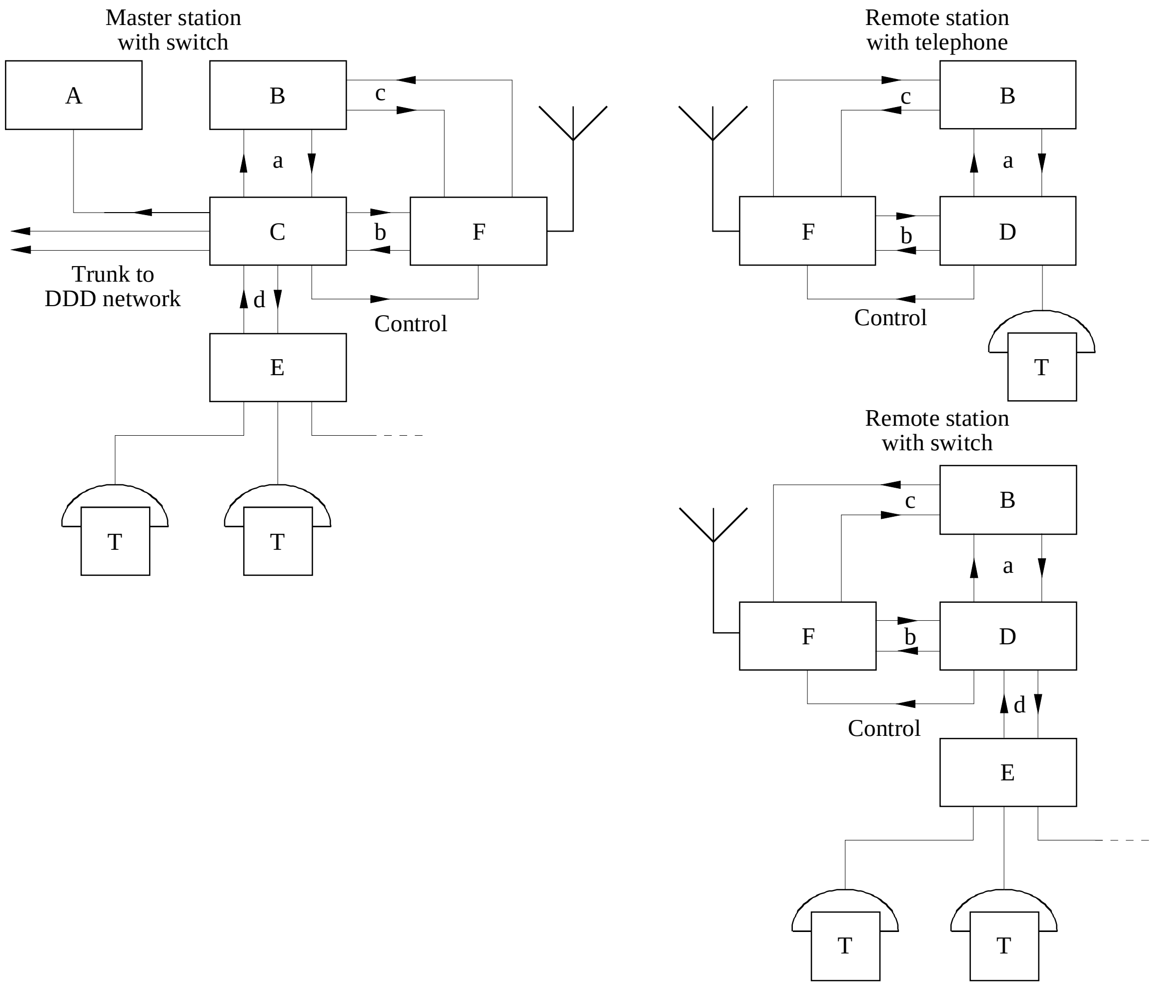
All subscribers in the system are assigned seven digit numbers according to the standard numbering plan; however, abbreviated (three digit) dialling is used for calls within the HF network. An access digit is used to differentiate these calls from those destined for the direct distance dialling network.

When no calls are taking place in the system the master station continuously cycles through the assigned channels (eight in the experimental system), transmitting a 48-bit digital message on each one. The digital messages are in the form FSK data using the 75 bit/s modem. To avoid the problems of selective fading, n-band frequency diversity is employed.

The remote stations synchronize themselves to the master station and maintain short-term statistics on the quality of the channels, derived from an examination of the integrity of the received data. The quality assessment is partly based upon detection of bit errors by means of error detection coding in the data. In addition, a “pseudo-error” measurement technique is used to define the selection process when several channels have similar error rates.

FIGURE 2

Block diagram of experimental system



A: printer (call detail recording)
B: 75 bit/s modem
C: master controller interface unit
D: controller interface unit
E: PABX switch
F: HF transceiver
T: telephone set

a: data
b: speech
c: data (modulated)
d: tie trunk

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When a landline subscriber dials a number requiring the HF network, the master station and the appropriate remote station begin an interchange of digital messages and transfer to the channel selected by the channel evaluation algorithm. If the procedure is successful, the voice paths are established and the usual telephone supervisory tones are transmitted to the calling party. If the HF network is unavailable or the call set-up procedure fails for some reason, a fast busy tone is returned to the calling party as an indication that he should attempt the call later. When one party hangs up at the end of a call, the HF station to which he is connected begins transmitting a digital “disconnect” message. This results in another brief message interchange and the system is returned to the idle state.

In the case of a call from one remote station to another the procedure begins as above, but when the master station recognizes from the contents of the message interchange that the destination of the call is another remote station, it transfers control temporarily to the remote station which initiates the call. The role in the channel evaluation procedure played by the master station is taken over by the remote station initiating the call during the call set-up. When the call set-up is complete, the master station returns to the idle state and is available for other calls (the channel in use by the call is automatically busied). The remote stations therefore communicate directly with one another during the call; this both frees the master station for other calls and avoids problems associated with operating two HF links in tandem.

When one party hangs up, the master station is informed that the call is ended. The "disconnect" process occurs as described before.

4 Test results and evaluation

Test and evaluation were carried out in two phases. The first phase tested the HF portion of the system alone. The second phase tested the HF system linked to the switched telephone network. Calls were made to and from the system from the switched network without operator intervention. The test sites were selected to provide radio circuits ranging from 60 to 1 000 km. Eight frequencies from 2.6 MHz to 21 MHz were used in each phase. Each phase lasted for about four months, and the stations were manned for periods of several days. During the days when the stations were not manned, automatic recording devices were activated to continuously measure the signal quality on each frequency.

In analysing the channel quality data, two levels of performance were distinguished. The first, referred to as level 1, is reached when the bit error rate (BER) on the channel is such that virtually all digital messages are received without errors. Such a channel generally offers a very good voice communications. The criterion for level 2 is that approximately one-third or more of the messages are received without error. This level was arrived at empirically and corresponds roughly to the lowest quality level at which voice communications can be carried out without major difficulties. Several dialling attempts will often be required when the channel quality is near this lower limit.

The results of the on-the-air tests were as follows: level 1 quality on at least one channel was attained for an average of about 70% of the test period. Level 2 quality on at least one channel was attained for 98% of the time (see Fig. 3).

5 Comments on the test results

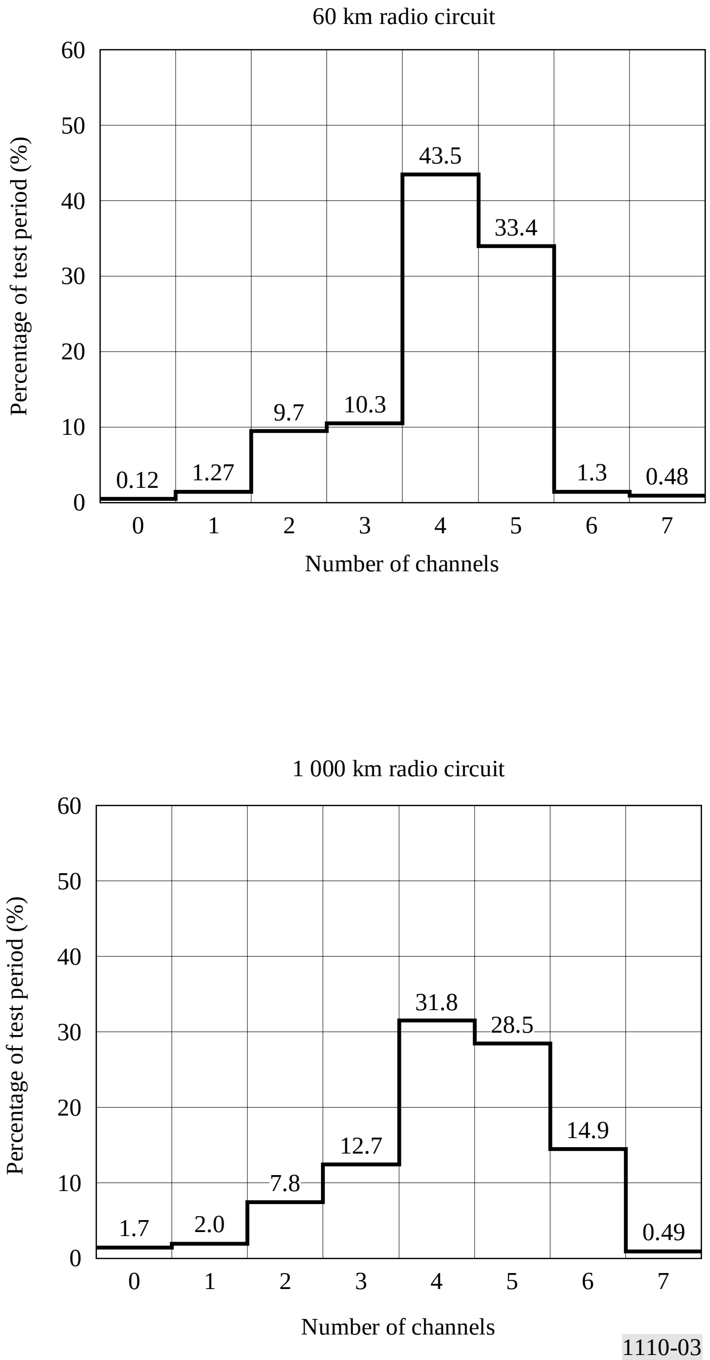
Disturbed propagation conditions were encountered several times during the test period, including geomagnetic storms on at least two occasions. The effects of these storms were observed in the recordings obtained during these periods and resulted in two blackouts, each of about six hours duration. These periods were short compared to the total time of the trial and were included in the statistics.

The test results revealed that there was nearly always more than one usable channel available for a given circuit: in fact, there were at least four channels available in the majority of instances. Moreover, the set of usable channels for two different circuits at a given time was often quite different, particularly where the circuit lengths differed considerably. One conclusion that might be drawn from these observations is that the availability of a suitable channel for setting up a call tends to remain relatively high even if several of the total set of channels are busy. There is also a strong indication that fewer than eight channels would provide good propagation probability; in fact, if only the best four channels for each circuit had been available, a usable channel would still have been present for more than 98% of the test period.

Finally, the results of the on-the-air tests clearly demonstrated the values of RTCE. Many instances of propagation well above the predicted MUF were encountered. On the 60 km circuit, for example, channels at 13.7 MHz and 20.5 MHz were usable on a number of occasions when the predicted MUF was in the 5 to 7 MHz range. Interference from distant stations sharing the same channel, another unpredictable element in HF communications, was also found to be a very important factor in determining the best channel to use. Even for the 60 km circuit it was demonstrated that the higher-frequency channels were best for a significant proportion of the time, even though these frequencies were above the MUF.

FIGURE 3

Percentage of test period for which the number of channels exceeded level 2 quality



ANNEX 5

Digital transmission HF radio system for voice, data and telegraph traffic, capable of integration with integrated services digital network (ISDN)*

1 Overview

1.1 System characteristics

The system described in the following provides:

– RTCE comprising passive channel analysis (PCA) and active channel analysis (ACA),

– integrated MUF prediction algorithm,

– automatic link set-up (ALIS),

– adaptive reaction to interference (AR).

