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**IEE PROCEEDINGS SECTION A-K, vol. 129, no. 3, part F, June 1982, pages 213-222, Old Woking, Surrey, GB. P.J. MUNDAY et al.: "Jaguar-Vfrequency-hopping radio system**

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## Description

This invention relates to radio communication apparatus and particularly to such apparatus in which the carrier frequency is changed periodically in an attempt to maintain security and overcome jamming of the radio transmission. Such periodic frequency changing is called hopping.

In a typical example of such a system operating in the VHF band (30—88 MHz) there are a possible 2320 channels at a spacing of 25 kHz. Of this number a limited fraction are made available to the radio sets in the network. The greater the number of available channels the more secure the system but the greater is the storage capacity required for the identification of the valid channels. The set of channels over which frequency hopping takes place, i.e. the available channels, is called a 'hop-set'.

Each radio set in the network may be adapted to operate on a common hop-set according to its own pseudo-random sequence thus giving what is called a random hopping system. In this system, statistically predictable interference occurs as a result of random frequency coincidences when two communications are being conducted simultaneously.

The alternative, so-called orthogonal, system is one in which both the hop-set and the pseudo-random sequence is common to each radio set in the network. Some means then has to be employed to prevent continuous interference between the channels used in simultaneous communications.

One system employing frequency hopping is described in US Patent No. 3584303. The transmitter and receiver operate on synchronized sequences of frequency steps, the pattern of frequencies being repeated in successive sections. To the extent that the sequences are not systematic they can be said to be pseudo-random. It appears that one station can be called from another, selectively, by the called station generating a frequency pattern in sequential time slots which, when heterodyned with the received signal provides a recognition code.

There is not, however, the degree of security provided by the present invention nor the facility for non interference between simultaneous independent communications.

An object of the present invention is to provide a random frequency hopping system which permits simultaneous non-interfering conversations in a radio network.

According to the present invention, a frequency-hopping radio communication system comprises a plurality of radio transmitter/receiver sets having means for changing their operating frequencies periodically, in synchronism, and according to a common main-line pseudo-random channel sequence, each radio set having means for modifying its operating channel sequence to a side track sequence which is dependent upon the point in said main line sequence at which the modification is initiated, and means for transmitting a signal to a selected other radio set to initiate said side track sequence in the receiving radio set at the same instant as in the transmitting radio set, both radio sets being arranged to revert to the main-line channel sequence on termination of transmission.

The modification may be effected by a change in a feedback path of a pseudo-random number generator in each radio set which generator determines the operating channel sequence of a radio set.

A frequency-hopping radio commmunication system in accordance with the invention will now be described, by way of example, with reference to the accompanying drawings, of which:—

Figure 1 is a block diagram of one radio set of the network indicating the generation of main-line and modified channel sequences;

Figure 2 is a timing diagram of the channel changes in different operating conditions of the system; and

Figure 3 is a diagram of a frequency hopping radio communication system employing two radio sets as a relay station.

Referring to the drawings, a number of different radio sets in a network, which are required to be able to communicate with each other, each include apparatus as shown in Figure 1. A real time clock 1 steps a random number generator 2 through a pseudo-random number sequence, the output number at any instant being determined by the original number, i.e. the key variable, with which the random number generator was loaded, and the time elapsed since that occurrence. All radio sets in the network are loaded with the same key variable and their clocks are initially synchronised, so that all radio sets will produce the same pseudo-random number sequence in synchronism. There may be a very slight phase drift between the number sequences of the different radio sets if they should run on for a substantial time without communication but this is accommodated as will be seen.

Each radio set has a stored table 3 of permitted frequencies, i.e. a large random selection of the total possible channels in the band. This hop-set is again common to all radios of the network.

The table 3 is addressed by each multi-digit random number as it arises and the resulting channel frequency identity is applied to a transmitter/receiver radio 14 which is frequency agile and electronically tunable. The operating frequency thus changes periodically and synchronously for all radios of the network in accordance with the number sequence provided by a number generator. This common basic sequence will be referred to as the main-line sequence.

The key variable initially loaded into each random number generator 2, can be changed periodically for different networks on a geographical or other basis.

