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Tropospheric scatter 2GHz systems

Summary

The development of tropospheric scatter communication systems has been accelerated by their use on North Sea Oil communications. This has meant that new equipment, working in the 1.7–2.7GHz frequency band, has had to be developed. The article first describes the general system requirements associated with a tropospheric scatter system. It then details the current equipment configuration for receivers, transmit drives and power amplifiers. The maintenance philosophy is briefly described together with the future possibilities for the improvement of tropospheric scatter systems.

Introduction

There have been a number of articles on a wide range of topics associated with tropospheric scatter communication systems, [1, 2, 3, 4] including descriptions of current Marconi equipment used in the 900MHz communication band. This equipment has been used as the basis of a new range of tropospheric scatter equipment specially developed for operation in the 1.7–2.7GHz communication band. The designs have retained the basic form of free-standing, open fronted cabinets, with modules in shelves to give front access for test and maintenance purposes.

The modular form of construction allows flexibility of design and customer requirements can be readily included without the need for large amounts of special development. The present article covers the latest designs of power amplifier, drives and receivers for the 2GHz band.

System requirements

When considering a tropospheric scatter link the system designer has to study the expected climatic conditions associated with the link. The chief parameters are the all year median path loss, which is determined by the free space loss (proportional to the path length) and the all year median scatter loss, which is affected by the scatter angle and therefore the geographical locations of the link. Apart from these losses, the designer must also consider the variations due to two main factors; the fast fading loss caused by multipath effects having a Rayleigh characteristic and a slow fading scatter loss caused by changes in the refractive index which, taken over a period of one year, brings about a variation in signal level of as much as 100dB on some links.

In order to provide a system having a very high reliability, a number of techniques for combating these fading characteristics have been devised in recent years. The main way of achieving this is by the use of diversity reception, there being four basic forms in general use which are as follows:

(A) Frequency diversity

If two signals are transmitted on different frequencies and received on the same antenna then, provided that there is of the order of at least 2% difference in frequency, there will be a lack of correlation between the two received signals. The use of frequency diversity has the penalty of requiring twice the number of operating frequencies for any given system. In general this form of diversity cannot go beyond a dual form because of the need to provide receive channels free from local transmitter interferences and the inflexibility higher orders of frequency diversity introduce.

(B) Space diversity

The scattered signals arrive over several different paths giving rapid variation of signal level. If two antennas separated by at least 100 wavelengths are used for reception, the two signals will be essentially uncorrelated.

(C) Angle diversity

It has been demonstrated that it is possible to provide diversity effects by utilizing two or more feeds in the antenna systems. This gives a sufficiently low correlation between received signals, though the different median levels is a slight disadvantage. Whilst this system can give antenna and site cost reduction compared with other diversity methods its predominant use is in providing overlays to existing systems.

(D) Polarization diversity

The polarization of the transmitted signal can be of two forms, vertical or horizontal. In a quadrature diversity system one transmit antenna will radiate on horizontal and the other on vertical polarizations. Each of the receiver antennas can receive both horizontally and vertically polarized signals which, together with spacing of antennas, gives the required order of diversity.

The order of diversity may be increased to four by transmitting and receiving on two antennas, the diversity paths being identified by using different frequencies or polarization. If a combination of space and polarization is used, then the frequency band occupied is reduced as only one frequency is transmitted at each end of the link.

Any modern communication system should provide as much choice as possible, provided that the complexity is not increased. In choosing diversity systems, space and angle are the most effective. If frequency diversity is used on its own not only are more frequencies involved, but the equipment requirements to allow the use of pre-detection combining become complicated.

The system designer usually has to design to specific customer requirements, therefore he requires equipment that is flexible and simple to alter so that the necessary link performance may be obtained. The system equipment performance is not always tied to CCIR requirements but as far as possible baseband levels, pre- and de-emphasis are made to conform. The system can be easily adjusted for optimum performance the deviation can for example be adjusted for equal basic and intermodulation noise, together with the appropriate i.f bandwidth.

To allow for different path lengths, the receiver gain and noise figure may be varied by choice of the appropriate input amplifier.

Equipment configuration

The factors under a system designers control are size of antenna, transmitter power, deviation, channel capacity receiver input noise figure, order of diversity and type of demodulator. To ensure that the lowest cost solution is obtained, all of these factors must be taken into account. To this end tropospheric scatter terminals have been designed to give the facility to do this by breaking down the system into relatively small modules. In addition, the problem of maintenance and fault finding is considerably reduced.

