

Ground communications equipment for large earth stations

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Summary This article discusses the requirements and design of large earth station equipment. The current range of ground communica-

tions equipment designed by Marconi Communication Systems is described with particular reference to an Intelsat Type A station.

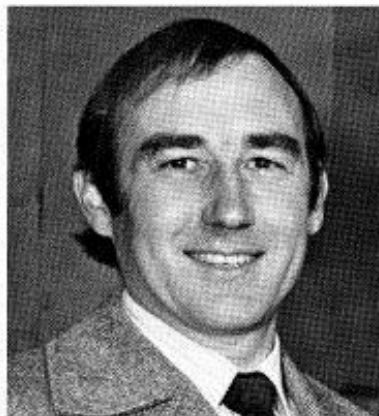
V. L. Nippierd

Vincent Nippierd obtained his degree in Electrical Engineering at the University of Aston, in Birmingham.

He joined The Marconi Company in 1967, and completed a graduate training programme, after which he spent four years in the Space Communications Division, concentrating on the development of low capacity FMFB threshold extension demodulators, together with wideband linear modulators and demodulators, both for telephony and television.

In 1972 he spent time assisting with Earth Station Installation, both at home and abroad, and then worked on microwave design of phase-locked oscillators and general microwave systems.

He was appointed Section Leader in 1974, responsible for the design of microwave oscillators and up and downconverters. In 1976 was promoted to Group Leader,



where his responsibilities include the co-ordination of development in the microwave, r.f and modem areas of satellite communications earth station equipment.

M. A. S. Watson-Lee

Mark joined The Marconi Company in 1968 as a student apprentice. He completed a 'thin sandwich' degree course at the University of Wales Institute of Science and Technology and joined the Space and Microwave Division in 1974 as a development engineer. He worked on phase-locked oscillators for tropospheric scatter and military communication systems, synthesizers and r.f power control systems for large earth stations.

In 1977 he became a Section Leader and has recently been responsible for the design of some of the new range of ground communications equipment.



On the transmit equipment the baseband, i.f and s.h.f circuits have all undergone major changes. The thermal noise of the f.m modulator and baseband amplifiers has had to be improved by up to 7dB, and the bandwidths increased to 8MHz. The earlier limiting varactor single upconverters have had to be replaced by dual upconverters which meet the linearity and spurious output requirements of a single channel per carrier (s.c.p.c) system. Since most transmit systems are now operating in the linear mode, all the transmit i.f to s.h.f circuits must be capable of operating over a typical temperature range of 0° to +40°C ambient, with minimal changes of output level. The specification for e.i.r.p stability is 1.0dB, of which nearly 0.5dB is attributable to the antenna pointing accuracy.

On the receive equipment most of the early single microwave downconverters have been replaced by double downconverters. These changes have mainly taken place to eliminate the need to tune a microwave filter every time a frequency has to be changed. The i.f bandwidth of these devices has still been maintained at 40MHz, although 80MHz will soon be required for t.d.m.a operation.

The significantly larger number and variety of channel capacities to be catered for, i.e global or spot beam, and regular or high-density carriers has put many more constraints on the design of the f.m demodulators.

The early Intelsat III demodulators necessarily had threshold extension built into their designs; they were physically large and bulky and necessitated extensive realignment procedures with complicated test equipment to change from one channel capacity to another. Today's demodulator has been designed not only to meet the current specifications, but also to satisfy the customer with regard to ease of changing channel capacity. To this end, two designs have evolved: a wideband design which caters for all capacities from 12 to 1872 channels, and a phase-

The effect of system specification changes to equipment design

The initial Intelsat III parameters defined three channel capacities (24, 60 and 132), together with their associated i.f filter bandwidths of 5MHz, 10MHz and 20MHz. Today, with Intelsat IV and V there are 18 channel capacities (12 to 1872), and 11 bandwidths (1.25MHz to 36MHz).

Baseband bandwidths have also increased from nominally 0.5MHz to over 8MHz, while the maximum test tone deviation has increased from 630kHz to 802kHz r.m.s.

These specification changes have taken place over the last decade or so, and it has meant that Intelsat III equipment designs were either very short lived or that they were being continually stretched to meet more stringent requirements.

