A new medium capacity radio relay system

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Summary The North Sea offshore communications requirements and the increasing use of tropospheric scatter systems have created a need for a medium capacity line of sight radio relay equipment in the 1·7 to 1·9 GHz band. The H7200, the first of a range of new radio relay equipment, has been designed to meet this requirement and the needs of the general world market. The equipment operates in the 1·7 to 2·3 GHz frequency band and can be supplied with standard channel capacities of 24, 72, 132 and 300 channels.

The article describes the objectives and design philosophy of the equipment. The configuration of the H7200 is discussed in detail together with the control philosophy and system performance.

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Having graduated from the University of Newcastle upon Tyne in 1966, he joined the Marconi Company, Chelmsford as a graduate trainee. On completion of his training he then joined the receiver development group of Space Communications Divison and worked on the development of satellite ground stations specializing in 70MHz i.f. amplifier design. From 1970 to 1974 he worked on the design of power station supervisory and control instrumentation with Reyrolle Parsons in Gateshead. In 1974 he rejoined Marconi to work on the development of the Band III r.f. head for TRIFFID. This was followed by a move back to space communication work, where he supervised the development of i.f. equipment for Madley and OTS ground stations.

He has been associated with the H7200 project from the proposal stage and moved with the project to Livingston, Scotland, where he is a Group Leader with Space and Microwave Operations Division.

Introduction

The H7200 microwave radio relay equipment, the first product in a new range of radio relay equipments, operates in the 1700 to 2300 MHz frequency band and provides a medium capacity radio bearer with a capacity of up to 300 simultaneous frequency division multiplexed traffic channels. As such the equipment can be used in a variety of applications and typical examples are subsidiary links to main trunk systems, oil pipeline communications, offshore oil communications and short haul terrestrial systems.

The equipment complies fully with the short haul CCIR[1] recommendations and with the British Post Office specifications RC4030[2]. This latter specification has been produced to cover the exacting requirements needed for the United Kingdom off-shore communications systems.

General description

The H7200 radio equipment is contained in a 19 inch unit and is suitable for rack or cabinet mounting. The complete equipment is shown in figure 1. Each radio unit contains two transmitters, two receivers, a duplexer, an engineering order wire and duplicated power supplies.

The universal power supply system included in the radio equipment allows operation from either a –24volt or –48volt d.c. supply or from an alternating current mains supply at frequencies of 50 or 60 Hz. Particular care has been taken to ensure that the thermal gradients within the equipment are minimized and that thermal dissipation is kept at a low level to ensure a high reliability.

Figure 2 shows the equipment with front panel lowered. The metering and control circuitry is contained on the printed circuit board mounted at the rear of the front panel. Located on the front panel are comprehensive light emitting diode alarms which show the operational status of the equipment. Status and control functions include auto/manual switching, digital metering and monitoring, an operator's loudspeaker, operator's handset and its associated controls. The modules are mounted vertically and are held in position by two locking screws. The duplexer components are mounted on an open plate assembly.

The two transmitters are arranged in a hot standby configuration to give automatic protection of the main transmit path. Two watts of r.f. power is available at the antenna port of the duplexer. The outputs of the two receivers are combined in a switching combiner where the signal-to-noise ratio of the two receivers is monitored, compared and used to provide an optimum traffic channel output performance. Clean relay contacts are provided for remote alarm and status indications.

A low-noise receiver preamplifier and its associated image rejection filter can be fitted in each receive path and when these are used, for example on marginal links, they are fitted on the

Fig. 1. H7200 microwave radio relay in desk mounting case

duplexer plate assembly. For baseband repeater applications a two to four-wire bridge is fitted which enables Engineer's Order Wire (EOW) and supervisory signals to be inserted or extracted at the repeater.

Design philosophy

The main objectives were:

To comply fully with C.C.I.R. Recommendations[1] and the British Post Office RC4030 Specification[2].

To provide:

a duplicated fully-protected system with 24, 72, 132 and 300 channel operation; -24 and -48 volts d.c., 110 and 240 volts a.c. 50/60 Hz, prime power.

Low power consumption.

High mean time between failures (MTBF), low mean time to repair (MTTR).

EOW—omnibus with call facility. Optional low noise preamplifier. Small size, simple maintenance and low cost.