Receive system

The receiver block diagram using Type H3412/3422 receivers is shown in figure 1, the respective input frequency bands being 1.7–2.35GHz and 2.35–2.7GHz. The r.f signal is applied to a pre-selector filter which restricts the bandwidth to approximately 30MHz. The interdigital filter is available in six editions, covering the complete input frequency range. The filter output is then applied directly to a down-converting mixer or if lower noise and more system gain are required, then a transistor or parametric amplifier may be used. The transistor amplifier, contained in a single module box, uses an amplifier Type ASD 804M which has its own internal power supply. The parametric amplifier gives an additional 18dB gain with a 1.6dB noise figure.

These three options provide for a sufficient range of input noise figure. It is, of course, possible to obtain lower input noise temperatures by the use of cooled parametric amplifiers. However, due to the low incidence angles tropo systems use, it is not economic to decrease the effective receiver noise temperature because of the noise thrown into the receive antenna by the hot earth.

The r.f. signal is converted directly to 70MHz in a mixer which uses strip-line techniques to provide a highly stable unit. The image rejection of the circuit is obtained by combining two i.f outputs in a quadrature phase hybrid. The local oscillator frequency is derived from a phase-locked oscillator (PLO) of which there are two versions. One unit gives an output frequency between 1.7 and 2.3GHz. The fundamental frequency of the voltage controlled oscillator (VCO), in the phase-locked oscillator, is half the required output frequency. This VCO is locked to a harmonic of a crystal controlled reference oscillator, the reference oscillator giving an output between 80 and 103MHz, depending upon the internal crystal used. The harmonic used can be between the ninth and twelfth, giving considerable system flexibility. The VCO output is applied to a frequency doubler to give the final local oscillator frequency. The second unit covers 2.3–2.7GHz, the VCO operates at the required output frequency, simplifying the circuit. The reference frequencies are derived from the same reference oscillator.

The mixer output is 70MHz which is the i.f frequency. At this point the i.f bandwidth is restricted, the amount of restriction used depending on the overall system requirements. The bandwidth is derived by using Carson's formula, and is dependent upon channel capacity and the deviation used. The filter module is available in four bandwidths. To obtain approximately

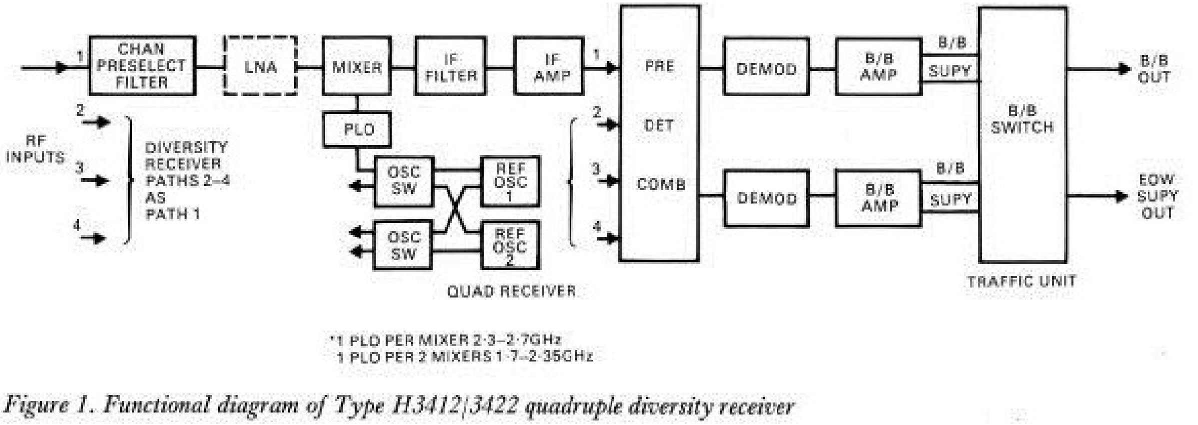

Figure 1. Functional diagram of Type H3412/3422 quadruple diversity receiver

the required Gaussian response for the two narrowband filters (1MHz and 2MHz) with a reasonable insertion loss, helical resonators have been used, but for the wideband filters normal lumped components are adequate. In each filter there is a variable gain amplifier and attenuator which buffers the filter and allows flexibility in adjustment of system levels.