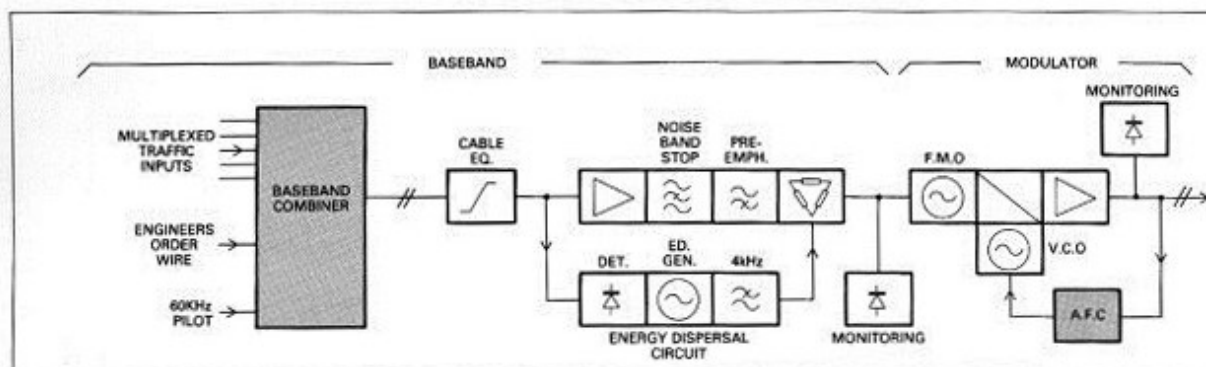


Fig. 1. Transmit chain

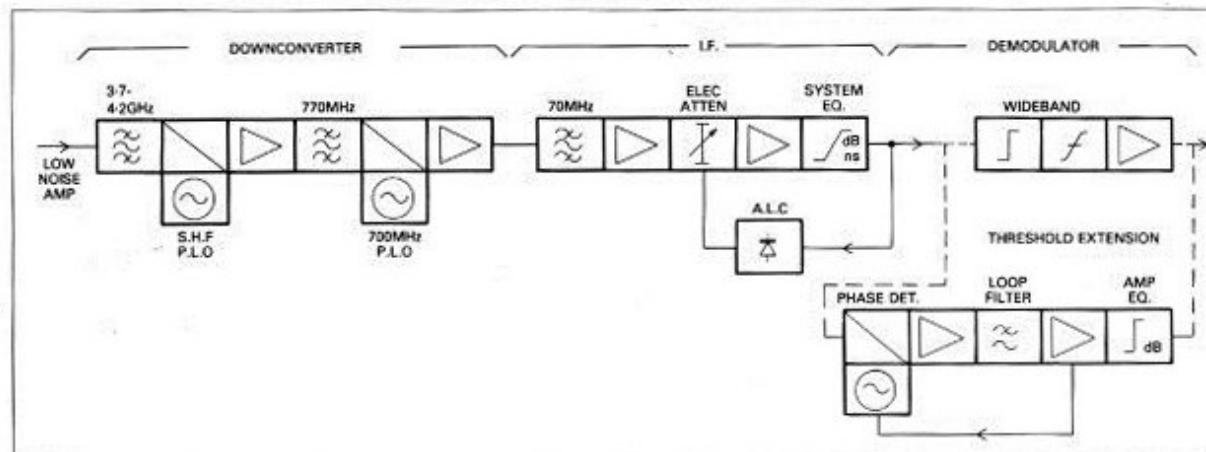


Fig. 2. Receive chain

locked loop demodulator, which offers extra threshold extension up to 252 channels.

Description of typical GCE for a standard 'A' station

The simplified electrical block diagram of the transmit and receive chains is given in figures 1 and 2.

The transmit equipment accepts the multiplexed traffic inputs, consisting of multiples of 12 voice channels at levels of -45dBm per channel, which are amplified, monitored and pre-emphasized in the baseband module, before being frequency modulated on to a 70MHz i.f. carrier. A pre-selected i.f. bandpass filter from the range 1.25 to 36MHz limits the transmit r.f. spectrum bandwidth as specified by Intelsat. Pre-group delay equalization for the satellite takes place prior to the frequency upconversion to the final transmit frequency band of 5.925 to 6.425GHz . This f.d.m/f.m. signal is amplified in a klystron or t.w.t. amplifier and then combined with a number of other similar carriers before

being finally radiated to the satellite.

