# ECONOMIC RADIO RECEIVER TECHNIQUES.

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# PART 1. HIGH STABILITY RECEIVERS.

The ability to design and manufacture radio receivers as economically as possible depends on a number of factors. Initiation of a project requires through examination of the market requirement for the proposed equipment. A specification issued by an Authority may indicate desires rather than real needs and it is necessary that the engineering and commercial staff identify the real needs and propose to the customer a receiver that has a performance which is fully suitable for their purpose, at an economical price and, at the same time, having consideration for other possible users to permit the highest production quantities. A study of the specifications, whether issued by Authorities, or developed from information fed back from users of equipment already in service, is a critical part in the process of designing economical radio receivers. For example, a specification that is written providing for the reception of all modes of transmission under all environmental conditions from $-40^{o}C$ to $+85^{o}C$, operating from batteries or mains supply, may be a real requirement or it may be a safe specification providing a comprehensive equipment that will never be fully utilised in service. Co-operation and discussion with a number of prospective customers will ensure a final specification that includes only the most appropriate requirements necessary for satisfactory operation in service, thus resulting in a more economical receiver for the end user.

Having discussed and achieved a specification which gives the best chance of producing the right equipment, Engineering Management must ensure that the engineers undertaking the designing are informed with clear directives - directives which do not limit initiative but strive to avoid different or more complicated design for its own sake.

It is our experience that we should not restrict our designers too firmly within the limits of available mechanical parts.

Equally, we would not aim to produce a design which was not expected to have a production life of less than one thousand units.

A few words now on design engineering at Eddystone Radio Limited. Eddystone Radio has always specialised in supplying receivers as separate units, commonly described as "black boxes", to suit communication manufacturers, Governments and Military Authorities and has, over many years, built up an establishment with personnel highly qualified to deal with the communication problems in the VLF, VHF and UHF bands.
I should like to refer to the more critical aspects of the improved performance necessary in the new generation of communication receivers. The ability of a receiver clearly to resolve a signal, sometimes of a very low level, say, less than 1 microvolt, in the presence of many other signals of high levels, has become of prime importance.
The figures for cross modulation, blocking and intermodulation form a significant part of the specification.
Frequency stability is another stringent requirement the designer must satisfy. Frequency stability only achieved under laboratory conditions some 25 years ago is now demanded in low cost medium performance receivers.
The performance of this equipment must be maintained under conditions of shock and vibration, particularly for Merchant Navy and Warship applications. The receiver must operate not only under conditions of low frequency vibration, as was typical when ships were powered by steam or low-speed diesels, but must also operate with high speed turbines and under rough surface conditions as, for instance, in a fast Naval Patrol boat. A small ship or patrol boat will also require that the receiver and transmitter aerials are sited closely to each other, therefore, the receiver has to be adequately protected from high voltages which are sustained for long periods and, at the same time, provide protection from a very high static discharges. It can be seen from the foregoing that the designer must develop a receiver which will operate under stringent conditions over a wide range of temperatures and under severe shock and vibration.

Let us first consider the design of an economically priced receiver meeting the frequency range 10 KHz to 30 MHz, with the greatest possible appeal to Government undertakings, such as Public Correspondence, Coast Stations, Marine main receiver users, Military and Para-Military operation. A study of the market and user needs and the introduction of new specifications, particularly for marine purposes, indicated that a receiver providing AM, CW, FSK, SSB, in one compact unit, capable of rapid continuous tuning and with coverage from 10 KHz to 30 MHz was required. High stability working within a limit of 20 Hz is of paramount importance to meet the requirements of the new regulations, due to become effective in the seventies.

Let us now follow the design and development of a general purpose LF, MF, HF communication receiver which has resulted in the Eddystone 958 Series of high stability receivers. Clearly, silicon devices, because of their higher temperature ratings, had to be used throughout. Circuits had to be limited in complexity, forming either a separate module or a separate circuit pattern on a larger printed board. This was required to facilitate testing and serviceability. This would mean simpler test procedures and would help to reduce the need for highly skilled test personnel. Integrated microcircuits should be used, bearing in mind that modern integrated microcircuits can often replace many discrete components with high reliability, the final cost being lower than similar circuits using discrete components. Field effect transistors should be considered, particularly for the RF and mixer stages, where their improved linearity would assist in achieving improved cross modulation and intermodulation performance. Ceramic or quartz filters should be used wherever possible to reduce complexity and testing requirements. However, one question considered in the first instance, which could have considerable effect on the final cost was whether the receiver could be designed to meet specifications using intermediate frequencies below 1.6 MHz

Our investigation showed that economic manufacture of filters and tuned circuits could be readily achieved at frequencies below 1.6 MHz. The stability of these filters and tuned circuits was fundamentally superior because of their operation at low frequency and, more importantly, any oscillator used for injection to a mixer for frequency conversion, would also be at low frequency. The lower the frequency, the smaller would be the deviation in frequency due to temperature shock and vibration.
The need to provide temperature controlled ovens for oscillators would be minimised, which would also further reduce the power supply requirements.
A design which utilised the lower intermediate frequencies offered a number of advantages, not the least being the ability, during manufacture, more easily to meet the physical and electrical tolerances required.