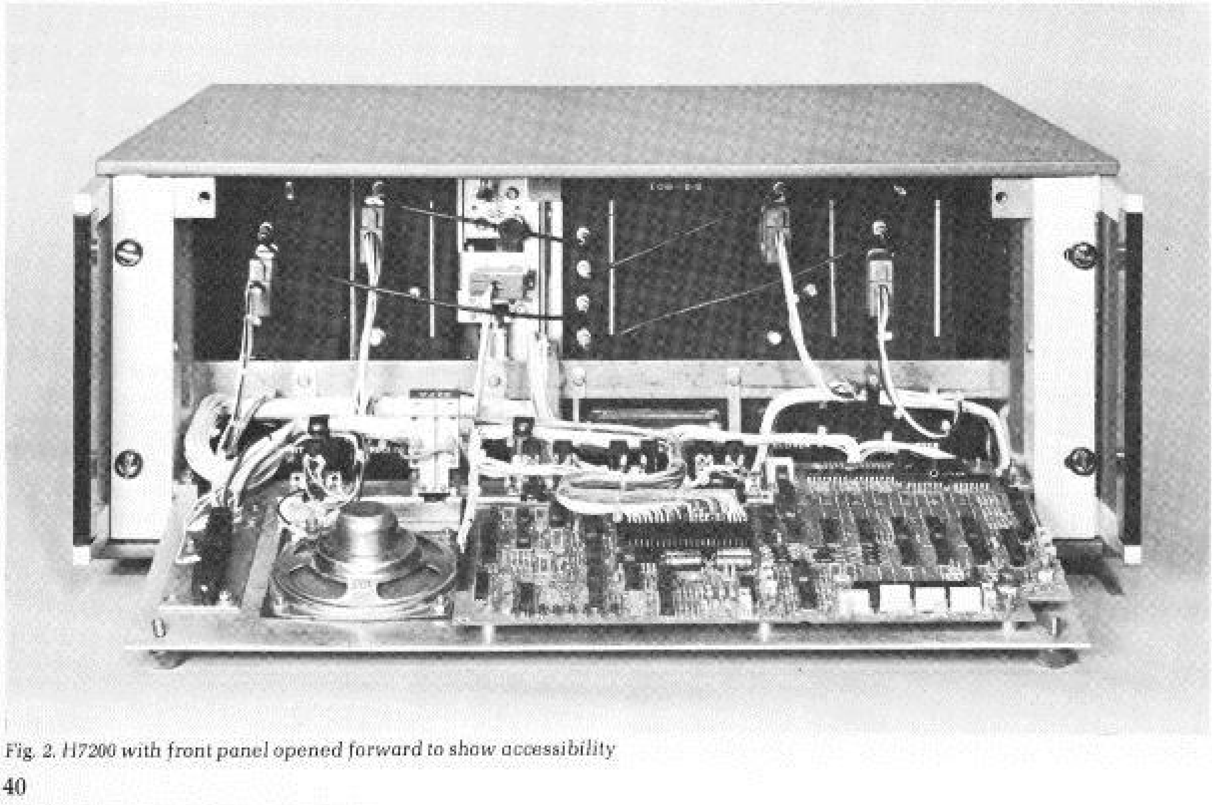


Fig. 2. H7200 with front panel opened forward to show accessibility

To simplify servicing and maintenance procedures, built-in test equipment is provided, which drives the digital metering and the displays on the front panel and a number of status-indicating l.e.d.s, mounted within the equipment and visible when the front panel is lowered. The equipment is arranged so that any transmitter, receiver, power supply, EOW, and the majority of the pilot and baseband circuitry can be replaced without interrupting traffic on the main path. Similarly no interruption to traffic occurs if the standby transmitter needs to be tested with either selected receiver on r.f. loop-round.

During the development of the equipment a theoretical thermal analysis was performed to assess the likely temperature rises within the equipment and within each module. The results of the analysis largely dictated the mechanical lay-out of the equipment, which will operate over an external ambient temperature range of 0 to 50°C.

Switched mode power supplies are used to provide a light weight and efficient unit and extensive use has been made of readily available integrated circuits throughout the design—particularly in the case of the receiver.

Equipment configuration

Figure 3 is a schematic diagram of the whole equipment. This shows the breakdown into modules, and indicates the monitored and controlled functions.

Duplexer

The duplexer is shown in figure 4 where the circulator, transmit power monitor, low-noise amplifier, r.f. switch and filters are also visible. Transmit and receive filters are identical. The principle of operation of the duplexer can be understood by studying figure 3 which shows the duplexer connected for non-diversity operation. When space diversity reception is required one receiver and r.f. filter are connected directly to a second receiving antenna. Two editions of the duplexer are used to cover 1·7 to 2·3 GHz to limit the tuning range required from the transmit and receive filters. The filters are of the 0.01dB ripple, three pole Chebyshev type. The specification for the filters is dictated by the r.f./i.f. selectivity requirements which are described in more detail later in this article.

Transmitter

The principle of operation can be understood by referring to figure 3. The transmitter employs a directly-modulated voltage-controlled oscillator (v.c.o.) operating over the 1·7 to 2·3 GHz band in order to generate a spurious-free output signal and to simplify the filtering requirements. A digital phase-locked loop (p.l.l.) is employed to lock the transmitter frequency to a highly stable reference source. Careful selection of the type of varactor diode used in the oscillator circuit has enabled both baseband modulation and frequency control to be applied to the one diode.

The p.l.l. is carefully designed to reject unwanted frequency components present at the phase detector output. These are the fundamental and harmonics of the reference frequency and modulation frequencies from 300Hz up to 1·5MHz. Indication of phase lock is supplied to the transmitter control logic and l.e.d. indicators.

The continuity pilot is monitored in the transmitter module at a point between the baseband amplifier and the v.c.o. varactor interface. The pilot detector is similar to that used to monitor the receive pilot which is described below. In the event of a baseband circuitry failure in the main traffic path pilot, continuity, or its absence, is used to initiate changeover to the redundant transmit path. The phase-lock and transmit pilot fail outputs are gated together. The control philosophy is described below.

The v.c.o. is followed by an isolator and a coupler which provides an input to the digital divider chain for the p.l.l. A power amplifier follows the v.c.o. to increase the transmitter module output to a minimum of 35·1dBm. There is a power monitor at the amplifier output which provides a d.c. output to the front panel metering and the transmitter control logic. The complete transmitter is housed in an aluminium block of overall dimensions 270 × 170 × 50mm.

Receiver R.F./I.F selectivity requirements.

R.F. Selectivity: Requirements are determined mainly by the need to suppress transmitter-to-receiver leakage and to provide interference rejection at the image frequency. Three types of interference were considered:

(a) Receive signals arriving at a common platform at a nominal level of –40dBm

(b) Transmit signals from other equipments on the site

(c) Transmitter-to-receiver leakage within the equipment.

In addition a frequency plan was drawn up and the minimum frequency spacing between the transmitter and receiver was fixed at 84MHz. Hence knowing the receive mixer third order intercept point, the i.f. filter selectivity characteristic, and by establishing interfering signal levels the r.f. selectivity was defined. Interferers within 20MHz of the receive frequency are suppressed by the i.f. filter.