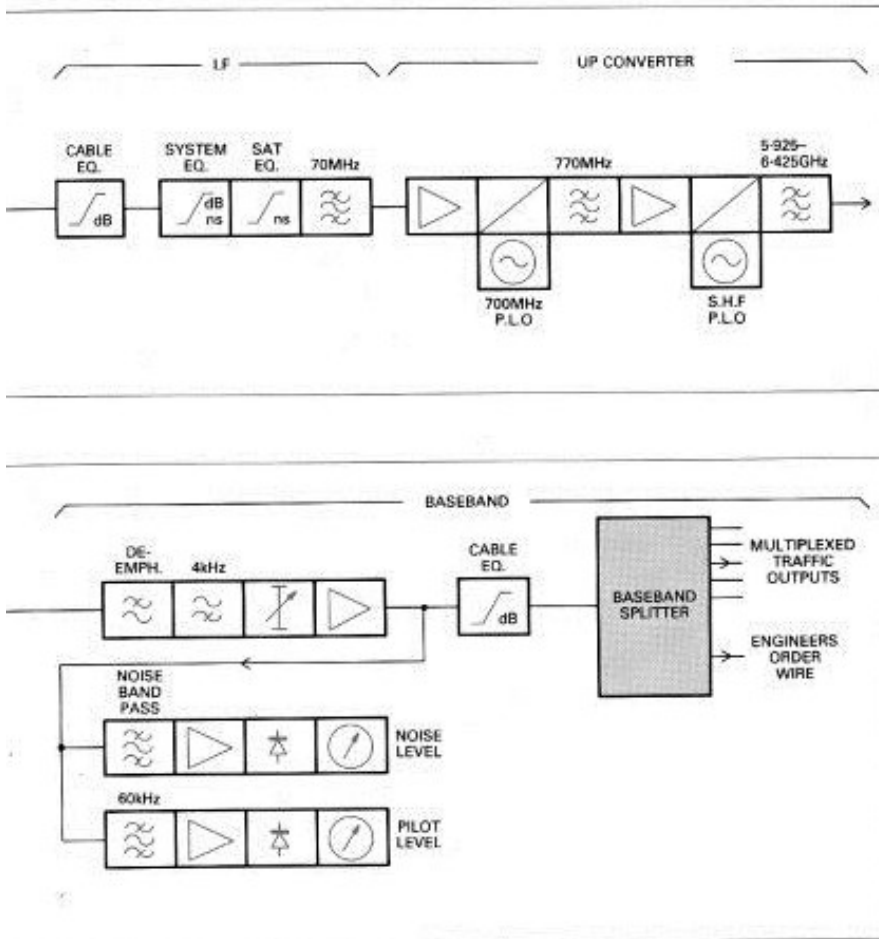
The receive equipment accepts the full 500MHz multi-channel spectrum centred around 3.95GHz after being amplified by a low-noise parametric amplifier and split into 'N' different paths. (N representing the number of incoming carriers which are required to be received.) Each wanted carrier is then selected within the 4GHz receiver shelf by tuning the s.h.f. local oscillator in the downconverter module, and selecting the i.f. filter (fitted in the i.f. module) for the required received-carrier bandwidth. The fully-automatic gain-controlled amplifier having a dynamic range of 50dB sets a constant level into the demodulator independent of channel capacity. Demodulation can be performed by one of two methods: i) by using a wideband frequency discriminator type demodulator for any carrier from 12 – 1872 channels where the carrier-to-noise (C/N) ratio in the occupied bandwidth is greater than about 14dB or, ii) by means of a phase-lock loop demodulator where threshold extension is required, typically for carriers up to 252 channels having less than a 14dB C/N ratio.

Baseband amplification to -15dBm per channel is performed in the baseband module, together with facilities for 60kHz pilot and out-of-band noise monitoring.

Equipment design and implementation

The new range of 4GHz Receive and 6GHz Transmit Ground Communications Equipment (GCE), which is designed to meet the requirements of Intelsat Standard A and B station specifications, caters for all f.m/f.d.m. telephony channels (12 – 1872), television and s.c.p.c. operation.

The 4GHz receive and 6GHz transmit GCEs occupy a 178mm (7in) high, 480mm (19in) wide shelf, making it possible to fit up to eight receive or transmit GCEs in a cabinet complete with s.h.f. splitters, baseband or s.h.f. switches and a 'Receiving Attention' alarm system. Figure 3 shows eight receive GCEs in a cabinet. Previously only two receive GCEs or four upconverters were fitted in a cabinet, so the new range of equipment will save a considerable amount of valuable floor space.



- 1) frequency upconversion or down-conversion;
- 2) i.f. filtering, amplification and equalization;
- 3) modulation or demodulation;
- 4) baseband amplification, pre- or de-emphasis filtering, and pilot or signal monitoring (f.m/f.d.m or television).

The modular system enables other requirements to be easily catered for, such as a split transmit system using a modulator shelf, followed by cross-site i.f. cables and an upconverter shelf.

One of the unique features of this equipment is that all the plug-in modules can be pulled out on runners for maintenance, and adjustments made while still powered up and carrying traffic. No extender boards or special connectors are required. This has been achieved by using a swan-neck cable system (attached to nylon straps for correct cable control) on each module. A separate patch panel is also provided in the top cover of the shelf (figure 5) to enable easy connections to be made to the inputs and outputs of each module. The front panels of the shelf are therefore totally free of unsightly patching cables.