It is suitable for transmitting:

– telegraph characters,

– data (computer data, facsimile),

– speech (analogue, digital),

with various data protection facilities:

– ARQ,

– FEC.

The system has a digital transmission capability using various techniques and speeds (depends on upgrade level):

– maximum of 228.7 bit/s, 2-FSK, 300 Hz bandwidth, frequency shift of ± 85 Hz, transceiver has integral modem,

– maximum of 720 bit/s, 8-FSK, 3.1 kHz bandwidth, system has integral modem,

– maximum of 2 400 bit/s, external modem, 3.1 kHz bandwidth, external HF modem connected into the system.

The system is also based on a flexible operating and interface concept (including remote control) for stationary and mobile applications; it can be integrated into various network configurations and, using a gateway computer, linked up with various communication networks, e.g. ISDN.

1.2 System structure

The ISO/OSI reference model (ISO: International Organization for Standardization, OSI: open systems interconnection) was used as a basis for communication between open systems (a system is defined as a complete communications system plus peripherals; open means that these systems can communicate with the "outside world" using standard protocols).

The automatically controlled HF radio system is an open system as defined by the ISO reference model. There is not a one-to-one correspondence between equipment and layers, for example, layers 2 to 5 are implemented by the communications processor. Function blocks are assigned to the various layers and give a more precise description of the tasks which have to be performed.

* For further information, see United States Federal Standard 1045A (HF Radio Automatic Link Establishment).

ISO layer	Device level	Function block
7 Application layer	Data terminal Control unit System processor	Data input/output Control Control Message handling Network link-up
6 Presentation layer	Encryption unit	Encryption
5 Session layer 4 Transport layer 3 Network layer 2 Data link layer	Communication Processor	PCA, ACA, ALIS, AR ARQ/FEC
1 Physical layer	Radio system	FSK, 8-ary FSK, USB, DPSK

DPSK: differential PSK.
USB: upper sideband.

2 Input data

The following data are entered into the communication processor via the control unit:

2.1 Permanent data

– Address list giving the coordinates and ranges of other stations relative to one's own,

– frequency pool,

– date and time,

– number of sunspots.

As a rule, permanent data is not modified, exceptions are the reconfiguration of the radio net, or a considerable change in the number of sunspots. The date and time are stored in the integral clock, the remaining data is stored in a backed-up RAM and need only be re-entered when the battery is changed or repairs are carried out.

2.2 Examples

Address list with coordinates and ranges relative to one's own station:

Address	*Station name*	*Coordinates/Distance*	*Code*
1234	ALPHA	C10.3E/40.5N	own
2312	BRAVO	C11.3E/42.4N	
5436	CHARLIE	D456	

(Coordinates indicated with C – longitude/latitude; E: East; N: North; W: West; S: South; D: Distance from 1-999 km)

A call is sent to the BRAVO station when the command "call: 2312" is passed to the communications processor.

The addressing provides the system with a selective call facility, however all network users can be contacted simultaneously by means of a broadcast address.

2.3 Frequency pool

The list of frequencies or channels that are to be used is stored in the frequency pool. This list has to be matched to the ranges in the address list so that the daily variations of the MUF and the LUF are covered. Generally, the frequencies are assigned by the appropriate authorities. A maximum of 16 frequencies can be entered in each pool and 25 different pools can be stored. However, the total number of frequencies stored must not exceed 100.

2.4 Date, time, sunspots

Using the date, time and number of sunspots, the integral radio prediction program calculates the MUF and hence the optimum working frequency (FOT) for the selected link and selects the best frequency from the frequency pool while performing PCA (see § 3.2 of this Annex).

2.5 Operating parameters

– Data protection ARQ/FEC,

– transmission mode data (normal, fast, extended speed), voice.

The operating parameters need only be re-entered when a different transmission mode is used, for example, switching from data to voice. Parameters need only be entered at the calling station, the called station receiving the operating parameters as part of the call.

2.6 Data protection ARQ/FEC

ARQ and FEC data protection has been provided for point-to-point or broadcast links. When ARQ is used, an acknowledgement makes it possible for both stations to react to a change in link quality (adaptive reaction). In the FEC mode, transmission quality is guaranteed by automatic channel selection and FEC.

2.7 Transmission modes data (normal, fast, extended speed), voice

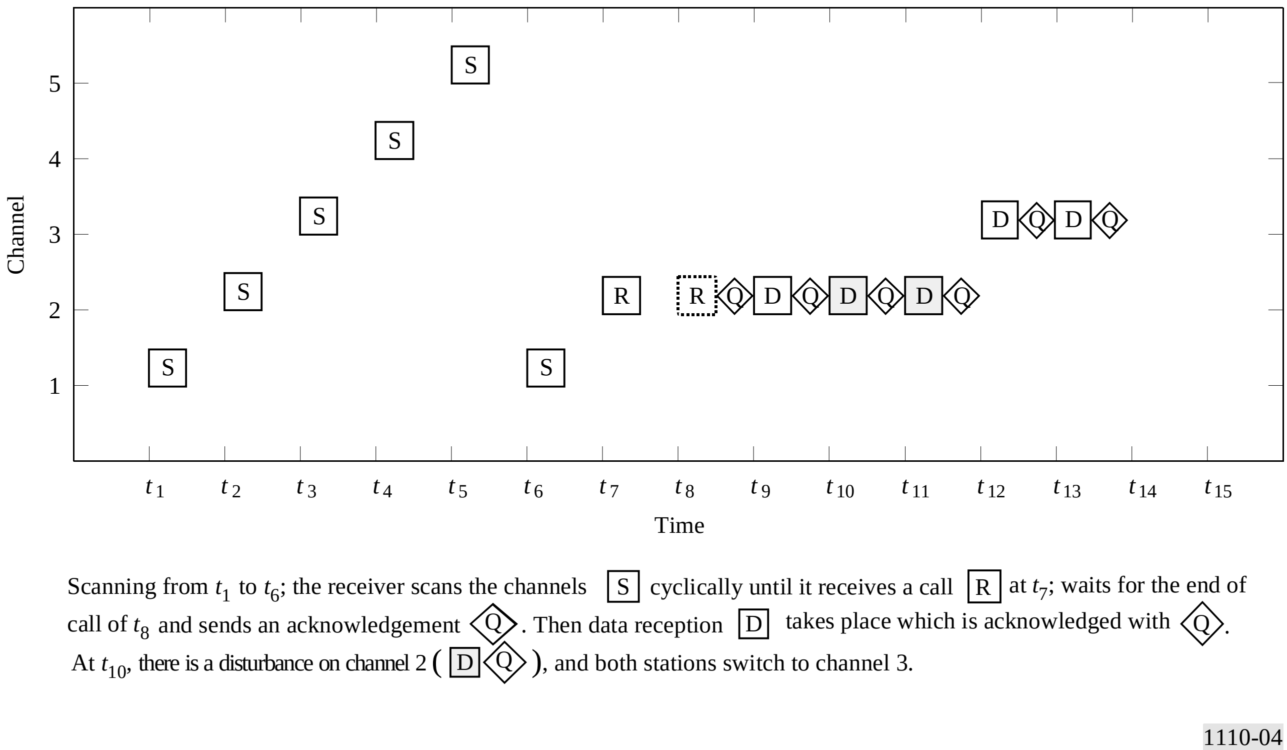
The user can select the mode he wants bearing in mind that the facilities available depend on the upgrade level of the systems taking part in communications. All systems must use the layer system defined by the ISO reference model.

3 Automatic functions of the communication processor

3.1 Passive channel analysis in scan mode (see Fig. 4)

In scan mode, the radio processor waits for a call from a co-station and at the same time checks the pool channels. The channels are connected cyclically and the dwell time for each channel is about one second. During this time, a correlation technique is used to search for a call sign and the channel quality is determined by measuring the mean level. The measured signal level is stored in a quality memory.

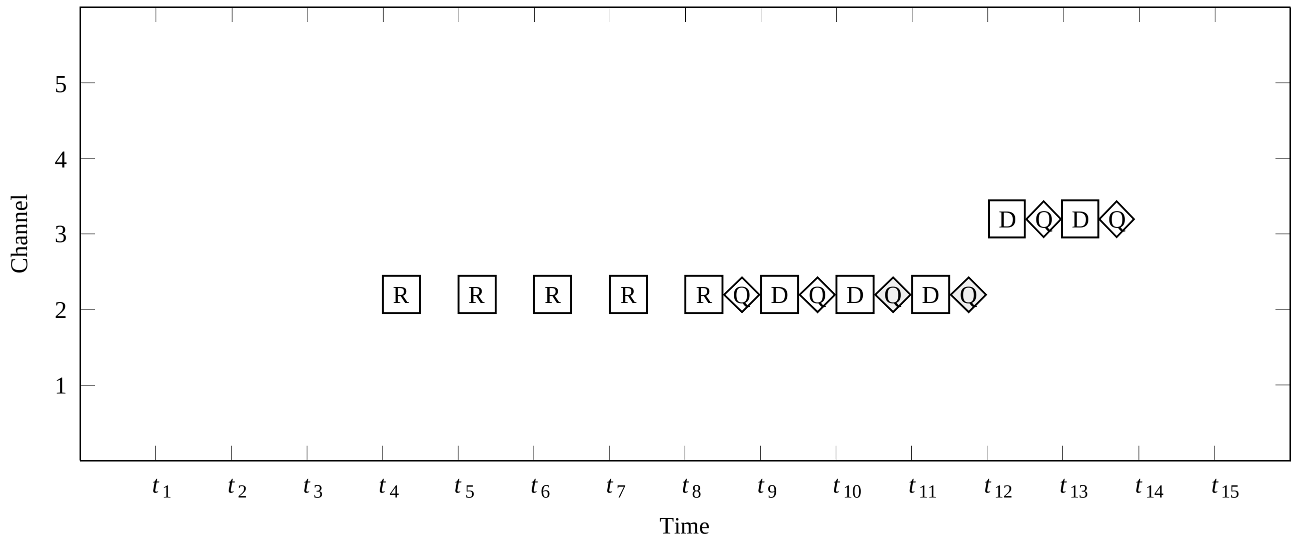
FIGURE 4



3.2 Calling procedure with active channel analysis (see Fig. 5)

The call procedure is started by a CALL command. This command aborts the scan mode; the communication processor then determines the FOT for the co-station using the integral MUF algorithm and selects the best frequency and the parameters in the quality memory.

FIGURE 5



Call from t_4 to t_8. The transmitter sends a call on the optimal frequency and after the acknowledgement ◇Q at t_9 starts with the data transmission [D]. At t_{10}, there is a disturbance on channel 2 ([D] ◇Q), and both stations switch to channel 3.

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A call is sent on this frequency. The call comprises a synchronization word, address, frame counter and status word. The sync word and the frame counter are used in conjunction with a correlation technique and weighted bit addition for bit and frame synchronization. The address makes selective calling possible; the status word is used to transfer radio mode parameters, e.g. speech/data.

The call is sent on one frequency long enough to allow the receiver to check all the frequencies. This ensures that the receiver checks the channel on which the calling station is transmitting for at least one scan period.

As a rule, the link is set up on the first call as the channel selection is supported by link prediction analysis and passive channel analysis.

If the call is not answered on a point-to-point link, the calling station retransmits the call on the next frequency; this process is repeated until a link is set up. In this way, active channel analysis is used to check quality while the link is being set up.

3.3 Transmission with active channel analysis

On point-to-point links, data is transmitted using ARQ. This method requires that each block transmitted is acknowledged by the receive station. The information sending station (ISS) and the information receiving station (IRS) are therefore in continuous, mutual contact. This makes it possible for both stations to check continuously the efficiency of transmission.