I.F. Selectivity: The 72 and 132 channel requirements are determined from the frequency plans and interference models stated in RC4030. The 24 and 300 channel selectivity requirements are based on existing troposcatter practice and CCIR frequency plans. The sensitivity to interferers of an available tropo demodulator was used in the determination of the 72 and 132 channel selectivity requirements. R.C.4030 states that for receive signals at a common North Sea platform the frequency separation between carriers is 2MHz minimum for 72 channel systems and 3MHz minimum for 132 channels. Additional protection is

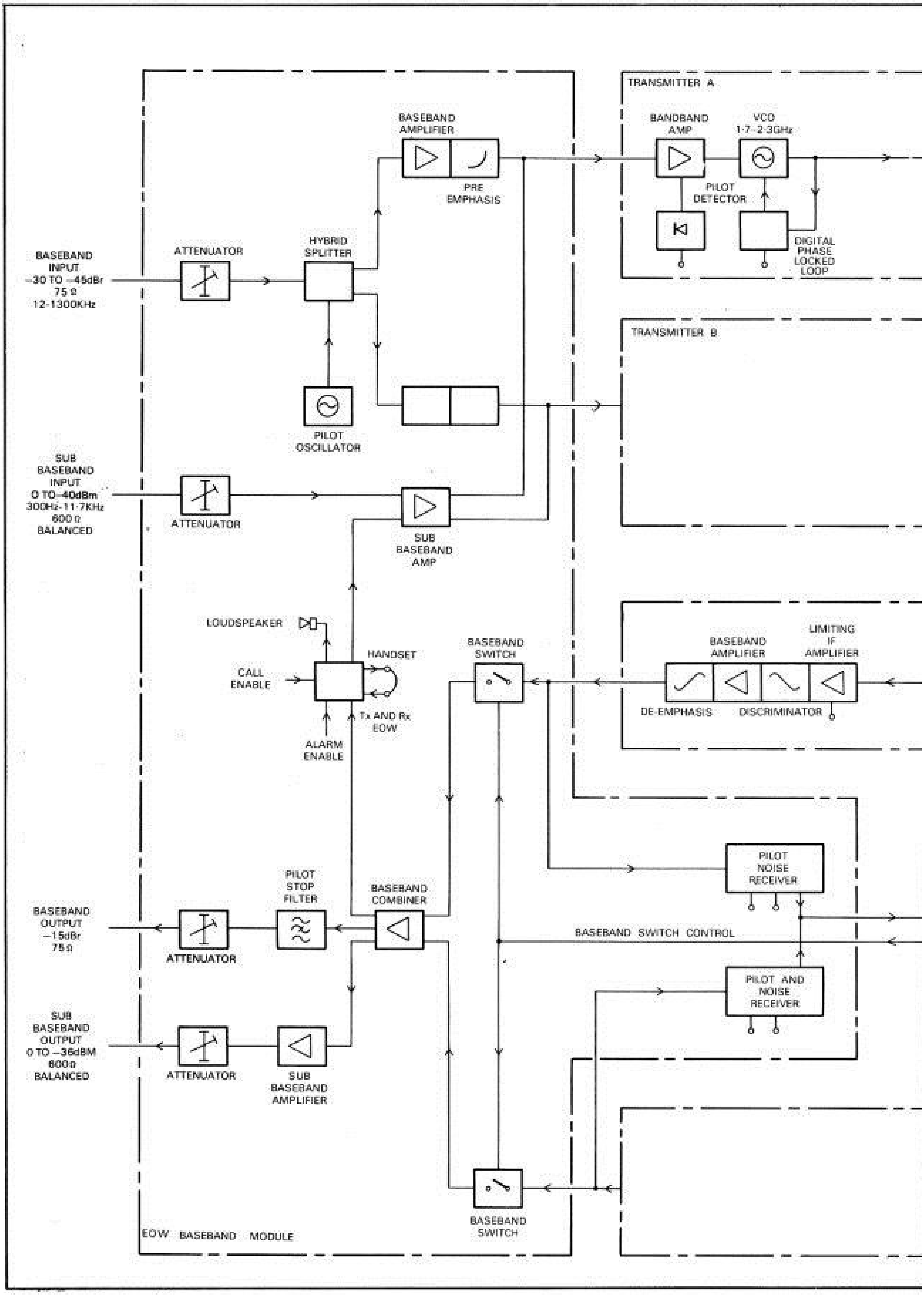
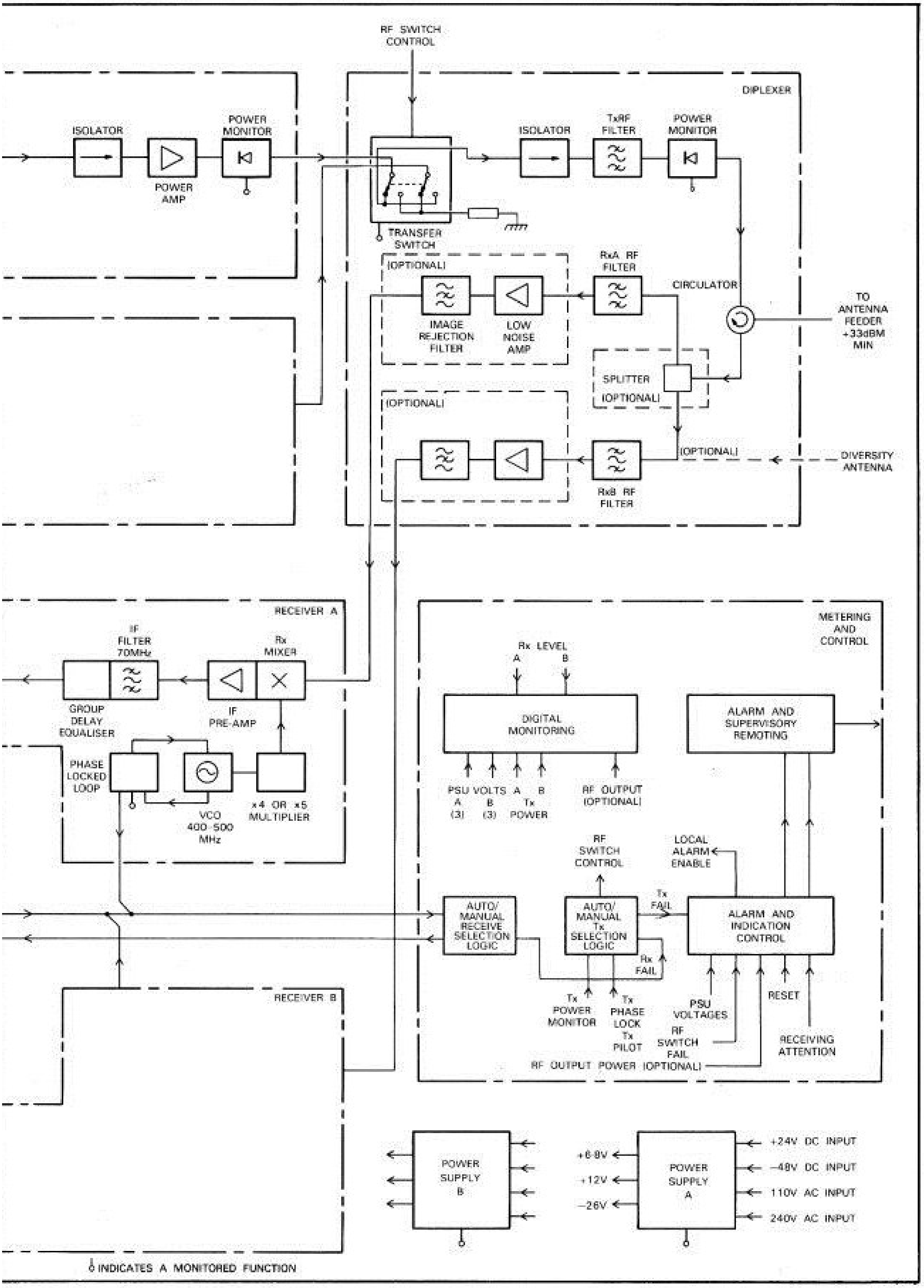