Both the receive and transmit GCEs use a standard 480mm (19in) × 178mm (7in) × 660mm (26in) deep shelf which contains a plug-in power supply and cooling fan both mounted at the rear of the shelf. As can be seen from figure 4 up to four modules are fitted to the shelf. Various modules can be selected with the following functions:



Fig. 3. GCE cabinet fitted with eight 4GHz receivers

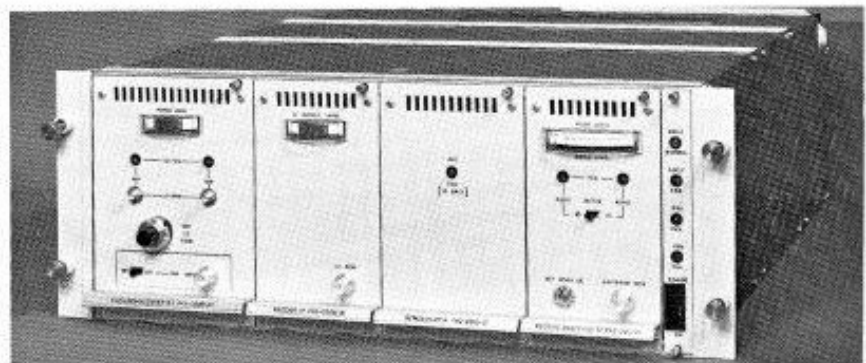


Fig. 4. Front view of 4GHz receiver

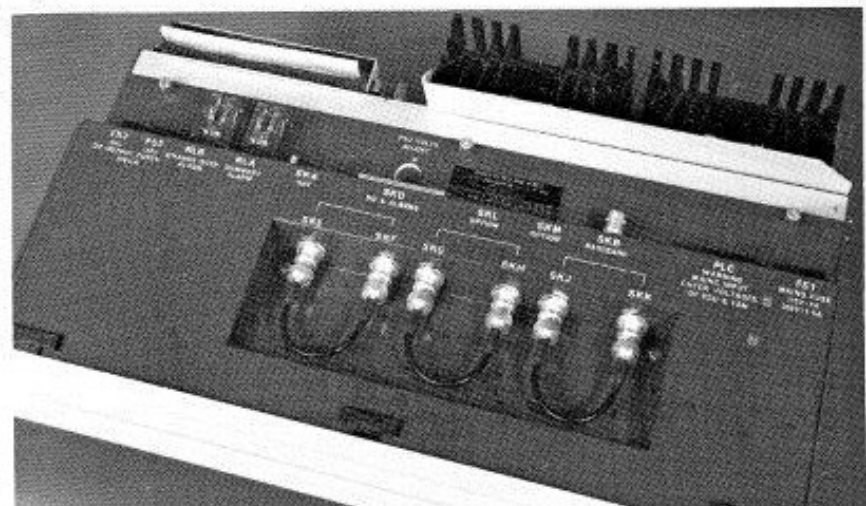


Fig. 5. View of patch panel

Power supply cooling and alarms

The Power Supply Unit (mounted at the back of the shelf) is a linear type to prevent any interference which can be caused by switching power supplies. The power supply is designed for a mains input of 120 or 240V (nominal), 50/60Hz, and a ± 24 V d.c. output. The regulators are rated at a far higher current than is used to ensure a high reliability. Overvoltage protection and overcurrent protection (re-entrant type) are fitted as standard.

The shelf is cooled by a built-in fan complete with slide-in air filter mounted at the rear of the shelf. The air is vented through slots on the front of the modules (see figure 4). This ensures a controlled cooling system and prevents hot air from circulating inside the cabinet. The fan is particularly quiet as it uses a low-speed axial motor.

An alarm printed circuit board is mounted behind the removable mains panel for easy access. The faults monitored are power supply voltage, shelf air temperature, and a variety of module faults (e.g. phase-locked oscillator failure, a.f.c. failure, incorrect deviation or baseband levels etc., depending on the module functions). Individual fail lamps are provided on the modules as well as the summary alarm indications. Two sets of clean contacts are provided for external alarms. A 'summary alarm' operates if any equipment fails in the shelf, and a changeover alarm (which can be wired to the automatic baseband or s.h.f. switch) operates for a power supply failure, air temperature high (e.g. fan failure) and for any specific fault functions selected by the customer. The fault selection is easily made by means of plug-in printed circuit board links.

Special features

As a result of careful design, a good deal of commonality exists between the receive and transmit equipment.

As stated previously, the mechanical design of the two equipments is identical in terms of the number of modules, the overall size and the electrical interconnections. Various plug-in options are also available which can be added to the modules to increase the facilities (e.g. plug-in system equalizer for the i.f. modules). All the channel-conscious items also plug-in for ease of change of channel capacity.

The frequency converters are particularly alike, each front panel providing facilities for monitoring local oscillator frequencies, and enabling the frequency of the s.h.f. oscillators to be quickly retuned. This is achieved either directly by dialling the frequency on the thumbwheel switches of a microwave frequency synthesizer, and mechanically tuning its cavity oscillator until lock is achieved, indicated by the front panel phase voltage meter; or by the more conventional method of changing crystals and retuning a phase-locked oscillator.

Pre-set amplitude and group delay equalization compensate for any non-linearities in the converters that may have occurred due to the frequency conversion and filtering processes.