The random number generator 2 consists of a shift register with predetermined feedback in known manner. In addition to the basic construction there is a controllable feedback path 4 which, when effective, changes the pattern generated in a predetermined manner. This feedback path is controlled by a switch 6, the modified number sequence produced by the generator then depending upon the content of the generator when the modification is initiated.

A bistable 8 determines the condition of the switch 6, the switch being closed when the bistable is 'set'.

In the passive condition of the network, i.e., with no transmissions in progress, all radio sets operate on the same main-line sequence of channels and are therefore all receptive to any transmission from another set. In order to make selective transmissions while operating on this main-line sequence therefore, a selected receiving set is identified by a calling signal, this address being transmitted to all sets. Prior to the called radio address however, a synchronising sequence is transmitted to correct any timing drift that may have occurred since the previous transmission. Each transmitter is thus assumed to have correct timing but each radio set as a whole will have its timing correct whenever it operates as a receiver. There will therefore be a tendency to bring all the radio sets of a network into synchronism.

Following the synchronising sequence and the address of the called radio, an absolute time marker is transmitted, a so-called 'bingo' signal. It is the transmission and reception of this signal which initiates the modification of the random number generator 2 in the transmitting and receiving radios.

Referring to Figure 1 again, this modification is initiated as follows. The bistable 8 has a set input derived by way of an OR-gate 10 from a 'bingo' detector 12 which monitors the signal received by the basic radio 14. Immediately therefore, on reception of the 'bingo' signal the bistable 8 is set, the switch 6 is closed, and a modified random number sequence is generated dependent upon the content of the generator at the instant of switch closure. At the transmitting radio the bistable 8 is set at the same instant by a signal following the synchronising and addressing preamble. This post-transmission synchronising signal is applied by way of the OR-gate 10.

Both transmitting and receiving radios are thus modified at the same instant and with the same content in their random number generators. The resulting modified sequences, which bear no relation to the main-line sequence, are therefore identical and communication can proceed between these two radios. If, of course, transmission to two or more other radios is required this is easily accommodated, by transmission of the respective addresses on the main line sequence.

Figure 2 shows the effect of closure of the switch 6 on the operating frequency sequences. The upper horizontal line indicates the main-line frequency sequence $F_5$ $F_{18}$ $F_6$ etc. (a typical part of the sequence), the frequency changes occurring at regular intervals determined by the clock. If, for example radio 1 calls radio 2, and the 'bingo' signal arises at the instant of the main-line change to $F_4$, then a sidetrack sequence will occur in radios 1 and 2 having typical frequencies $F_{15}$ $F_{10}$ $F_3$ etc. as shown. These latter changes will occur in synchronism with the main-line changes $F_1$ $F_3$ $F_{10}$ etc. Radios 1 and 2 will then operate on the modified or sidetrack sequence while the remainder of the radios in the network carry on passively on the main-line sequence.

If at a later instant radio 3 should call radio 4 and emit a 'bingo' signal at $F_{12}$ in the main-line sequence then the content of the random number generators of radios 3 and 4 will at that instant be different from the content of the generators of radios 1 and 2 and consequently a new sidetrack sequence will arise for the operation of radios 3 and 4. No interference between the two communications will arise other than the predictable statistical coincidence of frequencies.

At the end of a transmission an 'end-of-message' code is transmitted, which is detected by a detector 16. An output from the detector 16 resets the bistable 8 by way of an OR-gate 18, the switch 6 opens, and the generator 2 reverts to the production of the main-line sequence in the same phase as if it had not been interrupted.

A transmit key input 20 also serves to reset the bistable 8 by way of OR-gate 18 to ensure that on transmission the radio is operating on the main-line sequence i.e. on which all other (passive) radios are listening for their address code.

The system described has the significant feature, in contrast with fixed frequency radio systems, that an ongoing selective communication does not prevent the rest of the net communicating, or setting up selective calls of their own, since the sequence of frequencies used to set up calls, the main line sequence, is unrelated to the sequence of frequencies used for the message, the sidetrack sequence. Furthermore, there are as many different sidetrack sequences as there are points of departure from the main line sequence, the only limiting factor to their use being the acceptability of interference caused by the statistical probability that two or more sequences will alight on the same frequency at the same time.