A receiver on these lines, to meet and exceed international and national marine specifications for main ship receivers and Coast Stations applications, together with ability to satisfy many Para-Military and Military users, with IF frequencies lower than 1.6 MHz and providing the advantages outlined, has been designed and developed by Eddystone Radio Limited and is in full scale production. This receiver is the Eddystone EC.958.
The 958 covers the frequency range 10KHz to 30MHz, providing AM, CW, FSK, SSB reception modes in one single compact unit with a front panel 133mm high and weighing approximately 20 kg. The wide frequency range 10KHz to 30MHz is covered in ten separate ranges - each of these ranges can be tuned over rapidly and continuously. Above 1.6 MHz to 30MHz, high stability working is provided, the main tune frequency being locked every 100 kHz. Tuning of the frequency between the 100 kHz points is accomplished by a precision tuned oscillator, resulting in a stability of better than 20 Hz.

However, it is when one considers the 958 circuitry that clear differences are apparent, compared with other high stability receivers. The circuitry used in the 958 results in improved performance in the areas already mentioned, including cross modulation and blocking.

Blocking is defined as the RF level in decibels reference to 1 microvolt of an unwanted signal, adjacent in frequency to the wanted signal, that reduces the output power of the wanted signal by 3 dB. For the 958 the level of the unwanted signal removed from the wanted by at least 10 kHz will be greater than +120 dB over the range 10 kHz to 30 MHz. Cross modulation is defined as the RF level in decibels reference 1 microvolt of an unwanted modulated signal, adjacent in frequency to the wanted signal that produces output power -30 dB below that of the wanted signal, for this test the modulation of the wanted signal is 30% and the modulator is switched off after the power output level is set. For the 958 the level of the unwanted signal exceeds +90 dB over the range 10 kHz to 30 MHz.

The input stages are all tuned, bandpass aerial being used for frequencies from 1.6 MHz to 30 MHz and in the 958/5 model, 54 kHz to 30 MHz. These input circuits alone provide 40 dB attenuation at frequencies ± 10% off tune. Further, the aerial primaries on the 958 are designed so that the aerial input impedance is largely reflected from the tuned secondary winding. The tuned coils are wound on miniature formers specially designed for this receiver to achieve high performance at low cost. This ensures a very low impedance of offtune signals and the installation of a 958 receiver, in close proximity to a high power transmitter , for instance, in a mobile vehicle or patrol boat, can often be accomplished without special filters or protection circuits. Receivers with wideband input circuits invariably require additional filters and protection circuits.

The aerial step up is approximately 6 dB to the gate of the junction FET which forms part of the cascode RF amplifier. The complementary FET in the cascode is a MOSFET. The arrangement of the two FET's provides a high input voltage breakdown protection and, together with a stable RF amplifier over the range 10 kHz to 30 MHz, a gain of approximately 18 dB is achieved. The low step up from the aerial and improved linearity of the FET contribute to improved blocking, cross modulation and intermodulation performance.

AGC is not applied to the RF stage until the input exceeds 1 mV. This ensures that no early degradation of signal-to-noise ratio occurs due to AGC action and, consequently, good linearity is maintained. At the same time, AGC will limit the input to the following mixers to less than 100 mV. It should be noted that the FET mixer will permit a swing of 100 mV for about 1% cross modulation - about 10dB improvement over a bipolar.

In the design study, considerable thought was given to the sensitivity requirements of the receiver in terms of both customer requirements and the operating environment.

Sensitivity is defined as a rating of the ability of a receiver to detect signals. Absolute sensitivity is usually specified as the signal input power which is equal to the noise power at a particular bandwidth. As the thermal noise power is proportional to the bandwidth, it is important for maximum sensitivity that optimum bandwidths, no wider than necessary for a particular transmission, be used. The five bandwidths provided by the selectivity unit in the 958 permits this.

A limit to the performance of the receiver, as regards single signal sensitivity against noise is set throughout most of the world by atmospheric noise levels which are commonly at a minimum, several decibels higher than the noise figure for a 958, which is of the order 10 dB. Summing up, the thermal noise generated in the early stages of the 958 is sufficiently low to provide a receiving system in service that has a sensitivity only limited by external noise.