Within the i.f. modules there is a common design of i.f. filter which can be selected from various bandwidths from 1.25MHz to 36MHz. Each filter has been designed to meet the stringent Intelsat requirements adequately.

An optional continuously adjustable system equalizer can also be fitted to these modules to compensate for both amplitude and group delay distortions caused by other equipment within the earth station. It is particularly useful in the receive equipment for equalizing the inherent group delay slope caused by long cross-site waveguide runs.

The phase-lock loop demodulators offer a significant advantage over previous frequency modulation feedback designs. The information processing takes place at the 70MHz i.f. frequency, thus eliminating expensive and bulky frequency conversion circuits. A.F.C. circuits no longer become necessary and, most important of all, channel changing can take place without the need for special test equipment, by the substitution of different loop filters,

selected by plug-in links on a printed circuit board.

Advances have been made within the baseband circuit. Out-of-band noise monitoring filters have now been designed to have constant gain/bandwidth products, in order to eliminate special calibration procedures, previously necessary whenever a channel capacity change took place.

Channel capacity and frequency changing

The new equipment has been designed specifically to minimize the time taken to change from one channel capacity to another. To this end, the use of plug-in circuits, PCB links and other forms of test aids have been built into the design. Thus the need for special external test equipment has been eliminated.

In order to implement a capacity change, it is only necessary to substitute the frequency and bandwidth conscious emphasis and filter units and to reset baseband levels with reference to a table according to the particular capacity. The specific items requiring attention are highlighted in table 1.

S.H.F. frequency selection would normally be made by simply dialling up the required frequency on the microwave synthesizer and mechanically tuning a cavity oscillator until lock is achieved.

Equipment redundancy

One aspect of station philosophy that has changed over the years is the redundancy of equipment used for high capacity carriers. Early receive systems sometimes used 1 for 1 standby receivers which could change

Table 1: Items involved in channel capacity changing

Receive equipment	
PCB attenuator links	} Baseband module
De-emphasis PCB	
Noise bandpass filter	} Demodulator module
Loop filter (threshold extension only)	
I.F. filter unit	I.F. module
Transmit equipment	
PCB attenuator links	} Baseband module
Pre-emphasis PCB	
Noise bandstop filter	} Modulator module
PCB links (pilot monitor)	
I.F. filter unit	I.F. module

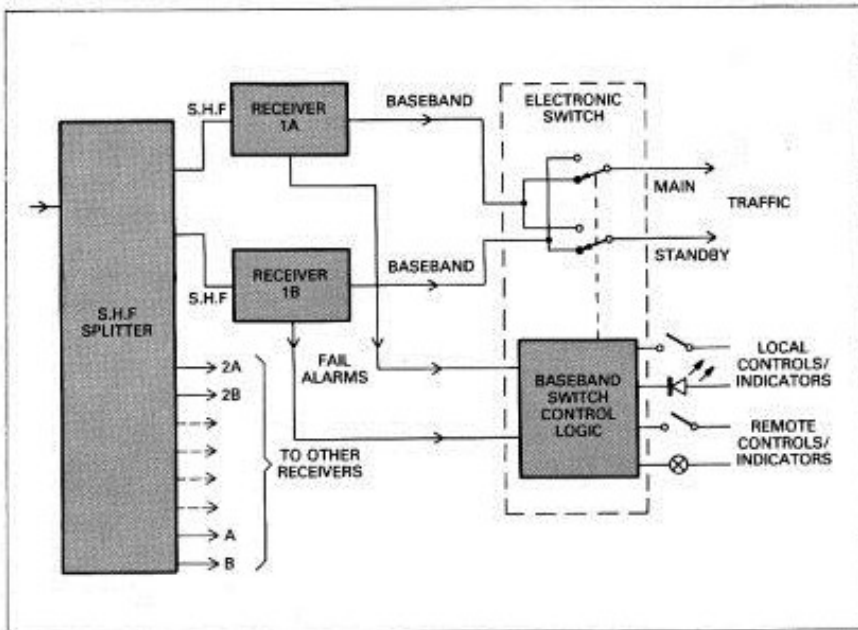


Fig. 6. 1 for 1 receive system

their carrier frequencies, but not the channel capacity or bandwidth. Thus, at least one '1 for N ' standby receiver was required for every different channel capacity and bandwidth combination used in the station. As the implementation of this philosophy

became too complex and costly to reconfigure in the larger earth stations, many stations today tend to favour one-for-one redundant systems which are simpler and more flexible. A typical '1 for 1' receiver would be as shown in figure 6. Up to four automatic

baseband switches can be mounted at the top of each cabinet to cater for up to eight receivers. A high-speed electronic switch is used (less than $5\mu\text{s}$ changeover time) to ensure no loss of traffic when manually operating the switch for test purposes. The receiver fail alarms (to initiate changeover) can be selected by the customer.