Some incidental advantages of the above 'divergent-key-operation' system arise as follows.

If a frequency hopping radio using the basic main line sequence for all purposes is captured by an enemy with its key variable and hopset programming intact, it would ordinarily be possible for the enemy to employ the radio to jam the rest of the net of which it was part, merely by switching it permanently to 'transmit'.

However, the system, as described above, makes this virtually impossible. If the captured radio is switched permanently to 'transmit' in an attempt to jam, it will, after the short initial preamble, switch to the sidetrack sequence of frequencies which will then not interfere with any other transmission. Even if a receiver is addressed, and follows the spurious transmission, the operator can, upon determining that the message is of not value, switch the receiver back to the main line by pressing the transmit switch 20 momentarily.

The main-line sequence could be rendered unavailable to a large extent by constantly switching a captured radio between transmit and receive. Software or hardware traps may be built into the radio to prevent a captured radio being switched in this way. Such a trap may for instance cause erasure of the key variable upon detection of such behaviour.

A captured radio may, of course, be modified by the enemy to bypass these traps; but that would involve laboratory work, and by the time the radio was returned to the field, the key variable would no longer be current. It may also be made extremely difficult to extract the key variable from one radio in order to transfer it to a modified radio.

In order to extend the coverage range of ground wave radio systems, retransmission is often employed, whereby the signal is received from the initiating transmitter on one frequency, and relayed on another frequency. Two conventional radio sets may be connected back-to-back to provide such an automatic relay station, as illustrated diagrammatically in Figure 3. In military systems, single frequency simplex is used on each leg of the path, and the relaying transmitter is keyed only when the receiver detects the presence of a valid signal. Since the two legs of the relay path must be on different frequencies to provide adequate isolation between the co-sited transmitter and receiver, the frequency on which a receiving station should best listen depends on its geographical position, i.e., whether it is nearer to the initiating station or the appropriate relay site. In a conventional system therefore, a mobile station may have to change frequency according to position. Thus, the relay station may comprise two radio sets B and C each as aforesaid but modified in that set B is made receptive to all transmission irrespective of address, any valid transmission so received on the main line sequence causing conversion to a sidetrack sequence at the BINGO code reception. The first radio link in the relay process, i.e. between the originating station A and the relay station B/C is then operated on a first side track sequence. On such valid reception the transmitting set C of the relay station is caused to initiate re-transmission on the main line sequence, of the synchronising and address preamble, the address being that of the out-station D, relayed from the originating station A. On transmission of the BINGO code by the set C both set C and out-station set D switch to a side-track sequence which is different from that in operation between the AB link since it arises at a later time. There is again, therefore, no interference between the AB transmission and the CD transmission.

In the return direction the functions of sets A and D are interchanged and the operation proceeds exactly as before.

The mobile radio set D will lock onto the first synchronisation preamble which is receives successfully whether from the initiating station A or the relay station B/C. As it moves out of range of one relay site and into the coverage zone of another, no action is thus required by the operator to pick up the new relay link.

**Claims**

1. A frequency-hopping radio communication system comprising a plurality of radio transmitter/receiver sets (Figure 1) having means (2, 3) for changing their operating frequencies periodically, in synchronism, and according to a common main-line pseudo-random channel sequence, characterised in that each radio set has means (4, 6) for modifying its operating channel sequence to a side-track sequence which is dependent upon the point in said main line sequence at which the modification is initiated and means for transmitting a signal to a selected other radio set to initiate said side-track sequence in the receiving radio set at the same instant as in the transmitting radio set, both radio sets being arranged (6, 8, 16, 18) to revert to the main-line channel sequence on termination of the transmission.

2. A system according to Claim 1, characterised in that each radio set (Figure 1) incorporates a pseudo-random number generator (2) and a channel frequency identifying store (3), each number generated by the pseudo-random number generator (2) determining a respective operating channel frequency for the radio set, and wherein the pseudo-random number generator (8) incorporates a controllable two-state feedback path (4) which, in one state causes the pseudo-random number generator to produce a said side-track sequence.

3. A system according to Claim 2, characterised by transmit-key means (2) whereby, before transmission, operation of said transmit key means causes said feedback path (4) to adopt the other of the two states.