Irrespective of the error ratio or type of impairment, the efficiency can be determined by measurement of the block repetition rate and applying a moving average technique. If it drops below a certain threshold, adaptive reaction takes place.

3.4 Adaptive reaction

Adaptive reaction is an automatic switchover to another frequency, the choice being based on the daily variation of the MUF. This frequency is checked by continuing data transmission to see if the transmission quality is adequate. If this is not the case, the frequency is changed again. If conditions are exceptionally bad, all the frequencies in the pool may have to be checked, but in most cases, communications are re-established on the first or second attempt.

3.5 Data protection

Standard ARQ operates at 228.7 bit/s on the radio link. Each data block contains 30 data bits, 16 cyclic redundancy checks (CRC) and 2 identification bits. An acknowledgement block has 16 bits. A transmit/receive cycle lasts 485.4 ms. If transmission is error-free, the terminal rate is 100 Bd. The residual error rate is given in Fig. 8.

When the 720 bit/s data modem is used on the radio link, the ARQ procedure uses for data protection a similar coding and structure to standard ARQ. The residual error ratio is shown in Fig. 8.

ARQ operation can be configured for 5 bits for telegraph characters, 7 bits for ASCII characters or 8 bits for bit transparent transmission.

Even though transceivers are used, automatic turnaround of the direction of transmission based on how full the input buffer is makes it possible to realise quasi-duplex operation.

The FEC techniques have been specially adapted for HF channels.

4 Upgrade levels (see Fig. 6)

The standard version of the system has the following functions:

– conventional radio operation,

– universal, automatic link set-up as described in § 3.2 for all upgrade levels,

– standard ARQ with adaptive reaction:

terminal speed	100 Bd
link speed	228.7 bit/s
error correction	16 bit CRC
for residual error rate	see Fig. 7,

– radio telex/data mode switching after automatic link set-up,

– operation: teleprinter, terminal (see § 5 of this Annex).

The system can be expanded in the following way:

4.1 Enhanced transmission performance

– Integral FEC unit

terminal speed	50/100 Bd Baudot code 110/130 Bd ASCII code
link speed	117/228.5 Bd
error correction	interleaved convolutional code.

– Integral data modem with 8-FSK modulation having ARQ and adaptive reaction capability

terminal speed	390 Bd
link speed	720 bit/s
error correction	16 bit CRC
for residual error ratio	see Fig. 7.

– Integral FEC unit

terminal speed	432 Bd
link speed	720 bit/s
error correction	(5,3,3) Reed-Solomon code with 3 bits per symbol
for residual error ratio	see Fig. 8.

4.2 Enhanced performance on the terminal side

– A system processor makes the following possible:

use of a message handling system (software to ITU-T Recommendation X.400),

system can be connected or integrated to various networks, e.g. ISDN.

4.3 Function set expansions

– Integral 2 400 bit/s modem for transmitting:

images on facsimile equipment,

digital speech with a linear predictive coding (LPC),

vocoder data transmission.

FIGURE 6

Upgrade levels

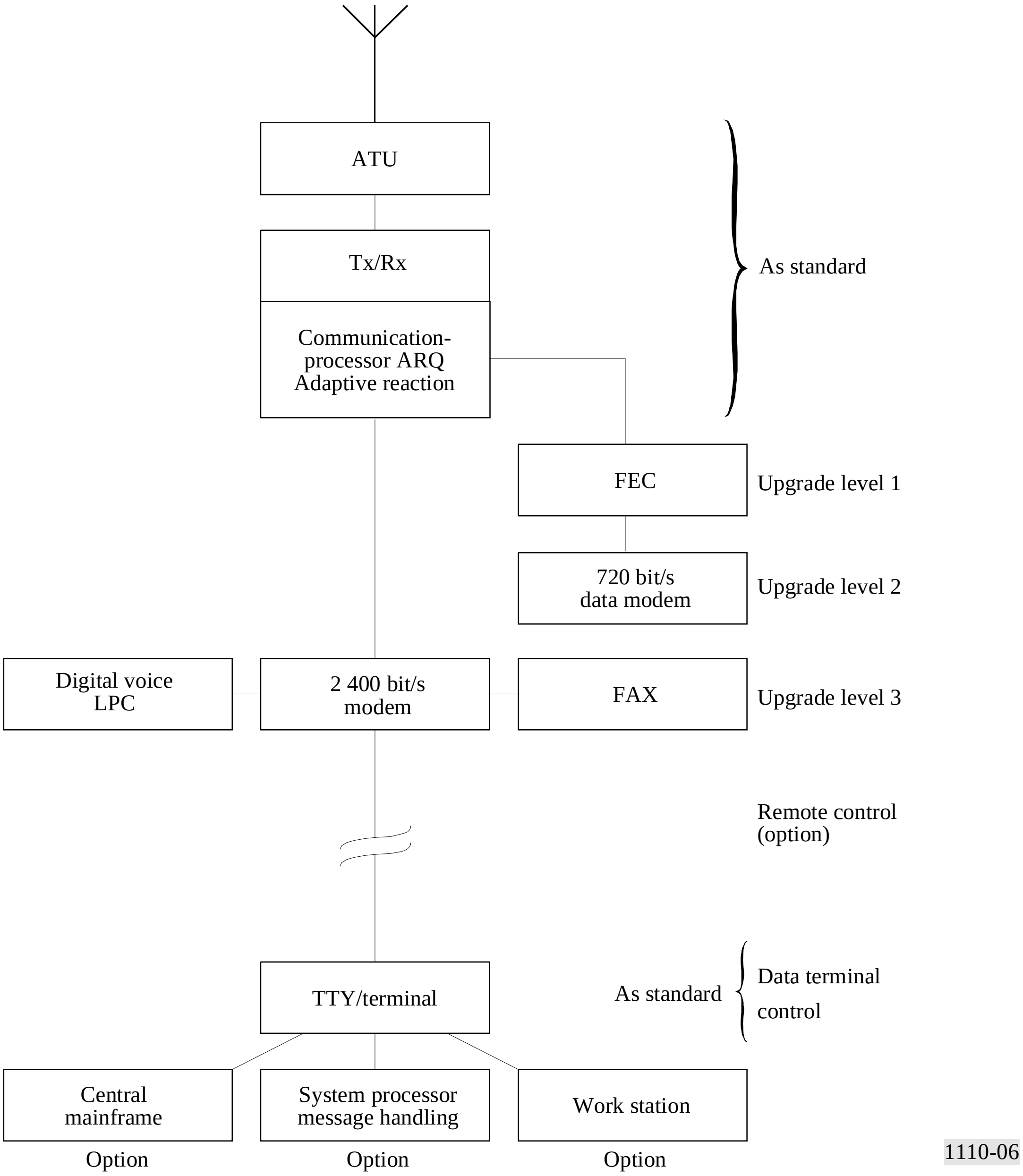
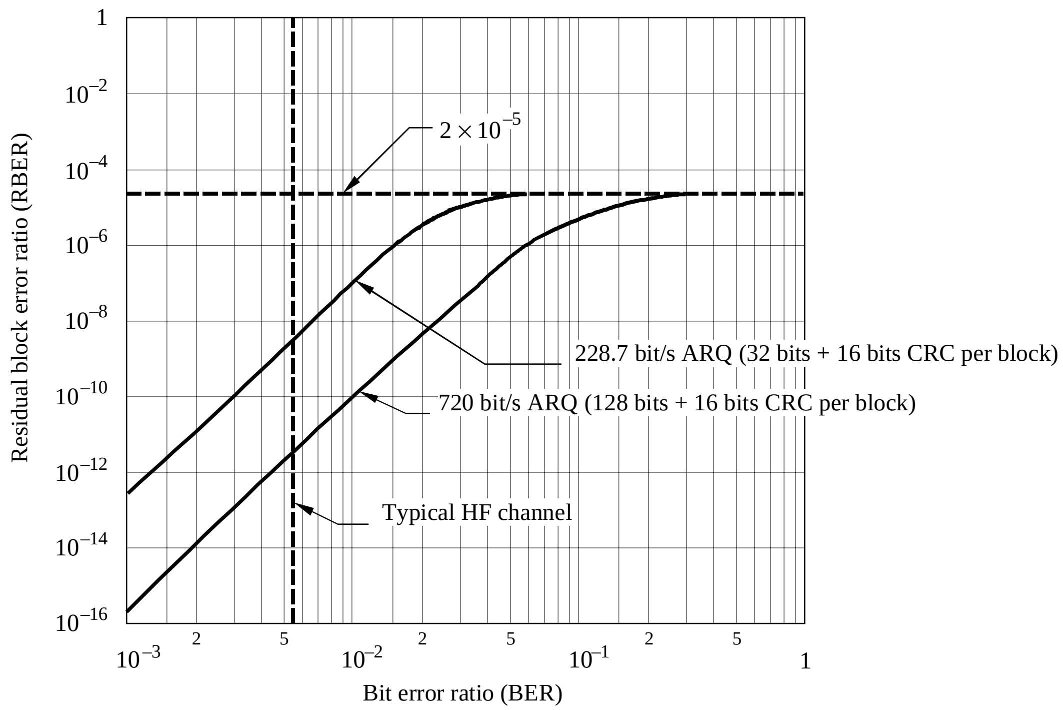


FIGURE 7

The residual block error ratio (RBER) for ARQ coding vs. the channel BER

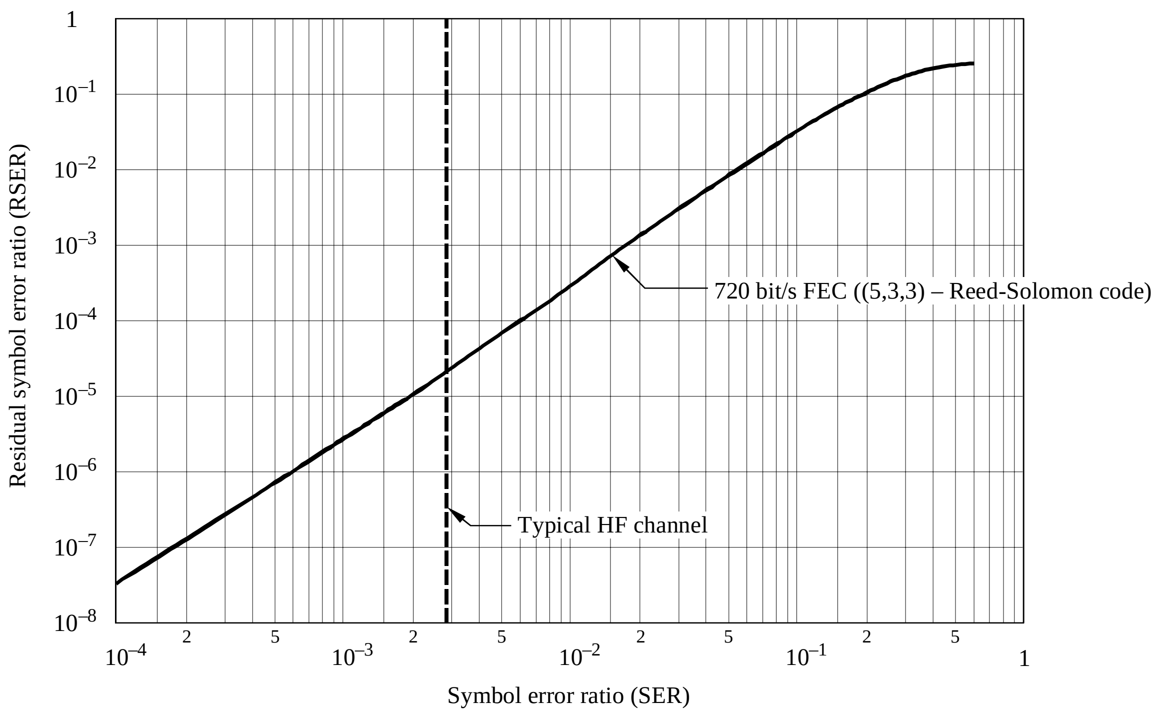


If the channel BER is 10^{-3} the probability that an error in a data block will not be detected is less than 10^{-12} or 10^{-16}.