The restricted signal is applied to a 70dB gain i.f amplifier which is capable of being varied by 45dB. The amplifier is designed to give high gain and low noise contribution to the system and besides following fast fades, maintains these characteristics in the presence of high input levels thus coping with the signals experienced when ducting occurs in the troposphere. The gain control voltage is derived from the i.f converter situated immediately after the pre-detection combiner system, the voltage being applied to each of the four receive chains to maintain the gain of each i.f amplifier. This takes up the difference in signal strength with the result that the i.f signal is maintained at a constant level for application to the pre-detection combiner.

Compared with the 900MHz equipment where only post-detection combining was available, the pre-detection combining system is a new development. The system consists of three modules, a phase corrector in each receiver chain the outputs of which are summed in a passive combiner module, its output being used as a control signal to the phase correctors for making the output phase of each loop identical. The great advantage of this form of combining is that, because it is performed before demodulation, an improvement in the carrier/noise at the input to the demodulator can be achieved, thus giving an effective extension of threshold up to 6dB for a quadruple diversity system. depending upon the level in each channel. This improvement gives the system designer a degree of freedom in the choice of antennas and power amplifiers besides enabling links having longer path lengths to be accommodated. The i.f converter is necessary as the process of combining produces an output at 59.3MHz. Although the demodulator could be made to operate directly at this frequency it would have produced test equipment and compatability problems with other communication links and so was not used.

Unlike the original conventional demodulators, the new limiter is an integrated circuit providing limiting and a.m. rejection for a wide range of input levels. The system is very flexible in that it can work for any channel capacity from 12–132, with a wide range of deviations. In order to increase the flexibility of the system and allow more freedom to the system designer there has been added, to the units available, the option of a threshold extension or conventional demodulator.

To achieve an extension of the system performance below the conventional f.m threshold of 10dB carrier-to noise, it is necessary to process the signal such that its effective deviation is reduced and the bandwidth restricted to a narrower spectrum than that calculated for a conventional system. There are two commonly used methods for achieving this. First, a frequency modulated feedback (FMFB) system the basic form of which is shown in figure 2. In this arrangement the input signal is mixed with a VCO and the difference frequency is applied to a conventional limiter/discriminator via a single pole filter. The recovered baseband is used as a control voltage for the VCO, thus tracking the input signal and reducing the effective deviation. This allows the single pole filter to be narrower than the normal i.f filter, thus giving a degree of threshold extension. Second, the phase lock loop (PLL) system which is shown in figure 3. This is similar to the FMFB except that the input signal is tracked in phase and the loop detector is actually a phase sensitive detector (PSD). In practice both forms are used in the Type

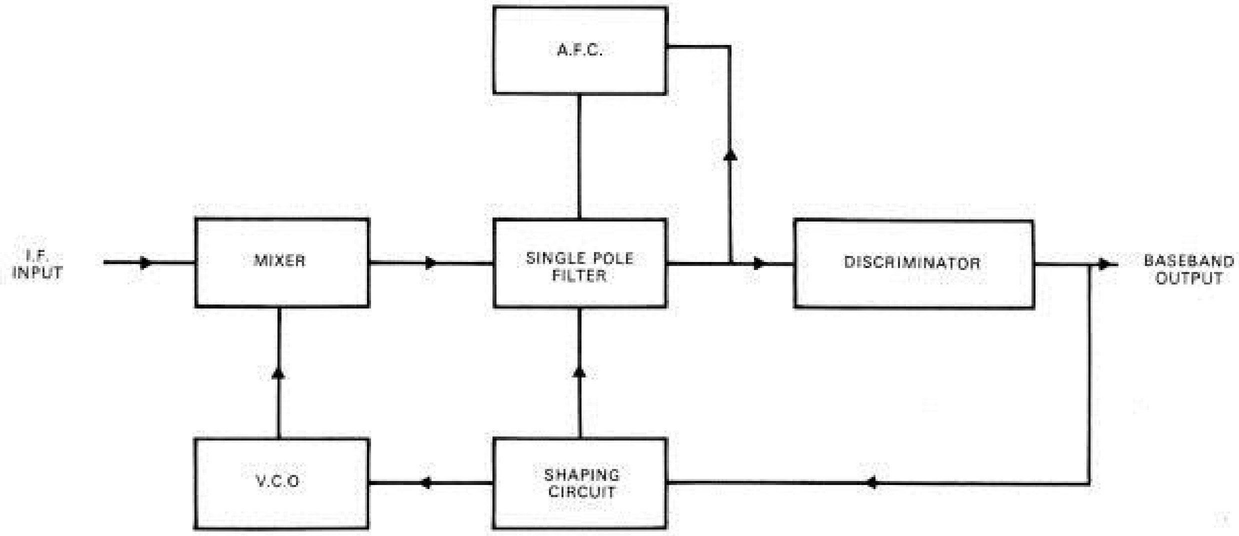

Figure 2. The basic form of a frequency modulated feedback system for threshold extension demodulator.