Recent advances such as lower cost and smaller microwave synthesizers, fully automatic wide ranging a.g.c./i.f. amplifiers, and the reduction in size and cost of the overall receiver, have now made it practicable to produce '1 for N ' standby receivers which can change channel capacity and bandwidths as well as carrier frequency at an economic cost. A typical '1 for N ' (channel, bandwidth and frequency changing) receiver could be as shown in figure 7. The '1 for N ' receiver will automatically select the required carrier frequency (microwave synthesizer), bandwidth (i.f. filter), i.f. gain (using the receive i.f. a.g.c. amplifier), de-emphasis and baseband gain, and the required noise bandpass filter (for monitoring out-of-band noise). The '1 for N ' standby receiver would require a

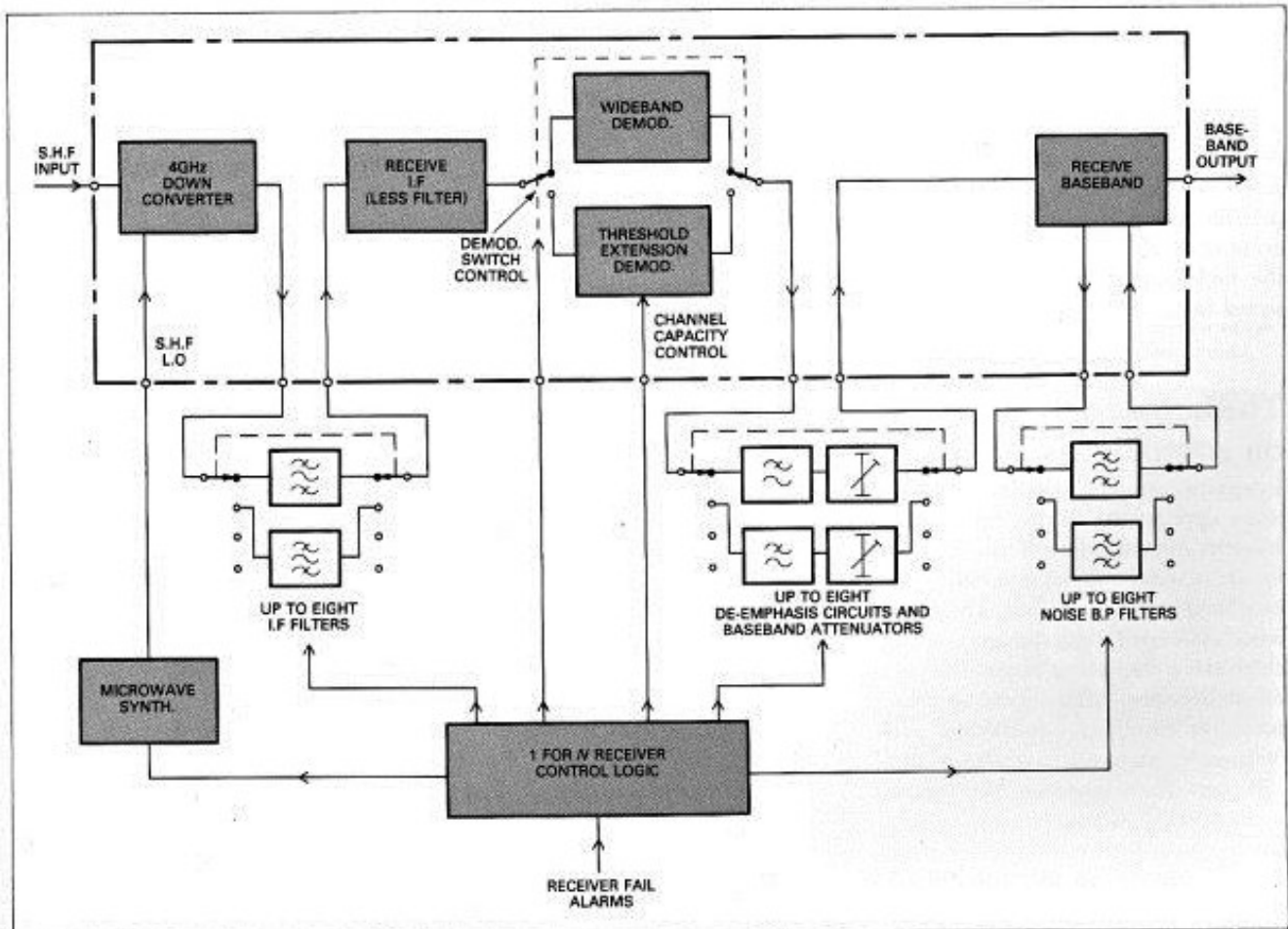


Fig. 7. Modified 1 for N receiver (standard receiver is shown enclosed within chain-dotted enclosure)