The receiver will detect signals, CW/SSB as low as 0.1 microvolt but one must emphasise that single sensitivity measurements have only a limited value and must be correlated with 2/3 signal measurements and overall selectivity characteristics.
These conditions led us to the design of the cascode, FET input and our particular bandpass front end configuration.
The first mixer is fed from a free running main tune oscillator which is ganged with the first tuned circuits. In the free tune ( or search ) position, the oscillator/mixer circuit operates basically as in a normal superhet. When in high stability operation, the output from the free running main tune oscillator is mixed with 100 kHz harmonics derived from a plug-in 1 MHz oven controlled crystal master oscillator ( $5 \times 10^7$) ( 0 - 40°C ) to form part of a drift cancelling loop.
Note here the operation of the drift cancelling loop. Simply, the signal (F Sig.) is mixed with the main tune oscillator (FOSC) which gives an IF of FOSC - F Sig. The main tune oscillator (FOSC) is also mixed with the harmonic of a crystal ( F Harmonic). These two IF's are mixed together, resulting in an output equal to ( FOSC - F Sig.) - ( FOSC - F Harmonic) - the term FOSC cancels leaving the term F Sig - F Harmonic - thus the stability of the variable main oscillator is cancelled and the stability is determined by the harmonics of the crystal, the crystal being stable to one part in 10 to the seventh.
A number of high stability receivers employ this type of circuitry but only the Eddystone 958 uses such a system with a narrow noise bandwidth. In the 958, the bandwidth of the drift cancelling loop is less than 20 kHz. In other receivers, it is several 100 kHz. Receivers with wide noise bands, very often with untuned front ends and pre mixer stages broadly tuned, often suffer from relatively poor blocking performance due to the wide band noise spectrum mixing with an unwanted signal and producing an intermediate frequency that degrades the wanted signal. Typical 958 performance is that a 10 microvolt wanted signal will not be degraded by any unwanted signals ± 10% from the wanted signal until the unwanted signals have a level greater than 15 volts. Alternatively, a wanted signal 60 dB will not be degraded by more than 3 dB until an unwanted signal ± 10 kHz, removed from the wanted, exceeds a level of 110 dB.

The output from the first mixer is fed to a variable tuned IF 1235 - 1335 kHz with a bandwidth of the order 20 kHz. A gain of not greater than 6 dB occurs between the first and second mixer in the interest of operating the second mixer at a low level to reduce the spurious responses and improve the two and three signal performance.

Ganged with the variable 1235 - 1335 kHz first RF is the interpolation oscillator which provides the second mixer with a variable frequency covering 100 kHz. This permits frequency setting and tuning between the 100 kHz locking points on the main tune oscillator. The interpolation oscillator operates at a frequency of 550 kHz to 650 kHz and has a thermal stability of better than 3 Hz per degree Centigrade and a very small frequency variation under severe vibration conditions.

Spurious responses, self-generated within the receiver itself, and spurious responses developed by the mixing of incoming signals with them, are problems the receiver designer must minimise. The use of low intermediate frequencies, because harmonics of the oscillator used for mixing fall within the tuning range of the receiver, can further aggravate the problem unless proper precautions are taken.

Stray coupling between stages can be held to a low level by ensuring that impedances, common to the various circuits, are kept to a low value. Screening must also be complete around individual circuits and this can be achieved by using a substantial one-piece aluminium casting, with recesses to house the individual circuits.

The generation of a comb of frequencies of high stability for injection purposes, say , every 100kHz up to 30MHz, provides a particular problem. Isolation of the comb of frequencies from other stages to a level of at least 90dB, is extremely difficult with conventional circuitry. Discrete components with connecting leads provide particularly good radiation conditions within a receiver, however, the advent of microcircuits with wide bandwidths and output impedance as low as 1.5 ohms permits this difficult consequence to be overcome.

The active elements in these microcircuits occupy an area only a few square millimetres, permitting the design and manufacture of a harmonic amplifier greater than 30MHz wide, enabling injection frequencies every 100kHz up to 30MHz to be achieved without these same injection frequencies being detected by the receiver itself, and thus degrading the performance of the receiver.

Its associated mechanical drive and display allows a frequency setting accuracy of the order 50Hz, from the control knob which is free from backlash and slip. So certain is the drive mechanism that an operator can readily resolve signals down to 2/4 cycles, continuously without fatigue. A very real requirement for SSB.

The RF tuning unit, with its main tune oscillator and precision interpolation oscillator and drift cancelling loop go far to ensure that the 958 is highly qualified for use under conditions of todays heavy, closely spaced traffic. The RF tuning unit and main tune oscillator are built together with the waveband change mechanism, precision slow-motion drive and the frequency display as a rigid mechanical assembly. This assembly is formed around a special aluminium investment, or "lost wax" casting, and is capable of withstanding severe conditions of vibration and shock for long periods.

The separate modules, all protected, can be rapidly assembled by relatively unskilled personnel.

( The modules and oscillator are on the display for you to see and I will give you details of some tests a little later. )

To display the frequency clearly, for both the main tune and interpolation oscillator, a scale length of 50" (127 cm) is required. The frequency of tune on the 958 is displayed on a polariod screen via a fine microprinted circular disc and a 5 - 1 projection system. This display clearly shows the 100 kHz calibration points, approximately ½" ( 1 cm) apart at the highest frequency on the main tune and 1 cm for 1 kHz on the interpolation ( incremental ) oscillator.

The mechanically geared frequency display, which allows frequency to be set better than 50 Hz, is lower in cost than a digital readout system .

In the basic receiver- now in extensive use - the light projection frequency display is ideal for search operation. The direction of tune to higher or lower frequency is clearly displayed, and the physical operation of the tuning knob related to frequency is clearly observed by the operator. These two points are not so easily achieved when the readout is digital, the frequency is displayed in steps, and the figures determined by the rate of count of the counter timebase. However, other versions referred to later utilise digital readout where this is appropriate for the operational requirement.