1110-07

FIGURE 8

The residual symbol error ratio (RSER) for the (5,3,3) Reed-Solomon code vs. the symbol error ratio for the FEC unit with the 720 bit/s data modem



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5 Operating/interface concept

5.1 Interfaces

Exchangeable interface boards are the basis of a flexible operating concept. The system is configured via the control interface.

5.1.1 Control equipment:

TTY, terminal, system processor, central computer.

5.1.2 Operating modes:

Local

Remote control via cable, modem or VHF/UHF links.

5.1.3 Control interfaces:

RS-232-C, ASCII code, selectable current loop, Baudot or ASCII code.

5.1.4 Data interfaces:

RS-232-C, asynchronous, synchronous, 5 to 8 bits, selectable current loop, Baudot or ASCII code.

5.2 Operation

The operating concept is designed to accommodate future upgrades.

For the standard configuration, one terminal such as a teleprinter is sufficient for both control and data input/output.

Equipment such as terminals, personal computers, system processors and central computers which have the interfaces mentioned above can be used as control equipment.

If the simple control unit is replaced by a system processor, the radio system can accommodate practically any network configuration.

6 Tests

Since 1983 tests have been continuously carried out on various radio links. Ranges varying from zero to a few thousand kilometres were tried in the Federal Republic of Germany and other countries.

HF powers of 150 W, 400 W and 1 kW, transmitted from broadband antennas or dipoles with antenna tuners, were used.

The following has been confirmed:

– the reliability and speed of the automatic link set-up. Using passive channel analysis and the MUF calculation program, call set-up was achieved in most cases after the first or second attempt;

– the effectiveness of the data protection methods, which reached the theoretical limit;

– the reliability of the adaptive reaction facility in the presence of interference, which increases the availability of the radio path.

ANNEX 6

Equipment system for adaptive transmissions

1 General

Adaptive transmissions are carried out on the basis of a system of 20 W, 100 W and 400 W SSB stations.

The following types of service are possible:

– analogue telephony (J3E),

– digital transmissions: telegraphy or data transmission (F1B).

2 Main characteristics

The system has been developed in France and can be used for selective calling to connect two stations automatically or for broadcasting to a group of stations.

The link establishment procedures are set up through a modem using 8-FSK 125 Bd modulation associated with a Reed-Solomon error correction-detection code.

Traffic is then handled:

– by voice (band 300-3 050 Hz);

– by digital transmission with bit rates between 100 and 200 bit/s, re-using the modem already employed in the link establishment phase, or with bit rates between 1 000 and 1 800 bit/s, using a high bit rate serial modem.

In point-to-point mode (simplex or half-duplex), messages and data are routed using an acknowledgement procedure, with the power, the frequency or the bit rate being adapted on the link, where necessary.

In the (restricted or general) broadcasting mode, messages and data are simply coded and broadcast by radio.

3 Organization of networks

A network consists of a number of stations, each possessing the same initial definition elements: frequencies (not more than 16); frequency plans; frequency selection mode; address plans (individual, collective).

For the purpose of establishing point-to-point communications, each station is allocated an address.

The number of stations in a network is immaterial.

A station can receive the initial elements of nine networks, with a single address.

4 Traffic frequency selection

The equipment offers two traffic frequency selection modes:

a) manual mode, with frequency selection by the operator,

b) automatic mode, with selection of a frequency providing the required quality of service:

   – by the network master station for broadcasting; or

   – by any two members of the network to set up a point-to-point call.

All members of the network have to use the same frequency selection mode, which is contained in the initial elements defining the network.

In the automatic mode, all stations in the network maintain a cyclical listening watch in accordance with the plan of frequencies selected by the network master station (there are two frequency plans: a daytime and a night-time plan); for limited periods (“listening watch periods”), they cover the frequencies in the plan asynchronously and are thus in a position to receive a station which initiates a call procedure.

4.1 Establishment of a point-to-point link

4.1.1 When a member A of the network wishes to enter into contact with another member B, he dials a call sequence containing *inter alia* the following information:

– synchronization sequence (as the network is asynchronous, synchronization has to be built into the call),

– calling station (source address),

– called station (destination address),

– type of service.

Simultaneously, he consults his QAF (quality, address, frequency) matrix, which constantly contains the frequencies to be used, according to the quality of the preceding links.

He then sends the call over the recommended frequency F_1 and listens for the reply of B on F_1.

4.1.2 As soon as B detects the call sent to him, he transmits over F_1 a reply containing the quality rating of F_1 used in the direction A to B; this rating is based on the quality output of the error correcting code used in the procedure and an estimate of the SINAD of the link.

This reply from B enables A to generate in the same way a quality rating for F_1 used in the direction B to A.

4.1.3 If these two quality scores are adequate for the type of service required, F_1 is selected as the simplex frequency of the link.

4.1.4 If this is not the case or if there is no reply from B, A sends a new call on another frequency F_2 and the process continues until one frequency (simplex) or two frequencies (half-duplex) have been found which will provide the link in both directions with the required quality of service for the type of service required.

It should be noted that it is not essential to have simplex operation (traffic frequency effective in both directions of communication) and it is possible to authorize a half-duplex type of operation. The procedure can solve the problem of the asymmetry of certain frequencies, which are effective in one direction and are interfered with locally in the other, or the problem of different frequency allocations on the two ends of the link.

4.1.5 If no reply from B is detected by A or if no frequency (or pair of frequencies) can provide the link, the calling procedure is stopped at the end of two call cycles, and then repeated after a random delay.

4.2 Establishment of a broadcasting link

4.2.1 The network master station can decide at any time to initiate a frequency selection procedure by transmitting a series of calls on the frequencies of the network.

The procedure followed is similar to that used for point-to-point links except that, since the messages are sent to several stations, a collective address allocated to this group of subscribers is used and that, to enable each of the subscribers to reply, their replies are time division multiplexed and a reply slot is assigned to each one.

This obviously increases the length of the watch-keeping phases for the reply of the calling station; these additional periods can be used by the other stations in the network to listen to the reply in progress and thus to assign in their QAF matrix a receive quality rating at the frequency used by the station to which the reply slot in progress is assigned.

4.2.2 The calls are transmitted successively in the order of the best frequencies contained in the QAF matrix; as soon as the master station has received a positive reply from all the subscribers concerned by the call on a specific frequency, he informs the subscribers of this positive reply and begins to handle the traffic on this frequency.

4.2.3 If no frequency gives rise to a positive reply on the part of all subscribers, the master station chooses the frequency on which most positive replies have been received.

In this case, some subscribers run the risk of not receiving the contents of the broadcast. To ensure that the message reaches these subscribers, the broadcasts have to be restarted on a second frequency suitable to those subscribers for which the selected frequency was not satisfactory.

4.2.4 The procedure may last up to several tens of seconds altogether.

5 Functional architecture of a station for implementing the automatic frequency selection procedure

A station of this sort comprises an HF transceiver associated with a management microprocessor which runs the various push-to-talk and frequency change phases of the transceiver. This management processor is linked to the transceiver by a frequency and transmit/receive command (TC) and by a measurement transmission return link (TM) from the receiver. In the selection phases, the microprocessor generates messages or receives messages via a data link from an FSK modem which can be based on a signal processor (PTS).

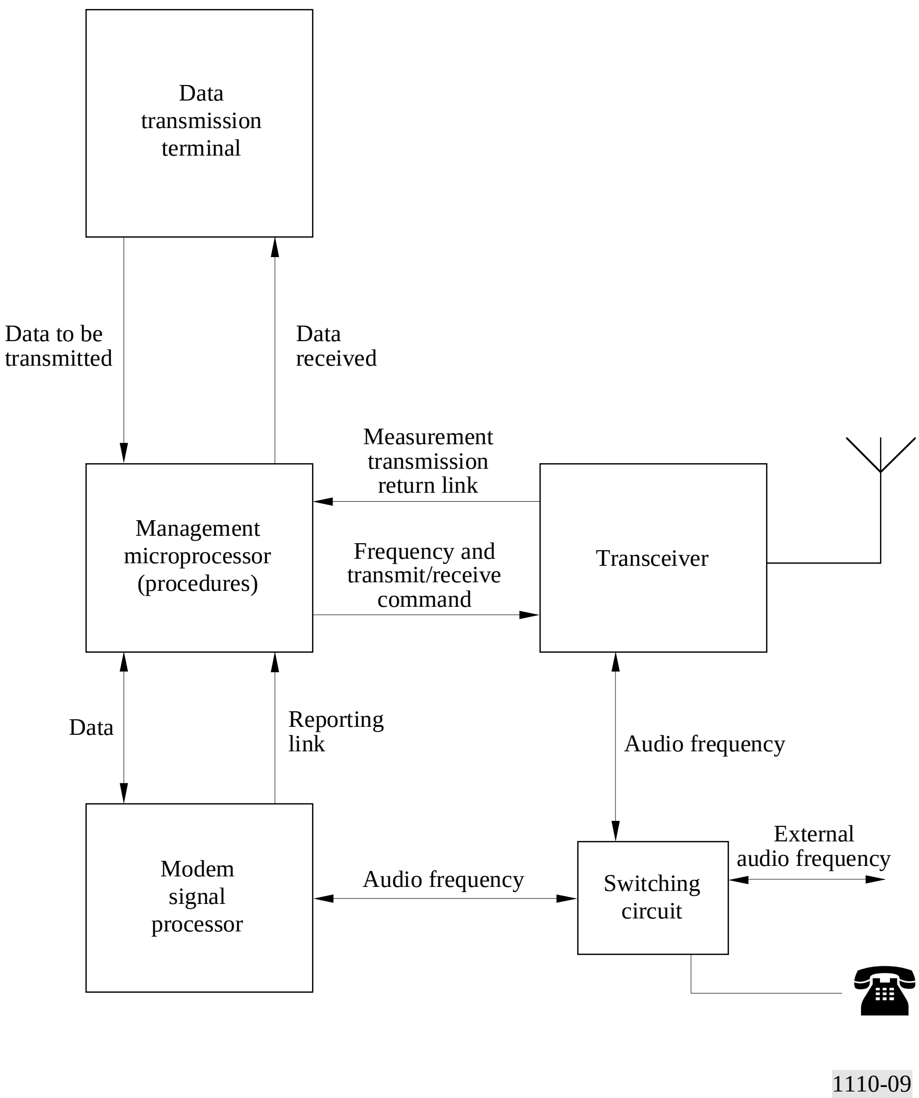
This processor may include correlation functions for detecting the synchronization sequence as well as facilities for the coding-decoding (Reed-Solomon for example, as mentioned in previous paragraphs) of the data to be transmitted or received. Using this arrangement, it is also possible to qualify the link by utilizing the error correction or detection capacity.

A reporting link (CR) is used to route this type of information to the management microprocessor.

The modem is interfaced by means of a two-way audio-frequency link to the transceiver via a switching device which is used to select either the FSK modem or an AF information from a telephone set or any other external device providing information in the 300-3 000 Hz audio band (external modem, telephone line, LINCOMPEX device).

FIGURE 9

Block diagram of a station with automatic frequency selection



ANNEX 7

An automatically controlled HF radio system

1 Introduction

An automatically controlled HF radio system (ACRS) has been developed in the United Kingdom which was designed to meet the following requirements:

– a network of 80 stations distributed throughout the United Kingdom,

– direct transmission over links of up to 1 000 km without relays,

– ability to work under disturbed conditions,

– automatic reception and transmission of stored messages,

– high traffic density with priority for urgent messages,

– high message integrity.