Fig. 3. H7200 Functional diagram


RF SWITCH CONTROL
DIPLEXER
ISOLATOR
POWER MONITOR
POWER AMP
TRANSFER SWITCH
ISOLATOR
TxRF FILTER
POWER MONITOR
(OPTIONAL)
RxA RF FILTER
CIRCULATOR
IMAGE REJECTION FILTER
LOW NOISE AMP
TO ANTENNA FEEDER +33dBM MIN
SPLITTER (OPTIONAL)
(OPTIONAL)
(OPTIONAL)
DIVERSITY ANTENNA
RxB RF FILTER
RECEIVER A
IF FILTER 70MHz
Rx MIXER
GROUP DELAY EQUALISER
IF PRE-AMP
PHASE LOCKED LOOP
VCO 400-500 MHz
x4 OR x5 MULTIPLIER
METERING AND CONTROL
Rx LEVEL A B
DIGITAL MONITORING
ALARM AND SUPERVISORY REMOTING
PSU VOLTS A (3) B (3)
A B Tx POWER
RF OUTPUT (OPTIONAL)
RF SWITCH CONTROL
LOCAL ALARM ENABLE
AUTO/ MANUAL RECEIVE SELECTION LOGIC
AUTO/ MANUAL Tx SELECTION LOGIC
Tx FAIL
ALARM AND INDICATION CONTROL
Rx FAIL
Tx POWER MONITOR
Tx PHASE LOCK
Tx PILOT
PSU VOLTAGES
RF SWITCH FAIL
RESET
RECEIVING ATTENTION
RF OUTPUT POWER (OPTIONAL)
RECEIVER B
POWER SUPPLY B
+6.8V
+12V
−26V
POWER SUPPLY A
+24V DC INPUT
−48V DC INPUT
110V AC INPUT
240V AC INPUT
INDICATES A MONITORED FUNCTION