4. A system according to any preceding claim characterised by a relay station which comprises two radio sets (B, C) each as aforesaid, one (B) of said two radio sets being adapted to accept transmissions irrespective of addressee and the other (C) of said two radio sets being coupled to said one radio set (B) to re-transmit all signals received thereby, the difference in time between reception by said one set (B) and retransmission by said other (C) causing the two links to operate on different side-track sequences and thus provide frequency isolation.

**Patentansprüche**

1. Frequenzsprung-Funkverbindungssystem mit mehreren Funksende-Empfangsgeräten (Fig. 1), die Mittel (2, 3) zum periodischen synchronen Ändern ihrer Betriebsfrequenzen nach Maßgabe einer gemeinsamen Hauptstrecken-Pseudo-

zufalls-Kanalreihenfolge aufweisen, dadurch gekennzeichnet, daß jedes Funkgerät Mittel (4, 6) zum Ändern seiner Betriebskanal-Reihenfolge in eine Nebenstrecken-Reihenfolge aufweist, die von dem Punkt der erwähnten Hauptstrecken-Reihenfolge abhängt, in dem die Änderung beginnt, und Mittel zum Aussenden eines Signals an ein anderes ausgewähltes Funkgerät, um die erwähnte Nebenstrecken-Reihenfolge in dem empfangenden Funkgerät zur gleichen Zeit wie in dem sendenden Funkgerät auszulösen, aufweist, wobei beide Funkgeräte so ausgebildet sind (6, 8, 16, 18), daß sie am Ende der Übertragung in die Hauptstrecken-Kanalreihenfolge zurückkehren.

2. System nach Anspruch 1, dadurch gekennzeichnet, daß jedes Funkgerät (Fig. 1) einen Pseudozufallszahlengenerator (2) und einen Kanalfrequenzidentifizierungsspeicher (3) aufweist, wobei jede durch den Pseudozufallszahlengenerator (2) erzeugte Zahl eine dem Funkgerät zugeordnete Betriebskanalfrequenz bestimmt, und daß der Pseudozufallszahlengenerator (8) einen steuerbaren Zweizustands-Rückführzweig (4) aufweist, der den Pseudozufallszahlengenerator in dem einen Zustand zur Erzeugung einer erwähnten Nebenstrecken-Reihenfolge veranlaßt.

3. System nach Anspruch 2, gekennzeichnet durch ein Sendeschlüsselmittel (2), durch dessen Betrieb vor dem Senden der erwähnte Rückführzweig (4) veranlaßt wird, den anderen der beiden Zustände einzunehmen.

4. System nach einem der vorhergehenden Ansprüche, gekennzeichnet durch eine Relaisstation, die zwei Funkgeräte (B, C) aufweist, die jeweils in der erwähnten Weise ausgebildet sind, wobei das eine (B) der erwähnten beiden Funkgeräte so ausgebildet ist, daß es Sendungen unabhängig von dem Adressaten akzeptiert und das andere (C) der erwähnten beiden Funkgeräte mit dem erwähnten einen Funkgerät (B) verbunden ist, um alle dadurch empfangenen Signale weiterzusenden, und wobei die Zeitdifferenz zwischen dem Empfang durch das erwähnte eine Gerät (B) und der Weitersendung durch das erwähnte andere (C) bewirkt, daß die beiden Verbindungen auf verschiedenen Nebenstrecken-Reihenfolgen arbeiten und auf diese Weise eine Frequenztrennung bewirkt wird.