The 958, as described, satisfies many users requirements at economical cost. The basic design permits variants to be manufactured for many special purposes. A version capable of operating on Lincompex transmissions incorporates a carrier amplifier which drives a beat indicator meter, enabling the operator accurately to tune the receiver carrier to within 1 Hz. Further development of the 958 to meet even higher stabilities of the order of 4 Hz under wide environmental conditions, with a frequency setting accuracy of 1 Hz, digitally displayed, has now been completed. Economy has been retained by virtue of the simple modular design and over 80% of the standard 958 components are used in the digital readout version.

To the user, this means the option to purchase variants of the 958, with common spares stocking and maintenance procedures.

The digital readout is displayed by means of gallium arsenide light emitting diodes, driven from a counter which counts the frequency of the incremental oscillator. To meet the stability requirement of 4 Hz, the incremental oscillator, which runs 550 kHz to 650 kHz in the basic 958, is made physically smaller to permit the use of a temperature controlled oven.

This is achieved by increasing the frequency to cover the range 5.5 MHz to 6.5 MHz and then dividing the frequency by ten back to 550 kHz to 650 kHz. The master oscillator standard is also improved to provide a stability of 0.5 parts in $10^7$. The final injection oscillator has been re-designed for oven controlled over the full temperature range of 0°C to 60°C.
This exploitation of the 958 results in a receiver which can be set to 1 Hz simply by the setting of two knobs or, alternatively, gives at low cost a stepless measurement of the received frequencies to 1 Hz. Other synthesised receivers require setting of up to ten knobs, frequently providing only 100 Hz steps. This simple setting allows rapid change in frequency to be made accurately.
The modules involved in the digital readout function are all basically simple and capable of very easy replacement ( should the need arise ).
In order to meet the various modes of transmission in use today and the next decade or so, five selectivity positions are normally provided in all models. This unit is a separate module consisting of coupled ferrite inductors. A switch varies the degree of coupling for the required bandwidth and the unit can be completely pre-tested in less than fifteen minutes.
The bandwidth choices are as follows:-

1 ) Bandwidth 400 Hz - for CW and narrow frequency shift.
2 ) Bandwidth 1.3 kHz - for FSK.
3 ) Bandwidth 3 kHz - mainly intended for DSB AM Transmissions with modulation up to 1.5 kHz.
4 ) Bandwidth SSB. For A3A. A3H, A3J, with extremely good shape factor. It can be seen from the curves on

Drawing No: BP.1260 that the internationally agreed CEPT filter requirement and the British TSC 102/105 main Specification are both met with the filter fitted in the model 958.

The design of the unique Eddystone ceramic or quartz SSB filter is an example of further economy. Study of the CEPT and British Specifications resulted in a filter design that met the minimum passband and skirt attenuation characteristic of both specifications. See BP. 1260.

5 ) Bandwidth 8 kHz - for AM/DSB reception provides satisfactory reception up to at least 4 kHz modulation.

It should be noted that AM transmissions taken in the SSB mode with this bandwidth setting allows for good quality music reproduction and is suitable for re-broadcasting.

Because of the modular construction of the receiver, other bandwidths, from 50 Hz to a maximum of 10 kHz can be provided to order.

Optimum AGC line constants are introduced, depending on the mode of reception selected - fast attack ( charge ) times of the order 20 milliseconds with a discharge of approximately 5 seconds for SSB, and a discharge of as low as 0.5 seconds are provided for other modes.

Audio output of maximum 1 watt at 5% maximum total distortion into 3 ohms impedance with a frequency response level 3 dB to 4 kHz which can be modified to order to 6 dB at 8 kHz, assures adequate output under conditions of high ambient noise. A 600 ohm output is provided for telephone line working and the level can be preset to meet Post Office line level requirements. Sidetone facilities can also be provided.

Special note should be made of the fact that, for teleprinter operation, an FSK unit can be fitted as an optional extra inside the receiver. Keying speeds of 200 bauds, with frequency shifts of 85 Hz to 850 Hz can be accepted. Thus the 958, in one single unit permits direct teleprinter operation.

Should any further ancillary equipment, already at an installation, require driving, IF and audio outputs are available. The AGC line is also brought out so that diversity operating is practical.

The whole receiver, as can be seen and indeed proved under tests against various international specifications, is extremely rugged and capable of withstanding wide ranges of temperature. The receiver can be operated in temperatures minus 20°C to plus 50°C and at a humidity level of 95% RH at 40°C.

The 958 withstands vibration over the range 0 - 300 cycles, even up to 5G, and it should be particularly noted that over the vibration range 0 - 50 Hz, the tune frequency deviation is less than 10 Hz in the standard set and is not measurable in the 958/7. A shock test of 35G, duration 25 milliseconds, does not damage the receiver.