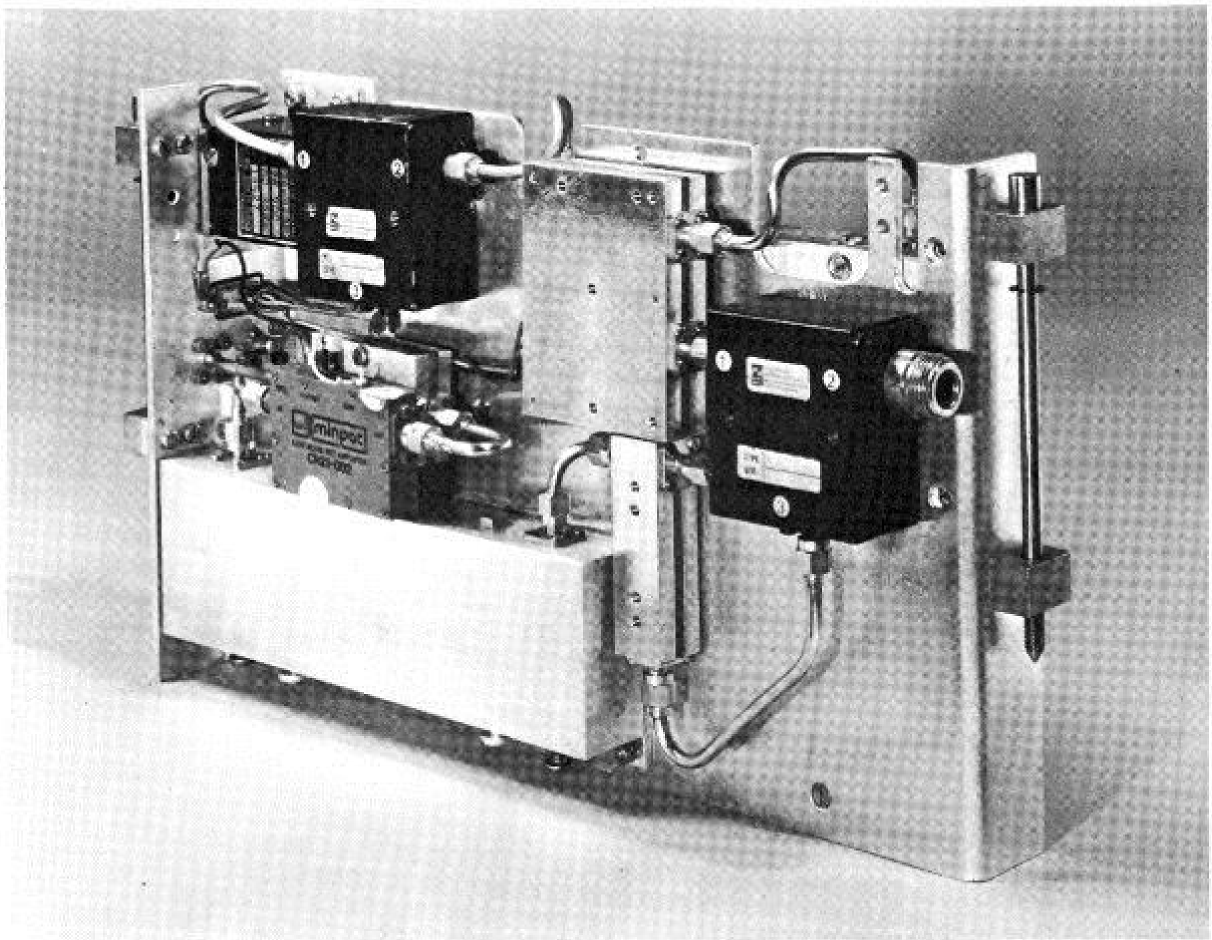


Fig. 4. Duplexer Assembly

obtained from antenna directivity and cross polarization, also specified in RC4030.

The interference conditions were considered for the normal case when the wanted and unwanted carriers are at the same level, and the worst case when the interferer may be 10dB above the median and the desired carrier is subject to a selective fade of 40dB.

Receiver

The receiver block diagram is also shown in figure 3. The receiver signal is directed by the duplexer to the receiver module, each receiver module contains a low noise mixer, 70MHz/i.f. amplification and filtering, discriminator and baseband units. The receiver module is shown in more detail in figures 5(a) and 5(b) which together indicate the layout of the receiver sub-system.

The mixer is double balanced, using balanced microstrip baluns and is connected directly to a 70MHz low noise i.f. preamplifier. The single sideband noise figure of this assembly is typically 7dB.

The local oscillator consists of a 400–500MHz p.l.l. referenced to a highly stable crystal source and is followed by a multiplier (either × 4 or × 5) to obtain the required output frequency. This approach provides an oscillator with the desired frequency stability, and the required low residual f.m. noise. The p.l.l. makes use of a digital divider and comparator and step recovery diodes are used in the multiplier.

The advantages of this solution are:

(1) The v.c.o. and the divider can use readily available components

(2) The multiplier operates with a low order of multiplication and is therefore efficient.

(3) The low order of multiplication means that the local oscillator output sidebands are removable by simple filters.

An out-of-lock output signal is supplied to the receiver control logic and to a l.e.d. indicator.

Two types of 70 MHz i.f. filter are used. A four-cavity 0.01dB Chebyshev helical resonator filter is used for 24 and 72 channel operation, no group delay equalization being necessary. On the other hand, discrete-component computer-optimized designs are used for 132 and 300 channel operation and these include group delay equalizers. Figure 5(a) shows a 132 channel filter fitted in the receiver. This filter is a four-section 0.05dB Chebyshev design which employs impedance transformation at the input and output so that the inductors are of manageable proportions. This is followed by a three-section group delay equalizer. The 300-channel design is similar but does not use