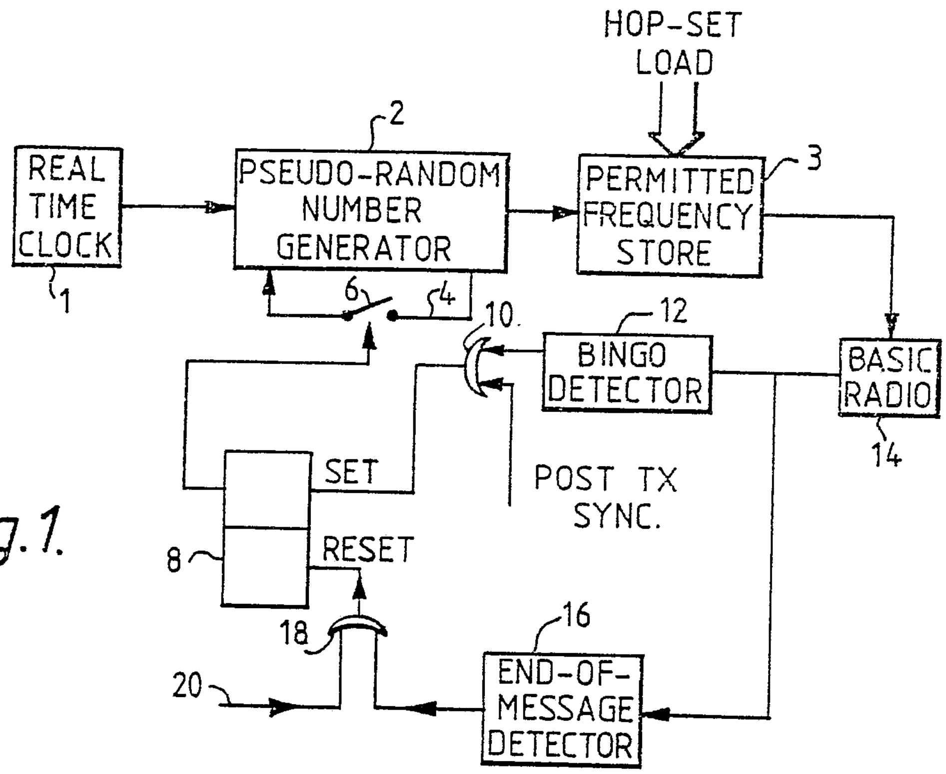
**Revendications**

1. Système de liaison radioélectrique à sauts de fréquences, comprenant plusieurs postes émetteurs-récepteurs radioélectriques (figure 1) ayant des dispositifs (2, 3) destinés à modifier périodiquement leurs fréquences de travail, en synchronisme, et suivant une séquence commune de canaux pseudo-aléatoires d'une ligne principale, caractérisé en ce que chaque poste radioélectrique comporte un dispositif (4, 6) destiné à modifier sa séquence des canaux de travail en une séquence de voie latérale qui dépend du point de la séquence de la ligne principale auquel la modification est déclenchée, et un dispositif destiné à émettre vers un autre poste radioélectrique choisi afin que cette séquence de voie latérale soit déclenchée dans le poste radioélectrique récepteur au même instant que dans le poste radioélectrique émetteur, les deux postes radioélectriques étant réalisés (6, 8, 16, 18) afin qu'ils reviennent à la séquence des canaux de la ligne principale à la fin de la transmission.

2. Système selon la revendication 1, caractérisé en ce que chaque poste radioélectrique (figure 1) comporte un générateur de nombres pseudo-aléatoires (2) et une mémoire (3) d'identification des fréquences des canaux, chaque nombre créé par le générateur (2) déterminant une fréquence respective d'un canal de travail pour le poste radioélectrique, et le générateur de nombres pseudo-aléatoires (8) comporte un trajet de réaction réglable à deux états (4) qui, dans un premier état, provoque la production d'une séquence de voie latérale par le générateur de nombres pseudo-aléatoires.