The 958 is designed for long continuous periods of service and many thousands of trouble free hours can be expected. However, I should say a little about maintenance and repair, should a fault develop. The design of the set is such that a fault can often be localised without removing the equipment from its cabinet. For example, different IF's are used in different ranges ( except for the final 100 kHz stage ). By switching ranges and identifying whether or not the receiver is working , a faulty IF stage can be isolated. Further, both high stability and free running oscillator operation is provided. It should be noted in this connection that the receiver can be kept operational even with a failure in its high stability circuitry, including the master oscillator. Having localised a fault condition, a simple replacement of the module in doubt is all that is required, the performance being assured generally within 3 dB by the replacement module. Individual mating connectors to the pins in the module boards have been used in preference to edge connectors. This results from our reliability studies and has been supported by our experience

In addition, this system gives us the ability to "TEE" into each individual pin connector.
This ready replacement principle is provided for also in the RF tuning unit - often a critical area for replacement/repair. The RF discs can be simply withdrawn and replaced - the coils being factory aligned; again, performance being assured. Even the oscillator disc replacement is satisfactorily achieved and, at most, a very slight adjustment may be required at some convenient maintenance period, ensuring economical costs in operation.
A feature of the receiver is its performance under difficult conditions of blocking and other close-in signals. With a receiver having a wide band input, signals within a band of many 100 kHz are able to degrade the desired signal. However, with three stages of pre-selection we can claim that with this design a signal 10% off tune would have to exceed 15 volts to degrade the desired signal and, from a practical installation point of view, the 958 performs much more satisfactorily in the presence of a high power transmitter and/or congested frequency bands than many other receivers. Study of drawing BP.1313 shows the increased attenuation provided by the bandpass RF circuits and the ability of the 958 to operate satisfactorily in the presence of a number of very high level unwanted signals - for instance - co-sited transmitters. BP.1268 is to show the importance of two signal measurements in determining a more realistic performance under operating conditions.
In the case of a receiver with wide band input, any signal that is present from close in to several MHz away from the desired signal will degrade the desired signal, as shown on BP.1313. In the case of the 958, far fewer interfering signals can affect the performance and in this respect, the design has repeatedly shown its superiority under actual operating conditions.

Summing up, the 958 has succeeded in meeting its design objective as a compact receiver, economical to manufacture and easy to use and install, simple to maintain and repair, and relatively lightweight.

It performs against the requirements demanded for many Military, Para-Military and Marine end-users on a World-Wide basis.



EDDYSTONE RADIO LIMITED. BIRMINGHAM. ENGLAND.

You have now read an economical approach to a VLF, MF, HF receiver. Let us look at the problem of a VHF, UHF receiver for economical production. What common problems exist, because if we can utilise any of the techniques and indeed, any of the hardware or mechanisms, a further economy for the VLF, MF, HF and VHF, UHF receivers will be achieved by increasing the quantity of hardware and mechanisms produced.

For more than 25 years the Company has designed and manufactured continuously tuned receivers covering frequencies in excess of 500 MHz and its continuous contact with Government Authorities in the United Kingdom and Overseas and the supplying of receivers to all these Authorities provides a wealth of information invaluable to the design of a receiver to meet the current and future needs in the frequency ranges from 30 to 1000 MHz.
It was clear that the requirement for a search, surveillance and monitoring receiver would mean continuous, rapid tuning over a wide frequency range and have a limited high stability capability. The Company was also aware of the need for a search receiver with the ability, having found a signal, to change to the high stability operation for monitoring operations. This would mean high stability at all and any frequency in the range. The quantity required seemed to be higher for the continuous tuned receiver, ( with an option for crystal positions, providing high stability operation on selected channels ) than for continuous tuning with high stability working over the whole frequency range.
Economically, it was obvious that the receiver should be developed as a continuously tuned unit. At this stage, let us consider the other requirements:
Sensitivity of less than 1 microvolt.
A noise figure of say, 4dB to 6dB.

Selectivity:- First, a broadband output of 1MHz wide at 25MHz, increasing to 4MHz wide at 200MHz and higher to allow visual examination of the signal by ancillary panoramic displays, followed by filters for 200kHz, 30kHz, 15kHz and 7.5kHz.
The dynamic range of the receiver would have to be of the order of 30dB to 40dB, permitting examination of pulses via a video stage for use with an external oscilloscope.
Audio output and 600 ohms line working are required.
AGC characteristics required a minimum performance of 10dB change in output for 80dB change in input.
Blocking, cross modulation and intermodulation performance would have to be of an order similar to the VLF, MF, HF receiver.
The receiver would have to perform satisfactorily from at least minus 10°C to plus 50°C, under bump and vibration, and conditions of high humidity.

Although in discussing the design of the VLF, MF, HF receiver, a specific model EC.958 was outlined, I would like, in the case of the VHF, UHF receiver, to discuss the fundamental design concept which resulted in the Eddystone Model 990R, which has been in production for some years and the Model 1990R which will be in production during 1973.

A single conversion superhet configuration offers the greatest number of advantages for an economical, high performance receiver. Spurious responses are a minimum, a single IF amplifier means a single unit to be manufactured and tested at one frequency, one single oscillator alone will determine the stability. Filters providing the required selectivity are available at reasonable cost with frequencies of 10.7MHz and 21.4MHz.