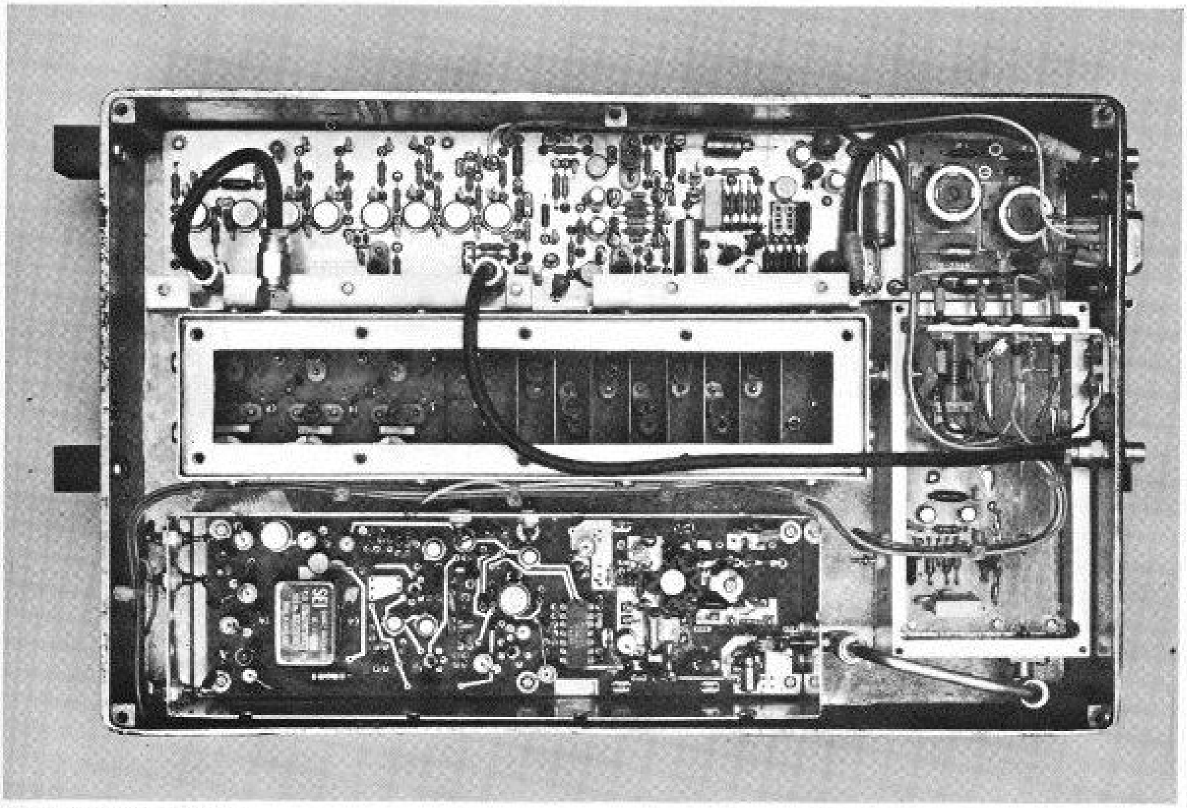


Fig. 5(a). Receiver module

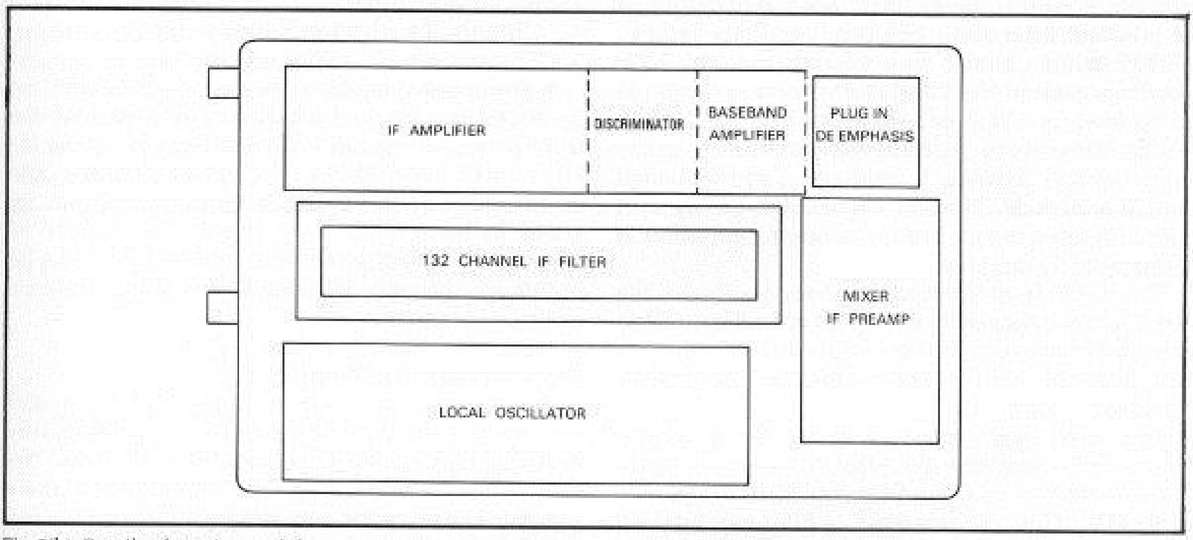


Fig. 5(b). Details of receive module

impedance transformation and requires a four-section group delay equalizer.

Typical filter noise bandwidths are as follows:

Number of channels:	24	72	132	300
Noise bandwidth, MHz:	1·13	3·66	5·89	9·75

The i.f. amplifier uses integrated circuits throughout and has a gain of 85dB typically. Two stages of linear amplification are followed by six stages of limiting amplification. The latter provides a detected output proportional to input level which is supplied to the digital meter. An i.f. monitor output is provided.

The discriminator is a conventional two tuned circuit type. The baseband amplifier uses discrete transistors, for, whilst many integrated and hybrid amplifiers were investigated, it was found that the discrete design provided superior performance and was the most cost-effective.

To upgrade the channel capacity of the receiver is a simple operation, requiring the change of the i.f. filter, a different plug-in de-emphasis board and a plug-in link adjustment of baseband amplifier gain.

E.O.W.—Baseband Module

This contains EOW, baseband, sub-baseband, pilot, noise and two-to-four wire bridge circuitry. The circuits are contained on a number of plug-in printed circuit boards which allows replacement of these units without interrupting traffic. A high proportion of the circuitry uses integrated circuits.

The EOW call tone operates at 1 kHz. The alarm tone uses this same 1kHz signal, but in this case the signal pulsates approximately once per second and maximum output is automatically obtained from the loudspeaker. The transmit baseband hybrid is a passive four-port device which splits the incoming traffic signal to two isolated outputs. After amplification, pre-emphasis and summation with the sub-baseband signal the combined signals are applied to the baseband inputs of the two transmitters. The transmit EOW signal is filtered to remove higher voice frequencies and noise by a 2 kHz low-pass filter.

The continuity pilot signal is directed to the two independent traffic paths by utilizing the fourth port of the baseband hybrid.

Baseband and sub-baseband input and output levels are adjustable over a wide range to cater for the interface requirements of the various administrations.

The receiver baseband combiner sums the two receiver baseband outputs via baseband switches, which are used to mute either receiver in the event of pilot fail, high noise, or a local oscillator failure. The switches can also be operated manually from the front panel. The baseband combiner output is of the form (A + B)/2 or 2A or 2B.

The latter cases indicate that combining is not occuring and either only receiver A or receiver B output is present. Therefore whenever a baseband switch is open the gain of the summing amplifier is automatically doubled.

The traffic from the combiner is connected to the baseband output socket via a pilot stop filter, and as the pilot frequency changes with channel capacity, the filter is easily replaceable for up-grading purposes.

The pilot and noise detector is a super-heterodyne receiver, the pilot frequencies being downconverted to a fixed intermediate frequency of 10 kHz. Thus the same active filter can be used for any four channel capacities by simply changing the plug-in crystal in the pilot receiver local oscillator.