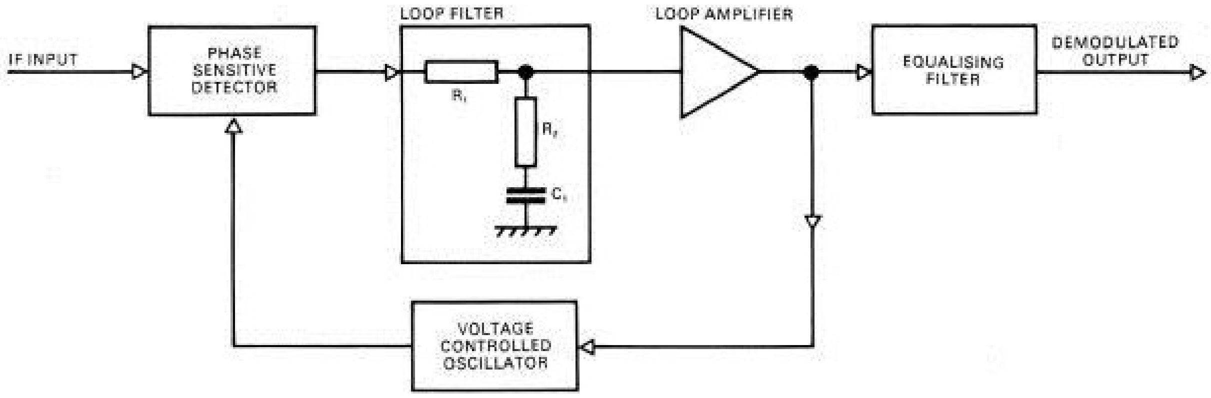

Figure 3. Typical phase-locked f.m demodulator

H3412/3422 series of receivers, the PLL being used for six to 48 channel operation and the FMFB for 60–132 channels.

The construction follows the normal modular form for tropospheric scatter equipments. The PLL is made up in the form of a double module consisting of the VCO Colpitts oscillator with its varicap diode as a tuning control and a linear PSD giving improved threshold and clean carrier-noise performance. The simplicity of the VCO circuit limits its linearity and therefore its clean carrier performance at the lower channel capacities. The FMFB demodulator is contained in a double and two single modules. The basic circuit is as described but with the addition of an a.f.c circuit as in an FMFB system, it is necessary to keep the signal centred on the single pole filter tuning frequency which is wobbled at a low frequency by varicap diode action. If the signal deviates from the centre due to variations of the 70MHz input or the internal FMO, the output signal which contains an a.f.c. modulating signal component will have a phase error compared with the wobble frequency. This error is detected and the voltage derived is applied to the FMO to correct the frequency error.

The threshold extension demodulator allows the system designer two options. It can be optimized for maximum extension at the expense, to a degree, of clean carrier-noise-power ratio (NPR) or the NPR can be optimized in which case the extension is reduced. The extension available gives system design flexibility, a 3dB extension allowing either a halving of the transmitter power, a reduction in the receiver input noise figure or operation over longer transmission paths.

The demodulator output is further processed in a baseband amplifier, where it is filtered, de-emphasized, amplified and includes a pre-set attenuator to allow the output level to be set to −14dBm regardless of system deviation. The lowpass filter, also channel conscious, is to prevent intermodulation noise on the output when used in a baseband combiner configuration.

Transmit system

A typical transmit system using Type H3212/3222 drives is shown in figure 4. The system provides a dual drive which can be operated at the same frequency, or if frequency diversity operation, is required then the reference oscillators are fed independently to each phase-locked oscillator.