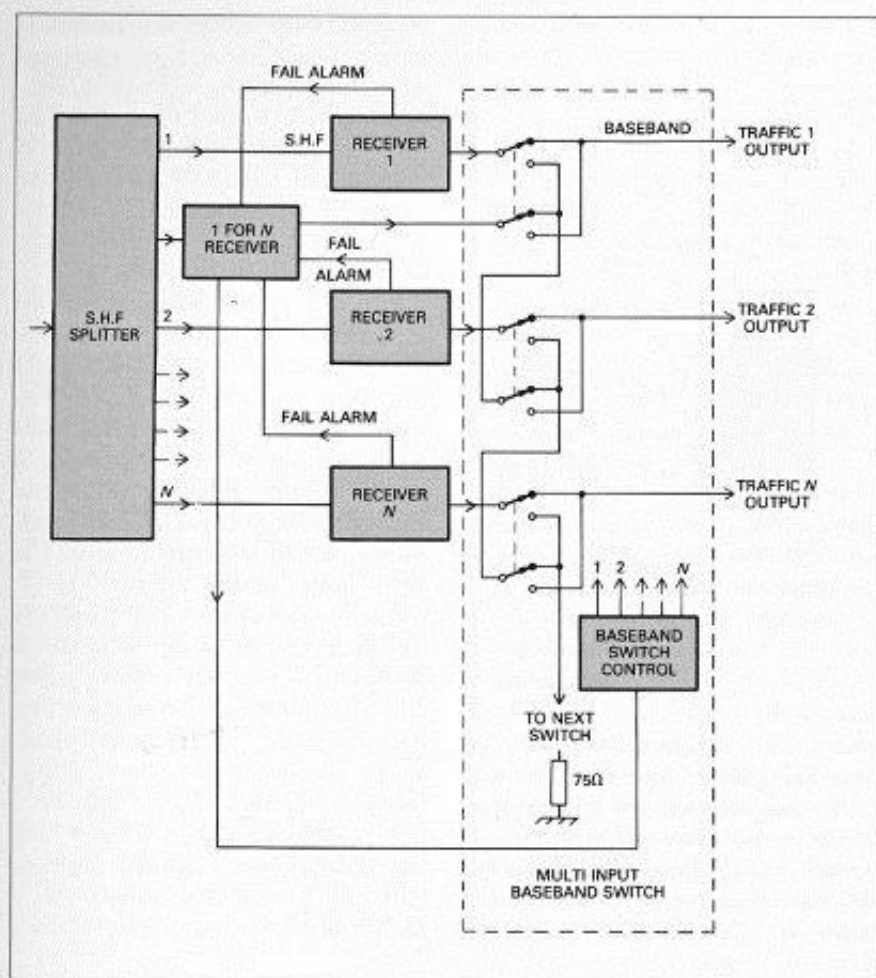


Fig. 8. 1 for N receive system

multi-input baseband switch similar to figure 8 to enable any of the protected receivers to be replaced. The '1 for N' standby receiver logic must include a priority system to ensure that in the event of two or more failed receivers, the highest priority receiver is protected first.

The impact of technology on equipment design

Integrated circuits are now finding more applications in this equipment; however, they are still not cost effective for use in wideband, high-performance baseband and i.f. amplifiers. The problems associated with integrated circuits are a limitation of high output capability into 75Ω systems, thermal noise (at baseband frequencies) and frequency response (at i.f.). Hybrid circuits (which use some discrete components in 'chip' form on a ceramic substrate) can be used to overcome some of these problems, but they are still of relatively high cost (compared with discrete transistor circuits) unless manufactured in a very high volume.

Integrated circuits, however, are suitable for the many monitoring functions in the system.

The availability of high-speed integrated circuit dividers and digital

phase detectors has made the designs of phase-locked loops for the modulator and the threshold extension demodulator more practicable. It has resulted in a smaller and cheaper product, and one that consumes less power and requires no warm-up period.

Carrier selection had previously been achieved by the replacement of v.h.f. crystals within the s.h.f. phase-locked oscillators. Thus, to change the transmitted or received frequency, new crystals had to be ordered some months in advance to allow for manufacturing and pre-aging of the crystals. More recently, to overcome the delivery problems of crystals a v.h.f. synthesizer has been used as the reference for the s.h.f. phase-locked oscillator, but this has resulted in a large and expensive piece of equipment. Currently, mechanically-tuned microwave synthesizers capable of 125kHz frequency steps are available which can meet the technical requirements of low f.m. noise and low level of spurious signals on the output. In the future it is hoped that electronically agile versions of these devices will become available to meet all of these requirements.