Accepting the single conversion philosophy, a critical area in design is the RF tuning assembly, with its drive mechanism. We set out to re-think our views on the highest frequency that could be tuned in a switched coil assembly, using reliable, economically-produced switch wafers. Considerable design and production experience over many years has proved that, if more than half the inductance required to tune to a particular frequency occurs in the switching assembly and connecting leads, optimum performance is difficult to obtain, and in production will be inconsistent and prove uneconomical due to extensive test time and high numbers of rejected units. The reasons for this are many. When half the inductance of a tuned circuit is in the switch assembly, variations in the thickness of the material making up the stator and rotor connections will cause an intolerable percentage change in the total tuned circuit inductance; this can occur from one production batch of switches to the next and sometimes, apparently, quite indiscriminately. The effect is a dramatic change in frequency. Further problems are excessive coupling to the other tuned circuits connected to the switch assembly and the lowering of the "Q" of the tuned circuits, due to inherent losses on the switch assembly which would exist across one half of the tuned circuit. These effects and the degree of their influence are virtually uncontrollable and are very serious indeed when the tuned circuit forms part of the oscillator circuit. Frequency stability and calibration accuracy attainable will be unacceptable. These problems occur apart from those created by the need for critical setting of the wave change switch itself. The most suitable low loss switch wafers, for operation at VHF frequencies, are miniature fibre-glass assemblies, with gold or silver contacts. These switches have an inductance from rotor to stator contacts of approximately twelve nanohenries. Adopting the rule of not having more than half the inductance in the switch assembly, a figure for the total tuned circuit of 26 nanohenries, which is slightly more than twice the integral inductance of the switch, would result in a frequency of 240MHz when tuned with ten picofarads. Careful design and layout of a switched tuning unit that closely integrates switch, coils and tuning condenser, can achieve a total of ten picofarads minimum capacity, inclusive of a small adjusting trimmer capacitor.

In order to overlap in frequency with the range of the VLF, MF, HF receivers, the lowest frequency to be covered must be at least from 30MHz. However, as many meteorological services throughout the world make use of frequencies around 27MHz that are frequency modulated, it is desirable that the lowest frequency limit is at least 27MHz. Suitable frequency coverage for the RF units then would be 25MHz to 240MHz. A satisfactory compromise solution is required between the number of frequency ranges, the maximum capacity of the tuning condenser, the rate of tune of the drive mechanism and frequency display. Experience and subjective tests have shown that rates of tune exceeding 10kHz per degree in the VHF ranges requires some skill and can be fatiguing if changes in frequency are frequent.
Accepting the drive mechanism with a ratio of 100 to 1, and 50 rotations of the knob to cover each range, the greatest frequency covered in one range would be 50 x 360 x 100kHz = 180MHz. Limiting the figure to approximately 100MHz for the higher frequency range gives us 140MHz to 240MHz, a tuning ratio of approximately 1.7 to 1 and a capacity ratio approximately $2.9(1.7^2)$, then with a minimum capacity of 10pF, the maximum capacity of the tuning condenser requires to be approximately 30pF. In practise, as the effect on the minimum capacity is negligible, it is normal to make the maximum somewhat higher to permit the greater variation in minimum capacity that will occur during production. Condenser maximum will be of the order 36pF.

The geared mechanism, basically of proved design, using many standard Eddystone components, drives a stainless steel tape 50" long, displaying the frequencies clearly and unambiguously. A small LED indicates the range in use. This drive unit is mounted directly to the RFcoil box which houses RF amplifier, balanced mixer and oscillator stages, together with switches and integral tuning condenser. The tuning coils are mounted on small printed boards so designed that they virtually form part of the switch and condenser assembly, minimising circuit losses and providing greater consistency in production. The coil box is made of brass and heavily silver-plated.

Dimensions are:-

Length: 150mm, Width: 105mm, Height: 55mm,
and you can see from the picture how compact and convenient it is for pre-testing as a separate unit.

The circuit configuration employs a low noise FET with tuned input, the output being coupled to a balanced mixer by means of two tuned bandpass coupled circuits. The gain to the balanced mixer is approximately 14dB. The combination of the low noise FET, three tuned circuits and balanced mixer result in a noise figure of 5dB. We have achieved image frequency protection of minimum 60dB and intermodulation, and blocking and cross modulation figures that exceed many single frequency equipments. The figures are superior to those demanded for VHF mobile requirements in most countries and typically are as follows:-

BLOCKING

With a modulated signal input at a level to produce a signal to noise ratio of 10dB and a power output of 50 milliwatts, a second unmodulated signal at a level of 20 millivolts (+86dB) does not cause the power output to change by more than 2dB or the signal to noise to fall below 8dB.

CROSS MODULATION

With a modulated signal input at a level of 600 microvolt (+56dB) and the receiver output set to 50 milliwatt and the modulation then removed, a second modulated signal applied at a level of 20 millivolt (+86dB) at a frequency greater than 5MHz from the tuned frequency does not produce an output power greater than -23dB relative to the standard output ( 50 milliwatt ).