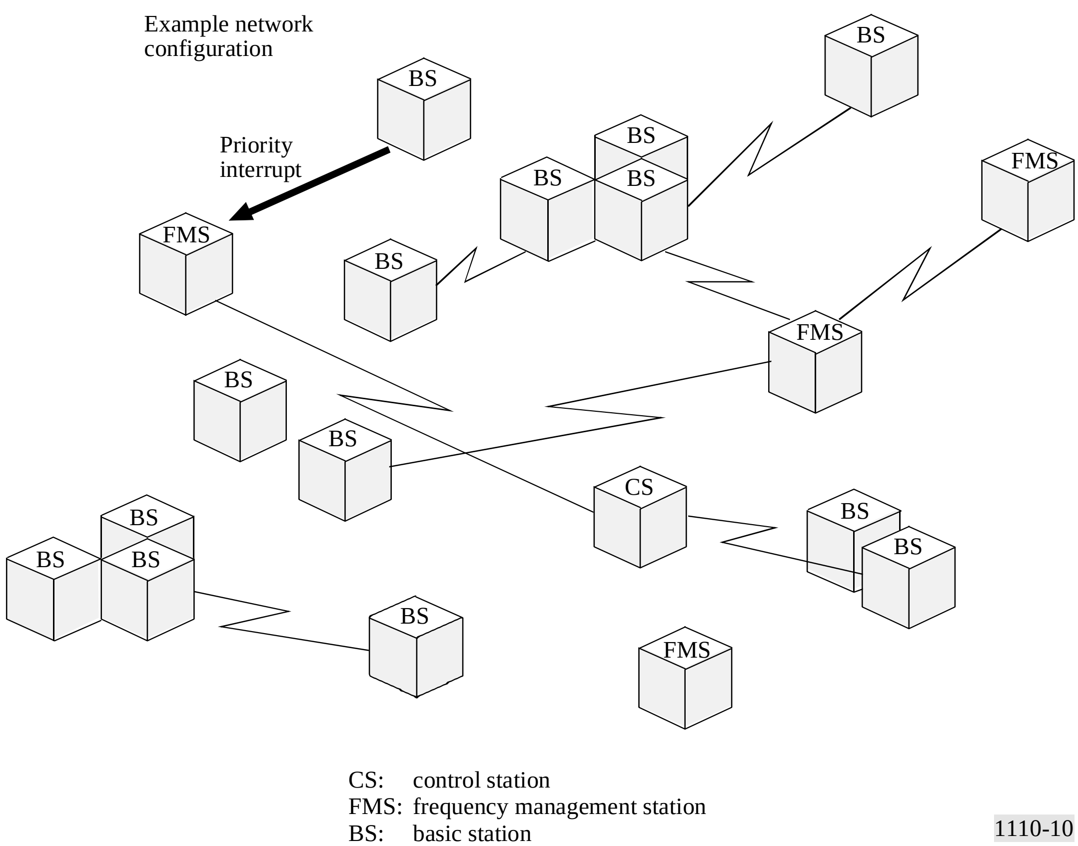
The system was configured to these requirements although the techniques can be adapted to other needs.

2 Operational data

As shown in Fig. 10, the stations within the system network may have any of three functions, i.e. control station (CS), frequency management station (FMS) or back-up control station (BCS) in addition to their normal basic station role.

FIGURE 10

Example network



The CS is a single station within the ACRS network and is made responsible for executing network management functions including network initialization, late entry and affiliation procedures, network frequency management and the distribution of engineering information. Any single ACRS station may take the CS role, but its traffic handling ability is then considerably reduced. The function of a CS is normally assigned to a lightly loaded station when operationally convenient. For that reason the CS is not normally allocated to a multi-station location.

The CS nominates up to four FMSs and performs active sounding routines with them during network initialization and at hourly intervals during normal operation. Any single HDRS station may act as an FMS if geographically suitable, but this again reduces traffic handling ability. HDRS stations at multi-station locations are not normally selected for the role of FMS. The first FMS nominated by CS is automatically defined as the BCS and will assume control of the network should the CS fail.

All ACRS stations are pre-programmed with the following frequency information:

a) full channel assignment (1023 maximum),

b) 20 engineering channels (from a)),

c) 40 FMS channels (from a)).

Prior to deployment and during initialization, ACRS stations are allocated the channels detailed above. These are distributed across the HF band (1.6 MHz to 30 MHz).

The "engineering" channels are scanned by all stations from power up and until they are synchronized and have joined the network. A station which loses network synchronization immediately reverts to scanning the engineering channels until re-synchronized. The engineering channels are interleaved with the 40 FMS channels allocated in frequency management. All 60 channels are swept hourly by the CS and FMS as part of the network frequency.

After network initialization "calling" channels are selected and distributed by the CS to all locations on an hourly basis. "Calling" channels are grouped in sets of five, normally selected from the 40 FMS channels and used to transmit call offers and acknowledgements when the network is operational. The traffic channels are also assigned to and stored at all stations.

These are channels not previously defined as FMS or calling channels. Each call within the network requires the selection of a viable traffic channel for passing message data.

An ACRS location is defined as an addressable node in the radio network at which one or more ACRS stations may be located. Most locations require only one station and are termed single-station locations. Individual stations within a multi-station location are not separately addressable, i.e. addresses refer to locations.

Two radio equipments are used in each station irrespective of role or classification. Each radio equipment comprises a transceiver assembly and control unit with its own separately mounted power supply unit (PSU). One radio equipment is designated "traffic" and is used for the transmission and reception of operational traffic to and from the station. The second radio equipment is designated "monitor" and is used to monitor the frequency spectrum and detect new call offers while the traffic transceiver is busy.

Messages may be either single address messages (SAM) or multi address messages (MAM). The messages are formatted using a detecting and correcting code and employ an automatic request for retransmission/forward error correction (ARQ/FEC) protocol.

3 Network management

3.1 Network initialization

Following deployment of the ACRS stations, network initialization takes place. The CS and FMSs are selected and the CS then executes a three state process to set up a synchronized and informed network of stations for passing message traffic:

a) Firstly, the CS calls the nominated FMS stations on each of the engineering channels and from the replies received estimates current propagation conditions.

b) Secondly, the CS performs a roll call of all stations on an optimum subset of five engineering channels.

c) Thirdly, the CS distributes engineering information and time synchronization to all stations, again using the five engineering channels.

3.2 Late entry facilities

The CS provides regular engineering information and time synchronization to enable late entrants to join the network. A late entrant may be a station that missed network initialization, or one that has lost synchronization with the network. Late entry transmissions are identical to those described at § 3.1c). Variable propagation conditions will cause the CS to review the list of channels used in this subset of channels.

3.3 Engineering updates

The engineering updates contain frequency management information, an active station list, a timing reference for synchronization and network control messages. They are sent hourly by the CS to all locations on one set of five calling channels, selected by the CS for the previous hour. A station which fails to decode an engineering update may collect the required information from late entry transmissions (see § 3.2).

3.4 Active location (station) list

The CS maintains a list of locations which it considers to be active within the HDRS network. This list is updated and distributed hourly, as part of the engineering updates (see § 3.3), to all locations. Locations are added to the list automatically during network initialization and when affiliation calls are received by the CS. Locations are retained on the list when call offers in the network are overheard by the CS and when locations are erased from the list manually by the CS operator, or automatically after a timeout period.

3.5 Network synchronization

Time synchronization is an integral part of call offer procedures and the ARQ message protocol. ACRS stations may only handle traffic if they maintain a local clock synchronized to the CS through time references included in all engineering transmission. Stations which lose synchronization must assume late entrant status.

3.6 Control station monitoring

The CS monitors calling channels and decode call offer transmissions in the network even when the transmissions are not addressed to the CS. This monitoring has two purposes, firstly to maintain the active station list and secondly to collect information on network loading from information on message queue sizes at individual locations.

4 Network frequency management

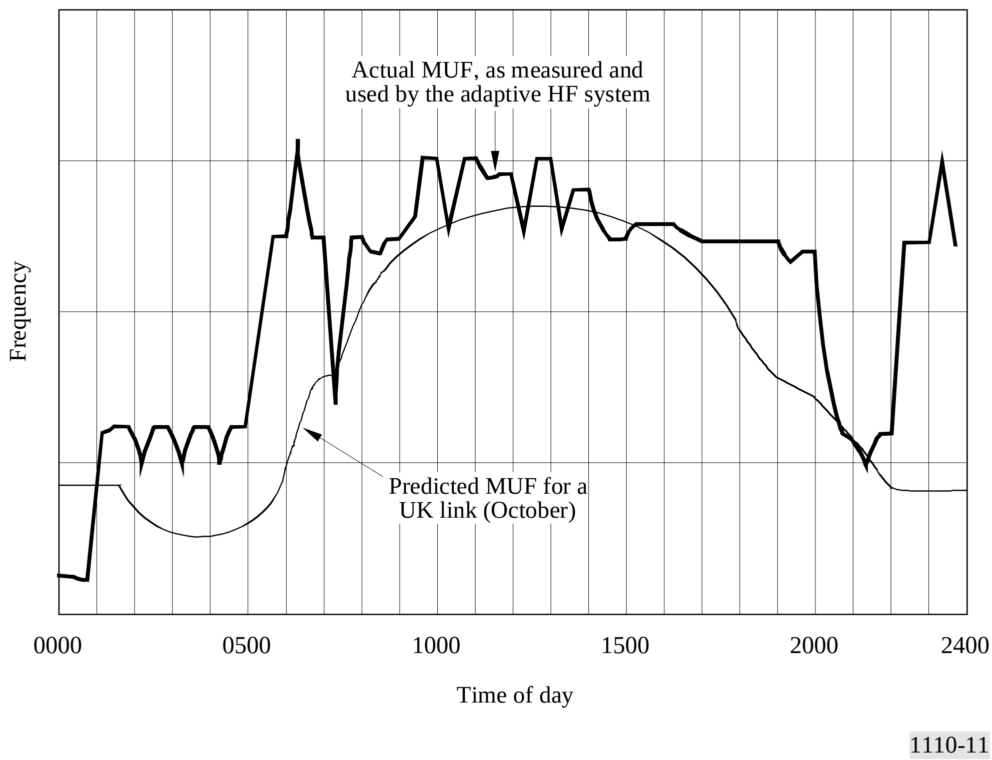
4.1 FMS sweep

The CS and its designated FMSs perform an hourly sweep of 60 channels across the HF band in order to ascertain the current state of the ionosphere. The sweep consists of the CS sending probe transmissions and the FMS stations transmitting acknowledgements to the probes received. The BCS (first FMS) which may be required to take over from the CS should it fail, will also transmit probes if it fails to receive any of the CS transmitted probes.

The results of the FMS sweep are used by the CS to estimate and distribute to all stations scaling factors for MUF and LUF and information regarding abnormal or disturbed atmospheric conditions. A 24-hour example of an FMS sweep is shown in Fig. 11. The FMS sweep results are also used by the CS to select the next hours subset of five engineering channels, to select the next hours subset of calling channels and to define the band limits for the next hour for the traffic channels. Calling channel and band limits data are passed to all stations during the engineering updates.

FIGURE 11

24-hour example of an FMS sweep



4.2 Link level frequency management

An ACRS station that wishes to transmit a message must first carry out a three-part procedure for selection of a traffic channel:

– Firstly a complex algorithm is used to select possible traffic channels. The criteria used by the algorithm are link distance and whether an SAM or MAM is being offered. Priority is given to a successful channel that has been recently used for sending a call (if relevant).

– Secondly, using the selected possible channels a simple noise level check is carried out. Those which appear blocked due to co-channel interference (which will in the main be due to other ACRS transmissions) are rejected. This procedure, being based on received signal level measurement alone, is termed "passive channel assessment". The channel selection and the passive assessment will end when sufficient "quiet" channels have been found for "active sounding".

– Thirdly, "active sounding" is carried out. To set up an SAM call, the source station will send test messages on each of five candidate traffic channels selected as outlined above. The destination will reply on the preferred channel and specify second and third choices. To set up an MAM call, the source will send test messages on up to four selected channels and collect replies from the destinations immediately after each transmission. In this case the active sounding will cease when sufficient replies are received for the call to proceed on the preferred channel.