Trends in equipment design and operation

The most important aspects of equipment design from the customers' viewpoint are price commensurate with technical merit, ease of operation,

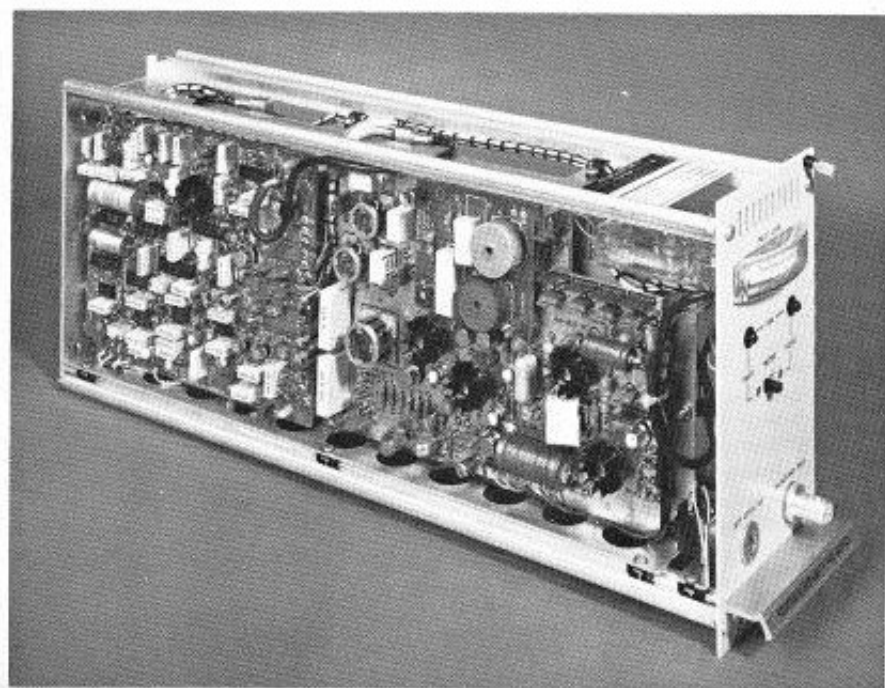


Fig. 9. Receive baseband module

reliability and physical size. Other factors which will influence whether a future user selects one manufacturer rather than another include delivery time, ease of maintenance and after-sales service.

In order to be competitive, SATCOM equipment manufacturers are finding it necessary to provide a product which not only complies with the mandatory specifications laid down by the Intelsat Board of Governors (BG) but also satisfies the demands of the user with respect to the general ergonomic and technical excellence of the design. To this end, special maintenance facilities in the form of monitors, meters, alarms and patch panels are being provided and major efforts have been made to reduce the complexity of a channel capacity change. There has also been a general trend towards equipment miniaturization and '1 for N' redundancy systems to save on the valuable floorspace available in earth station buildings.

The next era in the growth of satellite communications will be the advent of Intelsat V, when transmission from earth stations will take place in the 6 and 14GHz bands and reception by earth stations in the 4 and 11GHz bands. The higher frequency bands will be dedicated spot beams for communication between Europe and the USA, while the 4 and 6GHz bands will be used for global coverage.

Another generation of hardware will be required for these higher frequencies. The Marconi design of GCE can readily accept these changes simply by substituting the 4 and 6GHz frequency converters for similar designs at 11 and 14GHz. The current design is aimed at producing equipment which will also be compatible with the proposed new 11 and 14GHz European Satellite System, known as ECS. Here, t.d.m.a/p.s.k transmission will be used solely for telephony, while television will retain the analogue f.m mode of operation.

Conclusion

New technology and techniques have enabled equipment to become cheaper, smaller and easier to operate. The careful consideration given to the mechanical design has also ensured that channel capacity changes and routine maintenance can easily be carried out with the minimum of 'down time' by the user.

British Telecom, the communications part of the British Post Office Corporation, has ordered a quantity of Marconi ground communication equipment to cater for the initial requirement of 34 receive chains and 8 transmit chains for the Goonhilly 4 earth station, where transmissions are scheduled to start via the Intelsat V satellite, and for its Goonhilly 5 INMARSAT shore station, both due to become operational during 1982. Further GCE equipment has been ordered for the Nepal ST-B earth station for s.c.p.c and TV operation.

RÉSUMÉ

Cet article présente les modèles et les exigences ayant trait au matériel des grandes stations terrestres. La gamme actuelle du matériel de communications terrestres, mise au point par Marconi Communication Systems Ltd., y est également décrite, l'accent étant particulièrement mis sur une station Intelsat de Type A.

ZUSAMMENFASSUNG

Dieser Artikel befasst sich mit den Anforderungen und Entwürfen von grossen Bodenstation-Einrichtungen. Das derzeitige Angebot von Erd-Fernmeldeeinrichtungen von der Firma Marconi Communication Systems Ltd. wird mit besonderem Hinweis auf eine Intelsat-Station Typ A beschrieben.

RESUMEN

Este artículo trata de las exigencias y diseños de equipos para grandes estaciones terrestres. Se describe la variedad de equipos de comunicaciones de tierra diseñados por Marconi Communication Systems Ltd, con referencia particular a una estación tipo A del Intelsat.