The pilot frequencies are as follows:

Number of channels:	24	72	132	300
Pilot frequency, kHz:	119	331	607	1499

The downconverter in the pilot receiver also feeds a noise detector which in effect monitors the noise adjacent to the pilot frequency. The output from the noise filter is applied to a noise detector and also to a differential noise detector which compares the noise outputs from both receivers when the receivers are connected for diversity operation. The rules which govern whether the pilot, noise or differential noise detectors control the combiner output are explained below.

Metering and control

The metering and control module provides the following functions:

1. Auto/Manual selection of transmitter and receivers.
2. Front panel indication of transmitter and receiver operational status by green l.e.d. and failure status by red l.e.ds.
3. Metering of receiver input power levels and transmit output power levels.
4. Metering of output voltages of power supplies.
5. Local and remote failure alarm.
6. Alarm Receiving Attention and reset functions.

The metered functions are selected by push button switches and are displayed on a three digit seven segment l.e.d. front panel display.

The Receiving Attention push button cancels the audible alarm without affecting the visible alarms and the Alarm Reset button resets the alarm relay. The following failures are combined to operate the alarm relay (which is equipped with isolated changeover contacts for remoting) and the audible alarm.

1. Power of each transmitter
2. Phase-lock or pilot of each transmitter and receiver.
3. R.f. output power.
4. Outputs of each power supply.
5. Transmitter r.f. changeover switch.

In the event of an alarm the cause can be isolated by observing the red l.e.ds mounted behind the front panel, where failure indications are given for all failures listed above. The presence of the continuity pilot at the receiver outputs is shown by green l.e.ds. on the front panel. The failure of transmitter output power and receiver pilot can be indicated remotely by means of a single isolated changeover contact.

Receiver control philosophy

A failure of a receiver is recognized by a 4dB reduction in the level of the continuity pilot, or loss of phase lock by the local oscillator. In 'Auto' the two receiver outputs will be combined if their signal-to-noise ratios are similar. If the detected noise output from one receiver baseband is 6dB higher than the other, then the differential noise output logic mutes the noisier receiver; otherwise the receivers are combined.

This differential noise mute system operates over the receiver dynamic range. If both baseband outputs simultaneously degrade below a pre-determined signal-to-noise ratio then the high noise mute output ensures that both receiver outputs are muted. If either is selected manually the 6dB differential noise mute is disabled, but the high noise mute control remains active.

When a pilot failure or receiver phase-lock failure occurs, the logic detects the fault, enables the alarm and indicates which receiver has failed by illuminating a red l.e.d. on the front panel, whilst either can override the differential noise muting and initiate muting of the faulty receiver. The pilot failures are considered to represent a pilot generator failure at the other end of the link and although the alarm is enabled the receiver combining circuitry is not affected and the receivers operate normally.

Transmitter control philosophy

The transmitters are controlled by the outputs from the power monitors and from the combined outputs of the phase lock and pilot detectors. Failure of a transmitter is recognized by a 3dB drop in output power or loss of phase lock pilot. The operational status is indicated by l.e.ds on the front.

In the 'Auto' mode of operation, if a transmitter fails a changeover takes place to the hot standby transmitter if the latter is also functional. No changeover takes place if the standby transmitter is also faulty.

In the 'Manual' mode of operation if the selected transmitter fails no changeover to the standby transmitter takes place. Feedback from the r.f. switch ensures that the correct transmitter has been selected.

Performance

It is convenient to define the system performance in terms of a system value. This is defined as the weighted signal-to-noise ratio in the telephone channel at maximum baseband frequency when the transmitter output is connected directly to the receiver input. It is assumed that the receiver continues to operate in the linear region of its characteristic.

The system value S is given by the following expression:

$$S = 10 \log_{10} \frac{P}{FKTb} + 20 \log_{10} \frac{F}{fm} + W + PE$$

P= Transmitter power at antenna port of diplexer = 2 watts,
F= receiver noise figure at antenna port of diplexer,
W= improvement due to psophometric weighting,
PE= emphasis improvement at maximum baseband frequency,
fm= maximum modulation frequency,
b= telephone channel bandwidth, 3·1 kHz.

For a receiver without optional low noise pre-amplifier, connected for diversity operation (no 3dB splitter fitted) the noise figure is 10dB at the antenna port on the diplexer.

For convenience the system performance is summarized in the following table.

Channel Capacity	fm (kHz)	f (kHz)	Pilot (kHz)	S (dB)	T (dBW)	B (kHz)
24	108	35	119	158·71	−123	1130
72	300	100	331	158·96	−118	3660
132	552	200	607	159·68	−116	5890
300	1300	200	1499	152·24	−114	9750

In the table above, T is the typical receive level at the antenna port on the diplexer at threshold which occurs at a carrier to noise ratio of 10dB. B is the typical receiver noise bandwidth, f= r.m.s. test tone deviation.

Figure 6 shows the 72 channel performance of a H7200 transmitter 'turned round' to a H7200 receiver via an artificial path attenuation of 73 to 113dB. The system total noise power ratio was measured using internationally agreed white noise loading levels.