INTERMODULATION

With a modulated signal at a level to produce a signal to noise ratio of 10dB and the output adjusted to 50 milliwatt and the signal then removed, the simultaneous application of two signals at a frequency 25kHz (modulated) and 50kHz (unmodulated) above or below the tuned frequency produces a signal with a 10dB signal to noise ratio when the levels are +53dB with respect to the original input.

To provide the greatest versatility, particularly when a wide band of frequencies must be examined, the balanced mixer input can be fed directly from the aerial input.

The IF output of the balanced mixer can be used to drive a panoramic display unit for visual examination of signals.

The intermediate frequency is 21.4MHz and the conversion of input signals to this frequency is achieved by:

(1) A free running variable oscillator with a stability of one part in $10^5$ per degree Centigrade.

or (2) A crystal oscillator unovened with stability one part in $10^6$ per degree Centigrade,

or (3) A free running oscillator in conjunction with a synchroniser with a stability exceeding one part in $10^7$.

Items (1) and (2) are fitted in the basic receiver and (3) is an optional unit which will be discussed after describing the basic receiver.

The output from the mixer is routed to a selectivity unit, via an IF pre-amplifier and the gain to the input of the selectivity unit does not exceed 32dB.

In order to extend the usefulness of the receiver, it was considered desirable that the frequency range be extended to above 400MHz. If this was achieved, the design of a further receiver covering from 400+ to 1000MHz would also be more economical. The design of a tuning unit covering frequencies up to and above 400MHz is not practicable in a switched assembly, so two clear possibilities exist:

( 1) Lumped inductance and capacitor.

( 2 ) Tuned lines.

In the case of the lumped inductance, the requirements for stray capacity limitations at 400MHz are too stringent to permit consistency and hence, economical production. The requirement for adequate receiver specification, using lumped inductance can only be met with considerable testing skills.

Tuned lines offer the advantage of repeatability - lines can be cut to length and accurately positioned. The lines can, in fact, be stamped out and jig-fitted to the printed board or metal box assembly. A choice, however, still remains between half wavelength and quarter wavelength lines. A smaller assembly is possible with the quarter wavelength. Half wavelength lines terminated at one end with a capacitor and, at the other end by a variable capacitor, results in the tuning range not being restricted by the stray capacitance at the signal connection end of the line, as in the case of quarter wavelength lines. The availability of variable capacitance diodes at low cost for tuning purposes, makes diode tuning the most economical and repeatable design possible. This half wavelength design is used in the Eddystone receivers, a single line is used in the input circuits to the FET RF amplifier and a bandpass coupled pair of lines to the balanced mixer, a further line is utilised to control the oscillator frequency. A further economy is introduced by the fact that the balanced mixer used in the 25 to 240MHz switched coil unit has 50 ohms input and output terminations. The specification of the balanced mixer is maintained up to 500MHz; it is therefore possible to diode switch the balanced mixer from the 25 to 240MHz unit to the tuned line units for something like one-twentieth of the cost of a separate balanced mixer unit. This technique is adopted.

The variable voltage for the variable capacitor diodes is 2 to 16 volts and is generated by a small blocking oscillator ( this is necessary to provide for 12 volts DC working of the whole equipment ). The variation in voltage is arranged by coupling a precision potentiometer to the drive mechanism already driving the 25 to 240 MHz unit, frequency calibration being carried on the steel tape as is in the case of the ranges for the 25 to 240MHz unit.

The whole unit covering up to 400 MHz is housed in a unit approximately 75mm x 75mm x 25mm. The maximum number of adjustments normally required during manufacture is four trimmers, the matching of the vari cap diodes ensures close tracking of all circuits over the total frequency range meaning that noise figures and bandwidth characteristics are extremely consistent in production. Noise figures of better than 6dB are regularly maintained.

The selectivity unit will provide 6dB bandwidths, from 200kHz to 7.5kHz. Normally, two bandwidths are fitted, being 200kHz and 30kHz. A third bandwidth can be fitted to end user requirements. Bandwidths 50kHz and lower are met by means of quartz filters; consideration of ceramic filters indicated that the frequency tolerance with temperature was unacceptable and ageing rates at 21.4MHz would make fixed frequency crystal operation impossible. However, the cost of quartz crystal filters at 21.4MHz is closely related to filters at 10.7MHz, which are in constant quantity production.

Provision of a 200kHz bandwidth filter was met by aligning a bandpass L.C. filter with seven tuned circuits. The unit was made high impedance to permit the use of inductance values easily manufactured. The particular configuration employed is a modified Tchebycheff and produces a steep side response and low insertion loss. Stop band figures of 60dB are consistently maintained. Transistor switches are employed to change selectivity because this permits the filter to be physically positioned without consideration for mechanical switch positions and assembly. A compact unit can therefore be integrated on a printed circuit board with any active devices that may be necessary, allowing the unit to be located for maximum stability and ease of maintenance.