5 Link management

5.1 Single address messages (SAM)

The SAM call offer sequence comprises a single handshake between source and destination on one calling channel. The source station transmits probe signals on each of the selected calling channels in turn until a response is received, or all channels have been tried. The transmissions are synchronized to the times at which the destination will be listening on the respective channels.

An SAM call offer with zero message length addressed to the CS may be made by stations wishing to affiliate with the network. For an SAM call the source transmits long forward data packets of approximately 18 s length, the destination returning short ARQ acknowledgements between forward packets. The acknowledgements may request repeats of blocks within the forward packet which have been synchronization codes from which both bit timing and frame synchronization can be derived.

Facilities are provided to allow SAM calls to change channels should communications be lost. Changes are made to the second or third channel choice during active sounding. The SAM protocol allows either source or destination to interrupt a call in order to deal with a higher precedence call, or in the case of the CS or FMS, to execute network management frequency management functions.

SAM calls to busy locations are not acknowledged. Call back facilities exist which allow the destination to contact the source using a calling channel when it is able to accept the call.

5.2 Multi address messages (MAM)

MAM call offer probes are transmitted on each set of five calling channels, defining the destinations required. A group address is used to alert a set of possible destinations and a bit field within the call offer probe defines the subset required. After active sounding the MAM call is transmitted in sections, a section being equivalent to four SAM packets. At the end of each section the source allows sequential time-slots for each destination to reply with ARQ transmissions. Repeat requests will be held by the source until the whole message has been sent once. After this repeat requests are serviced within defined limits. Most MAM calls will require more than one transmission to reach all destinations because some destinations are likely to be busy when the call is first offered.

6 Message handling

All ACRS stations will maintain a queue of outgoing calls awaiting transmissions and incoming call offers which could not be accepted earlier. These queues contain information on the time the outgoing call should be offered and the precedence level. Unsuccessful outgoing call offers are returned to the queue with a re-offer delay determined by the precedence level. SAM calls within the network will be assigned one of four precedence levels. For MAM calls, more than one precedence level may apply, individual levels applying to subgroups of destinations, as follows:

– In the first instance, outgoing calls will be positioned in station queues according to precedence level. Should any call fail to reach its destination when its turn comes, it is returned to the queue for re-offer at a time determined by its precedence level.
– Incoming, unsuccessful SAM call offers are placed in the receive queue for callback according to precedence level.

7 Tests

Since 1988 testing of the system has been carried out. The validity of the test results obtained using a small number of stations (6-20) has been confirmed by a computer model of the system. By running the simulated system on the model, for the reduced number of stations, comparing the actual results of the trial and then running the model for the full system, it has been possible to confirm that the ACRS meets the design aims.

ANNEX 8

System for HF radio automatic link establishment*

1 Introduction and overview of automatic link establishment systems

The United States of America has developed a series of HF radio standards that characterize and specify protocols and parameters for automatic link establishment (ALE), networking, linking protection, high speed data modems, and basic HF radio parameters.

ALE is a robust, adaptive HF radio method for automatically establishing communications over HF SSB links. Using ALE, an operator or computer-initiated control signal can automatically initiate point-to-point or point-to-multipoint calls. The ALE controller can be programmed to scan one or more frequencies, pick the best frequency for operation, and switch to voice or data operation upon link establishment. The ALE system initiates calls on selected channels, which are rank ordered through an internally programmed link quality analysis (LQA) algorithm. This permits the link establishment process to have the most likely chance of success on its initial trial using previously measured LQA numerical channel scores that are stored in the system’s memory. The identities of the calling and called stations are exchanged between stations, along with call sign designators to distinguish the calling from the called station.

Optional features include linking protection, which employs security methods to prevent unauthorized network entry, transmission and reception of user data, and over the air reprogramming (OTAR).

The ALE link establishment and link management functions are performed by reliably conveying the ALE link information over HF channels between station pairs. This high reliability is obtained by triple redundancy transmission of the ALE data, interleaving, and Golay forward error correction.

* For further information, see United States Federal Standard 1045A (HF Radio Automatic Link Establishment)

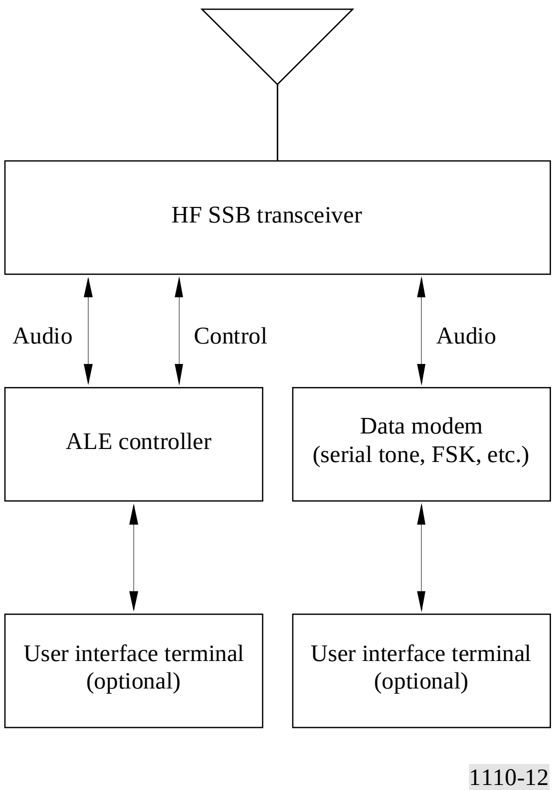
An adaptive HF radio system block diagram is shown in Fig. 12. The ALE controller provides the automation of the linking process. ALE networking functions and linking protection functions can also be incorporated into the ALE controller. After the link is established, data or voice communications can be initiated by switching a high speed data modem into the circuit.

ALE is designed to be modular in nature, and uses audio tones and serial data signals to interface the ALE controller with HF-SSB radios. It can be embedded as a low-cost, integral part of modern HF-SSB radios using digital signal processing (DSP), either as a standard or optional module. It can also be added to many existing HF-SSB radios as an external applique, either as a stand-alone component, or as a personal computer (PC) compatible kit of hardware and software.

Also available are tools such as calibration and test signals on audio compact discs (CD), which permit the development and interoperability testing of ALE products without costly channel simulators.

FIGURE 12

Adaptive HF radio block diagram



2 ALE transmissions and word format

The ALE waveform is designed to pass through the audio passband of conventional SSB radio equipment. The waveform is an 8-ary FSK modulation with eight orthogonal tones. Each tone is 8 ms in duration and ranges in frequency from 750 Hz to 2 500 Hz with 250 Hz separation between adjacent tones. Each tone represents 3 bits of data, resulting in an over-the-air data rate of 375 bit/s.

The ALE standard word consists of 24 bits which are separated into a 3-bit preamble field followed by three 7-bit ASCII character fields. The function of each transmitted ALE word, as designated by the preamble code, is related to the basic ALE capabilities. There are eight word types: TO, THIS IS, THIS WAS, DATA, REPEAT, THRU, COMMAND, and FROM. Each 7-bit ASCII character field is used to specify an individual address character or as ASCII text, depending on the preamble.

3 Protocols

3.1 Scanning

All ALE stations, when operational and not otherwise committed, continually scan a preselected set of channels, or “scan set,” listening for calls and ready to respond. The minimum dwell time on each channel is the reciprocal of the scan rate, and the channels in the scan set are repeatedly scanned in the same order. ALE receivers scan channels at either 2 or 5 channels per second resulting in a dwell time of 200 or 500 ms. When a transmitter wishes to “capture” a scanning receiver, it will transmit a signal that will be recognized by the scanning receiver. The duration of this “scanning call” must be sufficient to ensure that if the receiver is indeed scanning for calls, it will land on the channel carrying the scanning call before the transmitter ceases emitting.

3.2 Selective calling

Selective calling in an ALE system involves the exchange of ALE frames among stations. This selective calling capability supports all higher-level ALE functions, including link establishment and data transfer. The general structure of an ALE frame consists of one or more destination addresses, an optional message section, and a frame conclusion which contains the address of the station sending the frame.

The fundamental ALE operation of establishing a link between two stations proceeds as follows:

– The calling station addresses and sends a call frame to the called station.

– If the called station “hears” the call, it sends a response frame addressed to the calling station.

– If the calling station receives the response, it now “knows” that a bilateral link has been established with the called station. However, the called station does not yet know this, so the calling station sends an acknowledgement frame addressed to the called station. At the conclusion of this three-way handshake, a link has been established, and the stations may commence voice or data communications, or drop the link.

3.3 Individual calling

Systems for HF ALE have a protocol suite for both single channel and multiple channel linking. All ALE stations, when not otherwise committed, continuously listen for calls. The protocol consists of three parts: an individual call, a response, and an acknowledgement.

3.4 Sounding

A sound is a unidirectional broadcast of ALE signalling by a station to assist other stations in measuring channel quality. The broadcast is not addressed to any station or collection of stations, but merely carries the identification of the station sending the sound.

3.5 Multiple station operations

A net call is addressed to a single address that implicitly names all members of a pre-arranged collection of stations (a “net”). All stations belonging to the net that hear the net call send their response frames in pre-arranged time slots. The calling station then completes the handshake by sending an acknowledgement frame as usual.

A group call works similarly, except that an arbitrary collection of stations is named in the call. Because no pre-arranged net address has been set up, each station must be individually named. Called stations respond in slots, determining their slot positions by reversing the order that stations were named in the call. The calling station sends an acknowledgement as usual.

4 Orderwire messages

In addition to automatically establishing links, ALE stations have the capability to transfer information within the orderwire, or message, section of the frame. Orderwire messages include automatic message display (AMD), data text message (DTM), and data block mode (DBM) modes. These functions enable stations to communicate short orderwire messages or prearranged codes to any selected station(s). This permits station operators to send and receive simple ASCII text messages by using only the ALE station equipment.

5 Link quality analysis

ALE systems have the capability to support the exchange of LQA information among ALE stations. The LQA process measures the quality of a channel by placing a score on it, which incorporates three types of link analysis information: BER, signal-plus-noise-plus-distortion to noise-plus-distortion ratio (SINAD), and optionally a measure of multipath. The LQA scores are stored in memory for future use. ALE stations are capable of selecting the best channel to initiate a call to, or seek, a single station based on the values in the LQA memory, where the channel with the highest LQA score has the highest probability of being suitable for communication.

ALE radios obtain LQA scores by receiving sounds from other stations, resulting in a score on the received path from the sounding station to the receiving station. Another method of obtaining LQA scores is by initiating a bi-directional sound, a non-linking call designed to measure and transfer LQA scores. Bi-directional sounds produce LQA scores for the forward and reverse paths (in reference to the initiating station). A third method is during the linking process.

6 Network configurations

Multiple station operations are often required in HF networks where several types of network configurations individual links, networks and groups are encountered. The most simplistic configuration is a link which comprises only two stations and consists of a single path between the two. Star net and star group configurations consist of more than one link within the network.

Systems for HF radio ALE have a backup manual control capability.

6.1 Star net

A star net is a prearranged collection of stations that operates with a single hub station in a “one-to-many” configuration. In most cases the hub station has the function of the net control station that manages and controls the functions of the network. The star net is usually organized with significant prior knowledge of the member stations so that operation of the network is optimized. By using a single net address for all of the net members, efficient contact with multiple stations is achieved.

6.2 Star group

A star group is a non-prearranged collection of stations where typically, little or nothing is known about the stations except their individual addresses and scanned frequencies. Like the star net it operates in a “one-to-many” configuration using a net control station. A star group call is performed from a sequence of the actual individual station addresses of the called stations. The stations respond in a manner specified by the sequence of call addresses.

7 Addressing

The ALE system deploys a digital addressing structure based upon the standard 24-bit (3 characters) word and the basic-38 character subset. ALE stations have the capability and flexibility to link or network with single stations or with prearranged or as-needed groups of stations.