The normal signal transmitted is made up of three parts; the traffic baseband signal, the 5.7kHz continuity pilot and the engineering service circuits (ESC) supervisory signals. The traffic and 5.7kHz continuity pilot are combined together in the traffic unit. The combined baseband signal is split, one part being fed to the baseband amplifier where it is 're-emphasized to

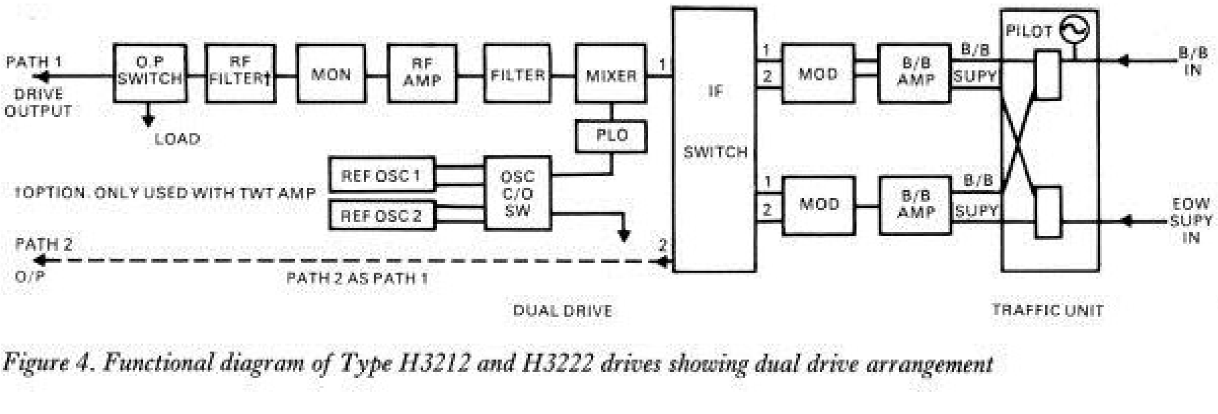

Figure 4. Functional diagram of Type H3212 and H3222 drives showing dual drive arrangement

meet CCIR Recommendation 275-1 for a range of channel capacities. After amplification it is combined with the ESC signal and fed to the modulator.

The modulation process is carried out by direct modulation of a 70MHz oscillator. In existing designs of tropospheric scatter terminals the frequency stability of the modulator is ±50kHz and in order to keep the centre frequency of the modulator on its correct frequency the circuit includes an a.f.c system which uses a conventional L–C discriminator. However, the requirements for modulator stability have, in recent years, become much more stringent and to meet these requirements a new modulator has been developed which uses the same basic form of modulator but has a digital a.f.c system that holds the centre frequency to within ±1kHz.

The two modulator outputs are applied to an electronic switch giving 80dB isolation between modulated signals. The switching takes place when monitoring circuits indicate no output from the working modulator.

The up-conversion of the 1.7GHz band is accomplished by mixing the 70MHz modulator output with the output of a phase-locked oscillator whose frequency is set by a reference oscillator. The signal is applied to a pre-selector filter, a narrowband interdigital circuit having a maximally flat response that varies with system requirements. This restricted signal is applied to a transmit r.f amplifier which can be tuned over the r.f frequency range, and in order to obtain repeatable and highly stable characteristics the design uses microstrip circuitry. The r.f amplifier output is applied to a transmit monitor via an isolator. This monitor, which also uses microstrip techniques, provides a sample output straight through to a drive switch assembly when monitoring the transmitter output power or for use with the 'turnround mixer' when system testing.

Power amplifiers

The allocation of the 1.7–2.7GHz communication band to tropospheric scatter links created the need for a new series of power amplifiers to interface with the new drive equipments. Two amplifiers have been developed to cover this band. Type H3712 for 1.7–2.4GHz and Type H3722 the remaining 2.4–2.7GHz but in other respects the characteristics are the same.

The amplifiers, complete with their own built-in air cooling system, are each housed in a single cabinet 1.6m high by 1.07m wide by 0.64m deep (63×42×25in) the total weight being 450kg (990lb). As shown in figure 5, the cooling air is drawn in through a filter at the bottom front of the cabinet and cools the whole equipment without the use of a heat exchanger, the arrangement being very simple and trouble free. All leads are taken through openings in the top of the cabinet, including the r.f output feeder.