The filter output is fed to the main IF amplifier, three cascaded integrated circuits are used, providing an overall gain of some 60dB. The advantage of the integrated circuits is that they enable a low noise, low distortion amplifier to be produced with the minimum of external components, the external number of components being reduced by a factor of 3:1. This means less production time, less likelihood of fault conditions due to imperfect solder joints and the total printed board area is reduced in size. Consistent performance is assured as each integrated circuit is gain toleranced to 2dB. Each integrated circuit is capable of accepting up to 100 millivolts before cross modulation exceeds 1%.
As the final integrated circuit does not have to accept greater than 20 millivolts at its input, low distortion and a high overload capability is achieved. The output from the integrated IF is fed to a power transistor which is coupled to a diode demodulator via a tuned transformer producing a maximum of 12 volts. The detector circuit can operate at low distortion from a level of 120 millivolts. This means, with the upper limit of 12 volts, a dynamic range of 40dB is provided, ideal for pulse measurement and examination.
AGC is arranged separately for RF and IF. RF AGC is not applied until the input signal exceeds 100 microvolts, this ensures no early degradation of signal-to-noise ratio with low level inputs. The overall AGC performance is such that a change in input of 80dB does not produce greater than 6dB change in output from a reference level of 2 microvolts. This is achieved by 30dB control of RF gain and greater than 50dB control in the IF gain. A separate IF output for driving ancillary equipment is provided.

F.M. demodulation is via a separate amplifier and incorporates a limiting amplifier and quadrature detector in integrated form. This integrated circuit also provides an automatic frequency control voltage for application to the oscillator in the RF tuning heads. The noise output from the FM amplifier is used to operate a Schmitt trigger for muting the audio stages of the receiver.

CW/SSB reception utilises an integrated circuit as a product detector. This is a very low-cost integrated circuit which incorporates a long tailed pair with stabilisation. " In band" two tone distortion figures of minus 30dB are achieved without critical signal and oscillator level adjustment. For stability, a crystal oscillator is employed, operating at 21.4MHz, adjustable by means of vari cap diodes over the range plus or minus 2kHz

A splitter stage producing negligible loading on the detected signals to maintain the frequency response provides for audio drive and video output. An integrated video amplifier, which has a response up to 6MHz, is used and extremely low distortion is maintained in this application which requires video frequencies up to 100kHz. The integrated circuit has both positive and negative outputs or, alternatively, can be used to provide Peak to Peak, push/pull output of 2 volts.

Audio output of 2 watts into 3 ohms and 100 milliwatts into 600 ohms centre tapped is provided with frequency response 3dB, 50Hz to 15kHz, median levels with less than 1% distortion. All audio stages are integrated circuits and provide economical high performance assemblies.

Wide use of integrated circuits, which have become increasingly available at low cost, permit the receiver to be designed with no more than seven small modules, plus the RF tuning and power units. Each unit can be pre-tested, ensuring that in final test, the expensive process of rejection and replacement during manufacture is at a minimum.

The mechanical construction consists of a flat steel front plate with a sub-plate mounted 25mm behind, to give a rigid front assembly on which is mounted the drive mechanism, integral with the RF tuning unit. Two steel side plates and rear plate, together with top and bottom steel covers, provide an extremely rigid form, resistant to axial distortion. Pressure exercised on the outside of the assembly produces negligible changes, even at the highest frequency. The whole assembly is capable of withstanding arduous bump and vibration tests. The equipment will operate over the temperature range minus 10°C to plus 50°C. Power supplies are 110V to 240V, 40Hz to 60Hz, and 12V DC negative earth.

Reference was made earlier to the provision of a synchroniser for the high stability working at all frequencies, providing stabilities of better than one part in $10^7$. This is an optional ancillary equipment that can be added to the continuously tuned receiver, providing a stability which permits the continuously tuned receiver to be unattended, tuned to any frequency in the receiver range. From the user's point of view, it means that receivers can be purchased and operated most economically- for search purposes, operator controlled, supported by the high stability version for continuous monitoring purposes in smaller quantities. Common maintenance and spares would provide a further economy. Basically, the synchroniser consists of an input amplifier accepting signals from the free running oscillator in the receiver, up to a maximum of 500MHz. Offset frequencies equal to the IF are incorporated so that the synchroniser dials read the received frequency. A trigger and prescaler divides to a lower frequency acceptable to a seven decade variable frequency divider which passes on the resultant frequency to a phase detector. An oven-controlled reference oscillator with a high stability of one part in $10^7$ operating at 5MHz, is passed via a fixed ratio divider chain to the phase detector.

The resultant DC output from the phase detector is used to control a capacity diodes in the receiver free running oscillator, thus effecting a complete phase locked loop. All that is required is for the operator to set the frequency dials on the synchroniser to the frequency required when his receiver is tuned to within 1% of the synchroniser, frequency phase locking will occur and full stability of one part in $10^7$ will be maintained.

The design has resulted in a production unit that covers the frequencies from 25MHz to over 400MHz, with option that allows choices of selectivity and stability, stability that can be either simple crystal control on ten channels, or synchronisation controlled over the whole frequency range.

The equipment is housed in a substantial steel cabinet or for rack mounting. ( Dimensions as 958 leaflet ), and is suitable for operation throughout the World, for both static and mobile use.