The ALE system provides and supports 3 hierarchical sets of characters; the basic-38 subset, the expanded-64 subset, and the full-128 set. The basic-38 subset includes all capital alphabetics (A-Z) and all digits (0-9), plus designated utility and wildcard symbols “@” and “?”. The expanded-64 subset consists of all ASCII characters whose two most significant bits (MSBs) are 01 or 10, and includes all capital alphabetics, all digits (0-9), the utility symbols "@" and "?," plus 26 other commonly used symbols. The full-128 set includes all characters, symbols, and functions available within the ASCII code.

7.1 Individual station addresses

The fundamental address element in the ALE system is the single routing word, containing 3 characters, which forms the basic individual station address. This basic address word may be extended to multiple words for increased address capacity and flexibility for inter-net and general use. An address which is assigned to a single station is termed an "individual" address. If it consists of 3 characters or less it is termed a "basic" size, while if it exceeds 3 characters it is termed an "extended" size. The 3 characters in the basic individual address provide a basic-38-address capacity of 46 656, using only the 36 alphanumeric characters. Extended addresses provide address fields which are longer than 3 characters, up to a maximum system limit of 15 characters. This 15-character capacity enables ISDN address capability.

7.2 Multiple station addresses

A common requirement in HF networks is to simultaneously (or nearly simultaneously) address and interoperate with multiple stations. A prearranged collection of stations with a common address is termed a "net," and the common address is a "net address." A non-prearranged collection of stations, i.e., a collection of stations lacking a prearranged common address, is termed a "group."

7.2.1 Net addresses

As a prearranged collection of stations, a net is organized and managed with significant prior knowledge of the member stations, including their identities, capabilities, requirements, and in most cases, their locations and necessary connectivities. The purpose of a net call is to rapidly and efficiently establish contact with multiple prearranged stations by the use of a single net address, which is an address assigned to all net members in common in addition to their individual addresses. The net address structure is identical to that of individual station addresses, basic or extended as necessary. At a net member's station, each assigned net address is associated with a response slot identifier to allow each station to respond to the net controller in a systematic manner.

7.2.2 Group addresses

Unlike a net, a group is not prearranged. In many cases, little or nothing is known about the stations except their individual addresses and scanned frequencies. The ALE group addressing mechanism provides a means to create a new group where none existed. This mechanism uses a standardized protocol which is compatible with virtually all automated stations, regardless of their individual, net, and other characteristics. The purpose of a group call is to establish contact with multiple non- prearranged stations rapidly and efficiently by the use of a compact combination of their own individual addresses. A group address is formed from a sequence of the actual individual station addresses of the called stations, in the manner directed by the specific standard protocol.

7.3 Special addressing modes

The special addressing modes include Allcalls, Anycalls, Wildcards, Self address, and Null address. The ALE basic address structure is based on single words which, in themselves, provide multiples of three characters. The quantity of available addresses within the system, and the flexibility of assigning addresses, are significantly increased by the use of address character stuffing. This allows address lengths which are not multiples of three characters to be compatibly contained in the ALE system address fields by "stuffing" the empty trailing positions with the utility symbol "@".

An "Allcall" is a general broadcast which does not request responses and does not designate any specific address. This mechanism is provided for emergencies, broadcast data exchanges, and propagation and connectivity tracking.

An "Anycall" is a general broadcast which requests responses without designating any specific addressee(S). It is required for emergencies, reconstitution of systems, and creation of new networks. An ALE station may use the anycall to generate responses from essentially unspecified stations, and it thereby can identify new stations and connectivities.

The selective "Anycall" is a selective general broadcast which is identical in structure, function, and protocol to the global "Anycall," except that it specifies the last single character of the addresses of the desired subset of receiving station (1/36 of all).

A caller may use the Wildcard character ("?") to address multiple stations with a single wildcard address. Responses to a call containing an address with wildcard characters are generated in pseudo-random slots to avoid collisions.

For self test, maintenance, and other purposes, stations should be capable of using and responding to their own Self addresses.

For test, maintenance, buffer times, and other purposes, stations may use a Null address which is not directed to, accepted by, or responded to by any station.

ANNEX 9

Adaptive HF communication networks with real-time frequency management for use in the fixed and mobile services

1 Introduction

Adaptive HF voice and data communication networks has been developed with real-time frequency management capabilities for use in the fixed and mobile services. Initial implementation is directed toward the maritime services, but the architecture is consistent with fixed and mobile applications. The network technology is designed to allow seamless transmission of electronic-based messages (e-mail), facsimile, and other data services through land-based, desktop facilities via a network gateway to fixed or mobile (i.e., shipboard) subscribers located anywhere in the world. The technology will also support conventional voice service.

This technology is adaptive in nature having access to a dynamic propagation nowcasting and forecasting system which enables the network to overcome the variabilities of HF communication service. The frequency management system derives its information from a limited network of low-power transmitters employing an frequency modulated continuous wave (FMCW) chirp waveform located at fixed (i.e., shore-based) facilities, along with compatible receivers installed as part of the communications suite of equipment at the subscriber location (viz., ship or fixed location). These subscriber units are augmented by a number of similar receivers deployed to fixed installations controlled by the network. The sounding component of this frequency management system is also used for network management and urgent paging functions and optionally serves as a robust low data rate communication mode.

2 Network concept and frequency management aspects

The adaptive HF network technology, uses HF radio to provide wireless connectivity to multiple users over thousands of miles. Traditional management of long-haul HF networks is difficult as a result of unpredictable ionospheric propagation variabilities, and thus frequency management methods based wholly upon climatological median models become quite inefficient for specification of useful communications frequencies. The adaptive HF network is managed through application of FMCW oblique-incidence sounders. These sounders, used for more than 20 years by the military for frequency management of fixed links, are associated with other input data sets providing ionospheric status information, and an updatable model, such as VOACAP (Voice of America Coverage Analysis Program), to form the dynamic frequency management system which is required.

The sounder-based system provides for an evaluation of the entire HF band (3-30 MHz), apart from selected frequencies which are blocked-out to eliminate the potential of harmful interference to specifically identified systems. Moreover, the system evaluates channel quality of a preselected set of frequencies which have been authorized for voice and data communication. This dual approach of full-band sounding and communication channel evaluation is an extremely powerful method for nowcasting as well as forecasting. The full-band approach is essential for forecasting in time and extrapolation of propagation information to other locations, since such processes require ionospheric predictions of high accuracy; and such results are not afforded by predictions alone, and are not derivable from stand-alone channel evaluation schemes. This dual approach distinguishes it from other adaptive HF systems.

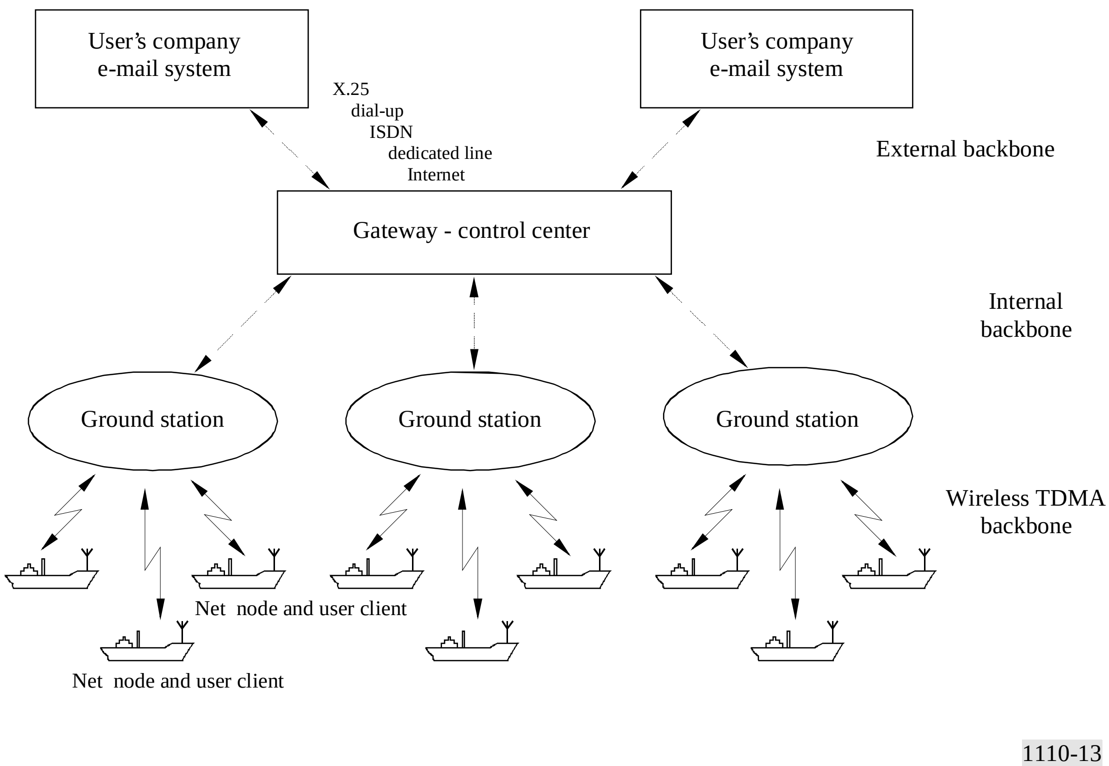
The benefits of the adaptive HF network include the following: low cost, reliability, accountability, serviceability, seamless e-mail, facsimile service, and voice service.

3 Network topology

The adaptive HF network has the following components: a user central site, a gateway site, system ground stations, and remote nodes (i.e. network subscribers). The user central site is comprised of an e-mail system on the customer premises and an e-mail gateway to the adaptive HF network. (The user central site is typically a fixed installation.) The network gateway site is a wireless gateway including connections to e-mail gateways and connections to system ground stations. System ground stations are comprised of connections with the network gateway, an HF radio network controller, and a sounder transmitter. The remote nodes are comprised of an HF radio network remote node, a sounder receiver, and e-mail gateway, and a remote client or network with e-mail capabilities. (The user remote nodes may be fixed or mobile, but the architecture is consistent with a maritime-mobile architecture.) This is illustrated in Fig. 13.

FIGURE 13

Network topology



3.1 User office

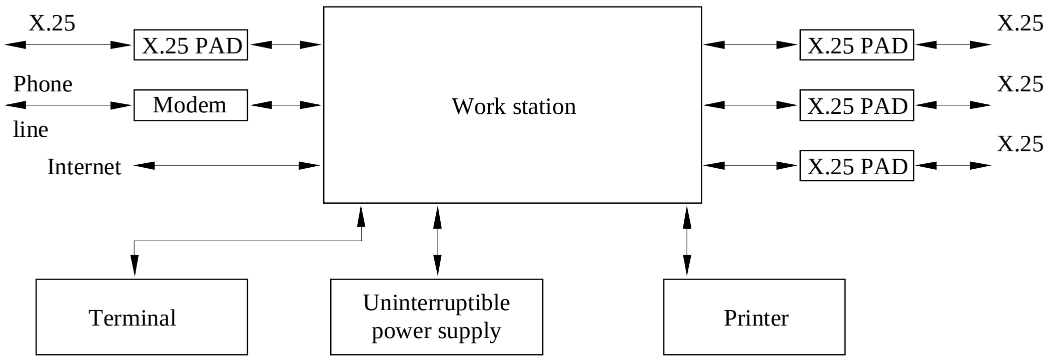
The adaptive HF network uses an e-mail gateway at the user site to transfer e-mail to the network gateway. The gateway operation is very similar to the Internet gateway scheme, wherein the messages are converted to a common format and make use of transmission control protocol/information protocol (TCP/IP) as the transport protocol. Native e-mail formats are converted when they pass through the e-mail gateway before reaching the system control center. The combination of protocol and the link type which is used to reach the network gateway is referred to as the external backbone. This backbone uses the simple mail transfer protocol/multipurpose Internet mail extensions (SMTP/MIME) protocol as a common mail format for the entire system, and the TCP/IP transport protocol over either public (i.e., Internet) or private (i.e., dial-up network, ISDN, X.25) networks.