The cabinet is designed to give full protection to the operating staff, a system of interlocks and isolators preventing a door or unit being opened unless the power supplies are first switched off and earthed. The mechanical interlock access keys are fitted in the earth-

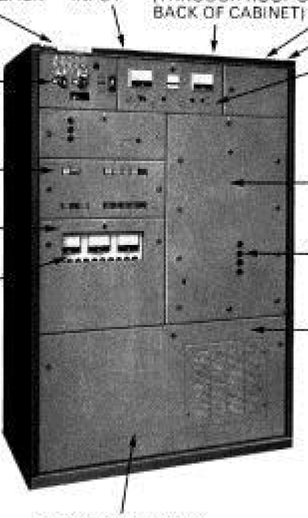

Figure 5. The complete 1kW Tropospheric Scatter Amplifier Type H3712

ing switch assembly and are held captive until the switch has been operated to the earth position. The control unit is not included in this arrangement as it only has a 28V d.c supply and may therefore be safely withdrawn for maintenance at any time.

Apart from the final stage which uses a klystron, the amplifier is solid-state throughout, has a minimum gain of 38dB and provides an output of 1kW when tuned for a 10MHz bandwidth. Two makes of klystron may be used, either the Varian Type 4K3SL or the Thomson CSF Type TH2046 for the 1.7 to 2.4GHz amplifier and Varian Type 4K3SK or Thomson CSF Type 2404B for the 2.4 to 2.7GHz amplifier, both types being directly interchangeable in each case for the respective equipments. The level of second harmonic in the 1kW output is typically 30dB below the carrier level and for the other harmonics 40dB. By using an external reflective type filter, this level can be reduced still further to 60dB. Forward and reverse power levels are monitored and displayed, together with other meters which indicate the collector voltage, cathode current, filament voltage, auxiliary supplies and filament hours.

The control circuits provide for automatic run-up and shut-down by the operation of a single OFF/START switch. In the event of a fault, the h.t to the klystron is automatically switched off and if, after three attempts at restoration, the fault still persists, the usual look-out conditions come into operation. For obvious reasons, the effectiveness of the air cooling system varies with altitude, the ambient temperature range for full performance for sites up to 2000m high being −2 to 45°C with humidity not greater than 90%. For sites higher than 2000m the maximum temperature is reduced, a typical figure being 20°C at 3000m.

The mains supply required is single phase 207–255 volts, 47–63Hz the power consumed being 7.5kVA at 0.9 power factor. The full output power from the amplifier is available ten minutes after switch-on and is stable to within 1dB for a 10% mains voltage variation within the limits stated.

Further development work has now been carried out on the Type H3712 amplifier with a view to making it in a form most suitable for installation in a container for mobile applications. This equipment has a smaller cabinet 1200m high, 830mm wide and 610mm deep ($47\frac{1}{2} \times 32\frac{1}{2} \times 24$in), the total weight being 350kg (770lb) which is a saving of some 100kg (220lb).

Other significant changes include the use of a different klystron, Varian Type 4K3SL-3, which is capable of rapid tuning to the required frequency. The mains supply is 3 phase, 4 wire, 380–440 volts, 47–63Hz but the power consumption remains the same at 7.5kVA. The environmental specification is also improved to conform with typical military requirements, the operating temperature limits being −32°C to +52°C, the container providing a good measure of protection against the environment.

Maintenance

The 900MHz tropospheric scatter equipment used a modular form of construction and this has been carried through into the new 2GHz designs. This form of construction provides easy maintenance as faults can be pinpointed quickly and cleared immediately by replacement of modules, thus ensuring maximum continuity of traffic. Once this has been done, repairs to the faulty module can be carried out, either on site or at a base repair workshop, where suitable facilities are normally available.

To further assist fault finding, both the receive and transmit cabinets are laid out so that Path A receivers are situated on the left hand side of the cabinet and Path B receivers on the right. This also applies to the power supply units situated at the base of the cabinet. This separation means that a complete drive or receiver chain can be switched off for maintenance purposes without loss of traffic. The pre-detection system cabinet can be used in a dual diversity mode by means of a special add-on test jig.

Conclusion

Possibly the main area for further improving the performance of tropospheric scatter systems now lies in overcoming the troublesome effects of ducting. During periods of ducting the receivers have to handle exceptionally high signal levels which, because of the high intermodulation noise this condition produces, results in poor quality reception.

The subject has been briefly covered in an article by Kennedy[7] in which general details are given of a practical solution to this kind of distortion. Development of the associated hardware has now reached the production stage and is commercially available, the type number being H3515. The addition of this power level control system not only nullifies the effects of ducting on the received signals but also provides a bonus in the form of reducing possible interference problems with other systems.

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