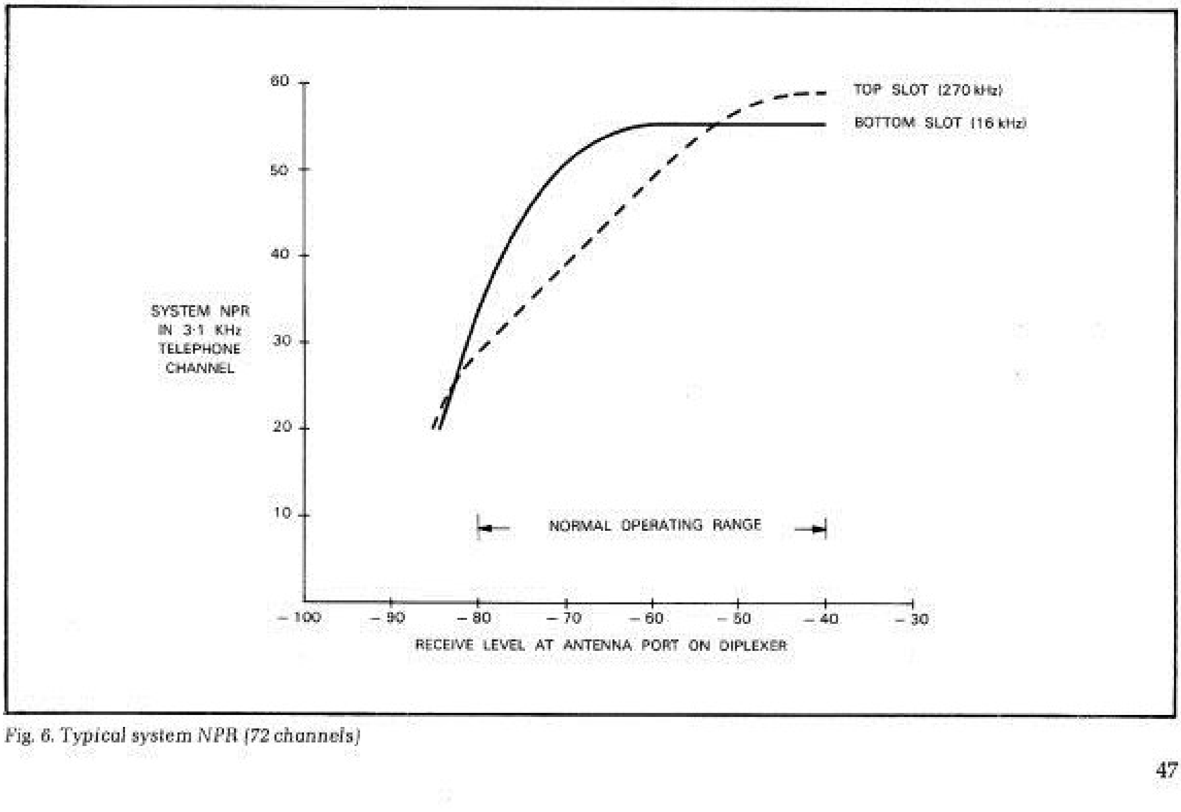


Fig. 6. Typical system NPR (72 channels)

Conclusion

Some salient features of a compact radio relay microwave link have been described. The prime objectives, other than of complying with the Post Office and CCIR specifications, were to minimize the component count and equipment complexity in order to reduce the equipment cost and improve reliability. This has been achieved by selecting the most cost-effective configuration for each part of the equipment, by theoretical and practical system simulation at an early stage to ensure that the equipment was not over-engineered, and by the use of readily available integrated circuits throughout the equipment.

Acknowledgements

The system design calculations, the system simulation, and the selectivity studies were carried out by Mr. T. Arthanayake, the systems engineer attached to the project. During the formulative stages of the poroject Mr. B. S. Skingley's encouragement and systems experience were most valuable to the design team.

References

1. CCIR–Geneva 1974 – Vol IX – Recommendation 395–1 Radio Relay systems for telephony using frequency division multiplex.
2. Post Office Telecommunications Development Department Specification RC4030 for overall performance requirements and supervisory requirements for 72/132 telephone channel radio-relay equipment for use in an off-shore communication network operating in the band 1700–1900MHz.

RESUME

En raison des exigences en matière de télécommunications offshore en Mer du Nord ainsi que de l'utilisation croissante de systèmes de diffusion troposphérique, il est devenu nécessaire de disposer d'un matériel de station-relais à portée optique de capacité moyenne sans la bande comprise entre 1,7 et 1,9 GHz. La conception du H7200, premier élément de toute une gamme de matériel de station-relais nouveau, répond à cette exigence ainsi qu'aux besoins du marché mondial en général. Ce matériel fonctionne dans la bande de fréquences 1,7 – 2,3 GHz et les capacités standard offertes sont de 24, 72, 132 et 300 canaux.

L'article présente les objectifs et la philosophie de conception de ce matériel. La configuration du H7200 ainsi que la conception d'un contrôle et la performance du système font l'objet d'une description détaillée.

ZUSAMMENFASSUNG

Die Erfordernisse im Offshore-Funkverkehr in der Nordsee sowie der verstärkte Gebrauch von troposhärischen Streuungssystemen haben den Wunsch nach einer Sichtlinienfunk-Relaisvorrichtung mittlerer Sende-leistung im Bereich 1,7, bis 1,9 GHz verdeutlicht. Das Modell H7200, das erste in einer Serie von neuen Funk-Relaisgerät, wurde sowohl im Hinblick auf diesen Bedarf als auch auf die Aaforderungen des ansonsten bestehenden Weltmarktes entworfen. Das Gerät funktioniert im Frequenzbereich 1,7 bis 2,3 GHz und kann mit standardmässigen Kanalleistungen von 24, 72, 132 und 300 Kanälen geliefert werden.

In diesem Artikel erfolgt eine Beschreibung der angestrebten Ziele sowie des Entwurfsgrundgedankens dieses Geräts. Ausserdem werden die Gestaltung des H7200 sowie die Art und Werse der Regelung und die Systemleistung detailliert behandelt.

SUMARIO

Las exigencias de las comunicaciones in alta mar del Mar del Norte, y el creciente empleo de los sistemas de esparcimiento troposférico, han creado una necesidad de una línea de equipos de radiorrelé visual de capacidad media en la banda de 1.7 a 1,9 GHz. El H7200, el primero de una gama de nuevos equipos de radiorrelé, ha sido diseñado para satisfacer esta exigencia y las necesidades del mercado mundial en general. El equipo funciona en la banda de frecuencia de 1.7 a 2.3 GHz, y puede suministrarse con capacidades tipos de canales de 24, 72, 132 y 300 canales.

El artículo describe los objetivos y la filosofía del diseño del equipo. La configuración del H7200 se examina en detalle juntamente con la filosofía del control y funcionamiento del sistema.