3.2 Network gateway

All incoming addressed mail is checked to verify access right to the HF network via its IP address. Once the mail is accepted by the system gateway, it is filtered using the "TO:" field. Filtered mail is saved in mail-slots according to the information in their message's "TO:" field. Each remote user in the network has its own mail slot. There are at least two levels of security supported for each mail slot. The mail slots are emptied in a round-robin fashion by a process which uses TCP/IP protocol to send messages to appropriate ground stations. This segment of the network is called the internal backbone. Being an internal network, IP addressing is implemented independently of the Internet addressing. The network gateway is shown in Fig. 14.

FIGURE 14

Block diagram of gateway



PAD: packet assembler and disassembler

Note 1 - The workstation shown may be a high-end UNIX workstation or an NT server. More than one active workstation may be connected via a local area network (LAN) in order to support the amount of traffic and/or provide the redundancy.

1110-14

The adaptive HF communication gateway e-mail system covers features contained in most native e-mail formats, including: TO, FROM, Attach binary and text files, delivery confirmation, and receipt status. Additional features include: accounting, access control, and auditing.

Once the e-mail is received by the ground station, it is converted to a slotted Aloha protocol used for conveyance in the HF link. The HF radio link protocol reliably delivers the TCP/IP packets to the remote terminal.

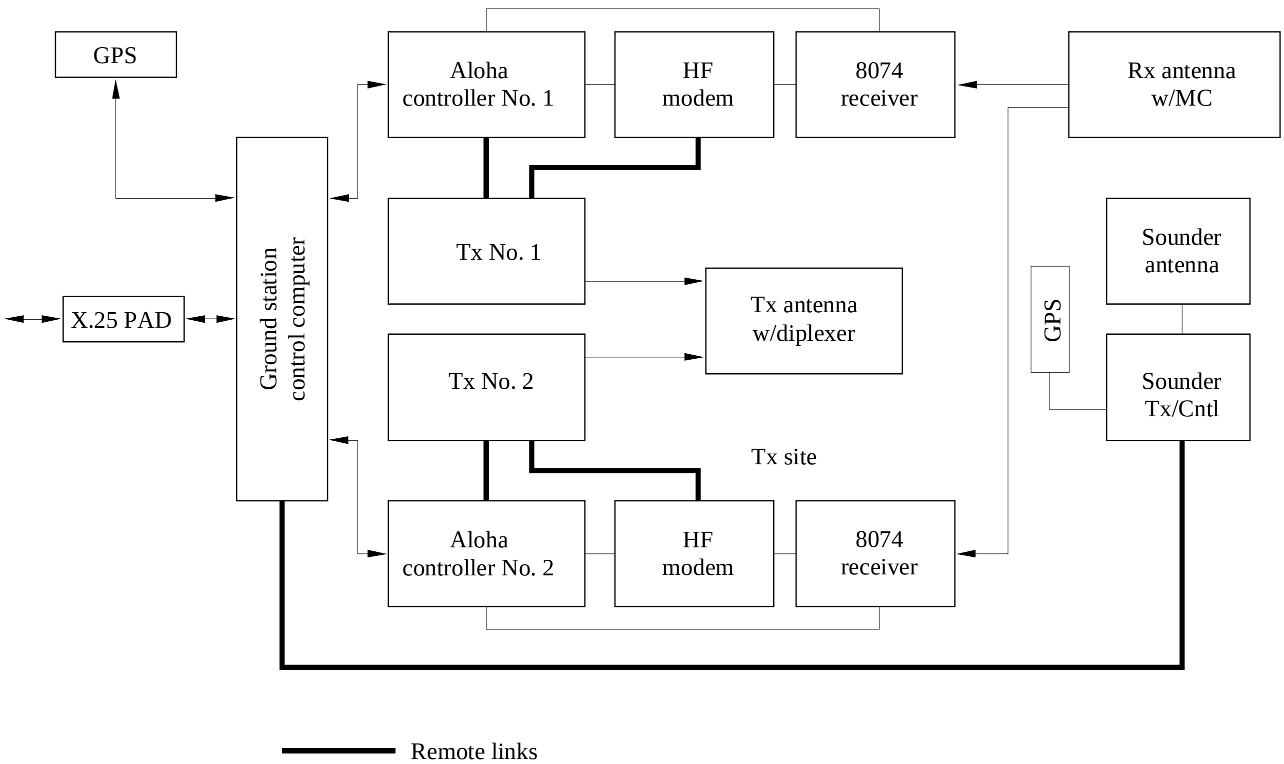
3.3 Ground station

The ground station is the entry point into the wireless network segment which is using the HF medium to transfer the data between the ground station and the shipboard system remote controller. Because individual ground stations use a slotted Aloha protocol, this segment of the network is referred to as the time division multiple access (TDMA) backbone. The physical layer of the TDMA protocol uses an HF modem with bit rates of 150, 300, 600, 1 200, and 1 800 bit/s depending upon signal quality. The ground station is depicted in Fig. 15.

Each ground station can operate on multiple frequencies (i.e, using a frequency division multiple access (FDMA) scheme), and on each of the frequencies it runs a TDMA protocol. Also, each ground station runs a chirpsounder transmitter.

FIGURE 15

Ground station configuration



GPS: global positioning satellite

Note 1 - The ground station is configured to operate on up to four frequencies, while two frequencies may be utilized in an interim configuration. The ground station uses split site operation, and it uses multiple Aloha controllers to support multifrequency operation. There is an overall station controller that coordinates all activity, including chirpsounder transmissions. All controllers run on a PC-based platform.

1110-15

3.4 Remote nodes

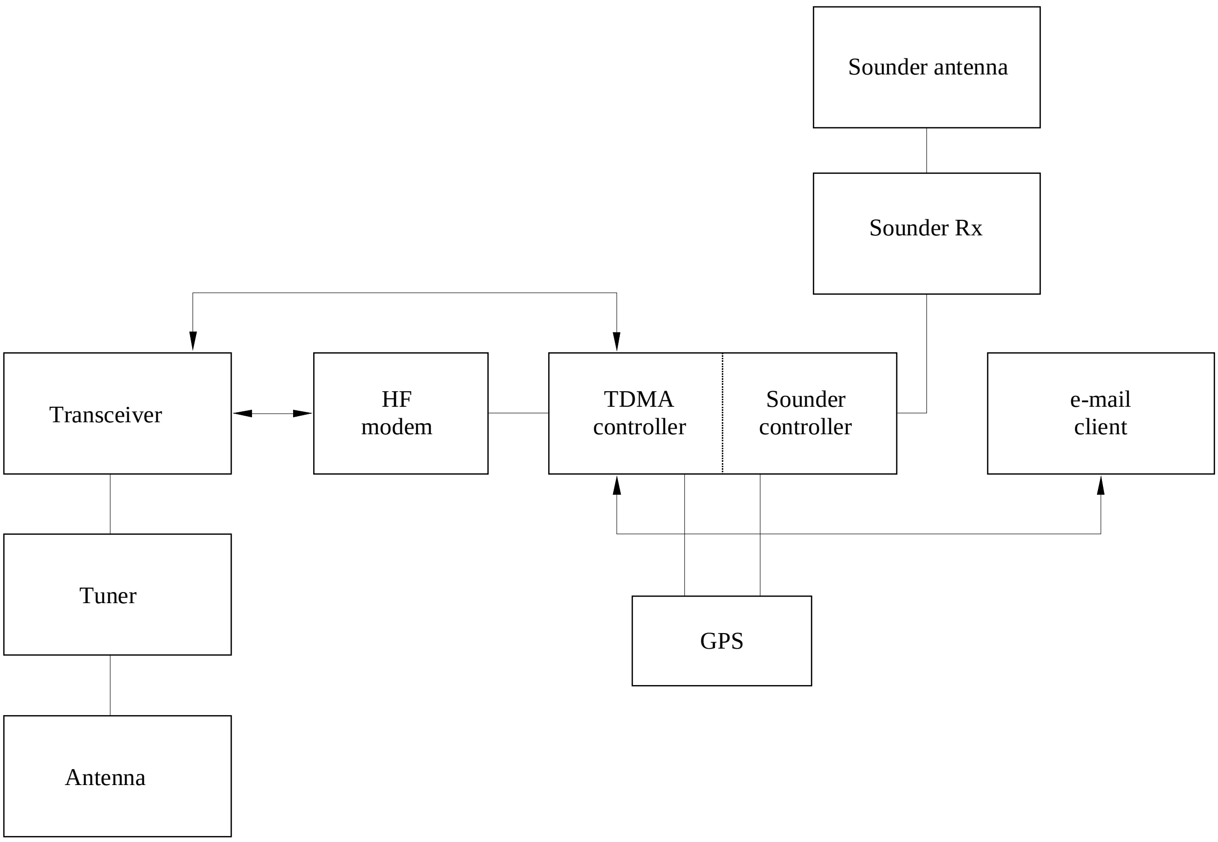
Each remote node (which may be fixed or mobile) uses an FMCW swept-frequency sounder receiver to receive the low-power chirp signals from up to four ground stations. This procedure enables station diversity to be exploited as necessary. Based upon the received chirp signal quality, the system controller picks the best frequency (from a list of maritime HF channels) to log-on to the network. If the “best” propagating frequency is not actively used by the ground stations, the remote terminal tries to log-on to the “best” frequency used by any of the monitored ground stations. During the log-on procedure, the remote node reports the its best propagating frequencies to the ground station. Based upon this propagation information, ground stations manage their channel assignments to provide the reliable HF communication with remote terminals.

The block diagram for the remote node is given in Fig. 16. The purpose of the remote node is to act as a gateway for the remote e-mail system to the network. In this function, it supports the TDMA protocol used on the HF radio, and the chirp sounder operation which is integral to the frequency management subsystem. It also connects with the user’s client e-mail application.

The user client software (i.e., e-mail application program interface (API)) can be as simple as a software package consisting on the same computer as the remote node software, or may be resident on a separate computer. The mail server for the system supports multiple computers acting as clients, configured as stand-alone or as an Intranet.

FIGURE 16

Remote terminal diagram



Note 1 - The remote terminal is comprised of a split backplane with two independent PCs. One runs the Aloha protocol, and one runs the sounder controller. Both the Aloha controller and sounder receiver controller require GPS, which will be a shared resource in general.

1110-16

4 Voice, fax, and telex services

Additional services such as voice can be enabled for fixed and mobile subscribers, for instance the network can provide ship-to-shore and shore-to-ship traffic for mobile platforms in the maritime environment. In the former case, the ship-to-shore voice communications may be started by a process in which the end-user calls an operator at the system gateway location requesting a call to a particular client. If the ship is logged onto the data network, the system gateway operator sends an e-mail message to the ship instructing it to initiate a voice call procedure. In this procedure, the ship communications controller will request from its ground station the grant for an exclusive use of a frequency. Once the exclusive frequency request is approved by the controller, it will automatically call the operator to establish a phone voice circuit from the ground station to the gateway. At the same time the ground station will send a message to the ship indicating that it has access to voice channel frequency, and it will patch the audio from the ship into the voice circuit to the gateway. Once the ship voice message is received by the operator, he will perform the final patch by dialing the shore-based end-user who has requested the voice service and patch him into the voice link with the ship. Once the handset aboard the ship is back on-hook the ship controller will again log-on to the data network, and its log-on will be used to free the allocated frequency for either data or voice service.

Ship-to-shore voice call is set-up in a similar manner. The ship will request exclusive use of the frequency, and also pass the number it wants dialled. The dialing could be passed to an operator at the gateway, or it may be carried out at the ground station. In either case, dialing will occur when the ground station grants the exclusive use of the frequency. The voice call termination is the same as in the case of the shore-to-ship call.

For a fixed network of subscribers the procedure is approximately the same. Facsimile and telex services are supported by means of a gateway at the network gateway station.