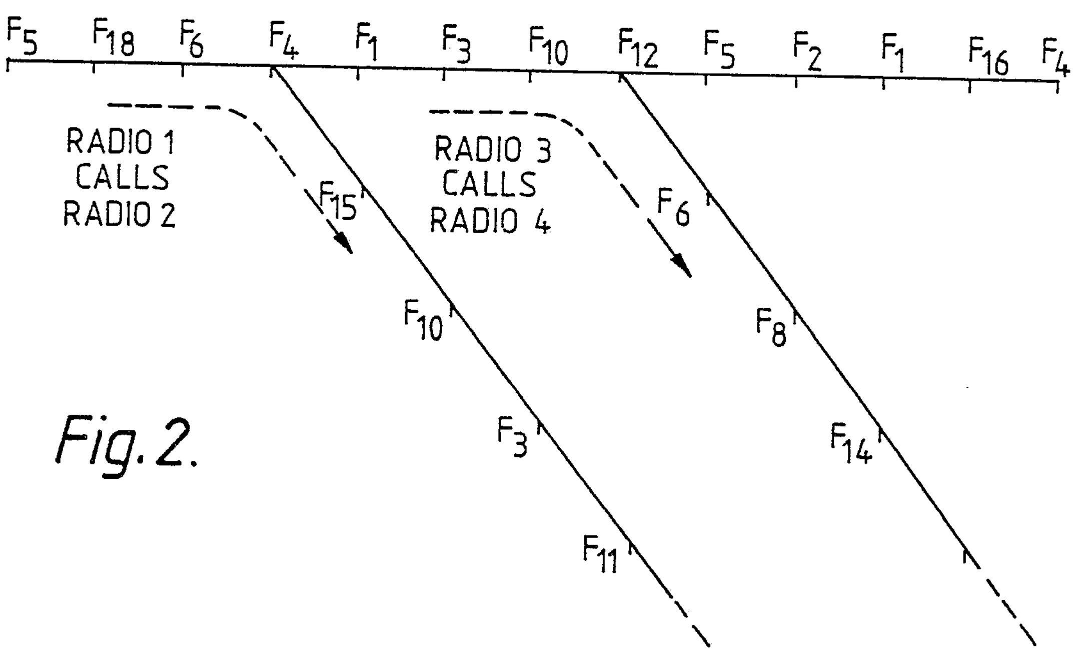
3. Système selon la revendication 2, caractérisé par un dispositif (2) à clé d'émission tel que, avant émission, la manoeuvre du dispositif à clé d'émission provoque l'adoption de l'autre des deux états par le trajet de réaction (4).

4. Système selon l'une quelconque des revendications précédentes, caractérisé par une station relais qui comprend deux postes radioélectriques (B, C) réalisés chacun comme indiqué précédemment, l'un des deux postes radioélectriques (B) étant destiné à accepter des émissions indépendamment du destinataire et l'autre (C) des deux postes radioélectriques étant couplé au premier poste radioélectrique (B) afin qu'il réémette tous les signaux qu'il en reçoit, la différence de temps entre la réception par le premier poste radioélectrique (B) et la réémission par l'autre poste (C) provoquant le fonctionnement des deux liaisons sur des séquences différentes de voie latérale et ainsi assurant l'isolement en fréquence.



HOP-SET LOAD
REAL TIME CLOCK
PSEUDO-RANDOM NUMBER GENERATOR
PERMITTED FREQUENCY STORE
BINGO DETECTOR
BASIC RADIO
SET
RESET
POST TX SYNC.
END-OF-MESSAGE DETECTOR
1
2
3
4
6
8
10
12
14
16
18
20


Fig.1.



F5 F18 F6 F4 F1 F3 F10 F12 F5 F2 F1 F16 F4
RADIO 1 CALLS RADIO 2
RADIO 3 CALLS RADIO 4
F15
F10
F3
F11
F6
F8
F14


Fig.2.

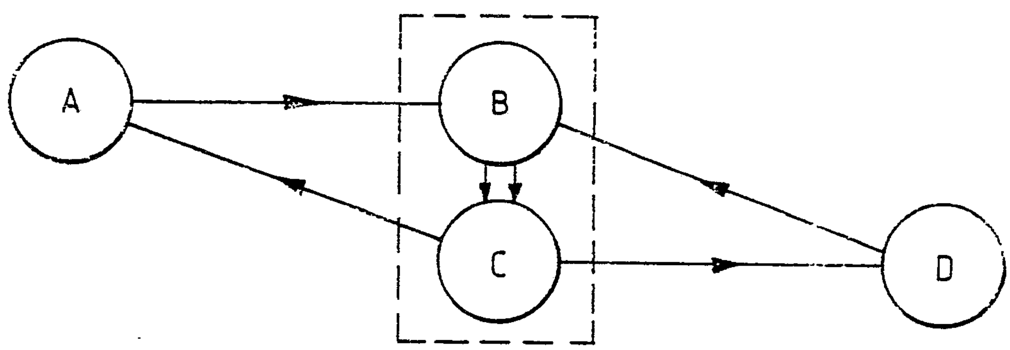



Fig. 3.