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A New Detection System for Television and V.H.F. Radio Receivers

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Following the introduction of alternative television programs and the rapid increase in the number of television receivers in use, it has become increasingly difficult to detect unlicensed receivers with the existing detector cars. A new system of detection has been developed that overcomes the present difficulties.

INTRODUCTION

THE introduction of television broadcasting by the Independent Television Authority (I.T.A.), coupled with the rapid increase in the number of television receivers in the British Isles, has made the detection of unlicensed receivers by the existing television detectors increasingly difficult. The present system,[1] which was evolved before the I.T.A. came into being, relies on detecting magnetic radiation from the line-deflexion circuits of the television receiver at the second harmonic of the line time-base frequency. The line scan frequencies of the British Broadcasting Corporation (B.B.C.) and I.T.A. transmissions are not accurately synchronized, although each is nominally locked to the 50 c/s mains supply, and the second harmonics of these frequencies may differ instantaneously by several cycles per second. Thus, if two television receivers, one tuned to the B.B.C. and the other to the I.T.A., are close together, the signal received by the detector will be the combined signal from the two time-bases, and the signal-strength meter will follow the amplitude of the combined signal, i.e. it will respond to the beat frequency. This prevents accurate location of the receivers and is the fundamental obstacle to improvement of the existing system.

Further difficulties associated with detecting radiation from the time-base circuits are the low field-strengths encountered, due to improvements in television-receiver design, and the high level of electrical interference occurring at very low frequencies, much of which is generated by the electrical circuits of the detector car itself and cannot be adequately suppressed.

To overcome the difficulties described above a new system of detection has been developed.

METHODS OF DETECTION

The two most powerful sources of radiation from a modern television receiver are the line time-base circuits and the frequency-changing oscillator. Radiation from the line time-base can be detected owing to the existence of a low-frequency magnetic-induction field. The system in current use for detecting this radiation, although straightforward in design, has the drawbacks mentioned earlier. The frequency-changing oscillator supplies the energy for a radio-frequency electromagnetic wave that can be radiated from the receiver chassis, the aerial feeder and the aerial.

Detection of radiation due to the frequency-changing oscillator is more complicated than the detection of radiation from the line time-base owing to the variety of frequencies at which radiation occurs, the poor frequency-stability of the frequency-changing oscillator and the fact that several receivers in close proximity can radiate signals with very little frequency separation. Techniques have been developed that take account of these factors, however, and the new system is based on detecting radiation caused by the frequency-changing oscillator. All television and v.h.f. broadcast receivers now made commercially are superheterodynes and the new system is therefore fully effective.

Frequency Range of Oscillator Radiations

Television receivers of modern design have a nominal vision intermediate frequency (i.f.) of 34·65 Mc/s, but older sets still in service use frequencies around 13·5 and 16 Mc/s.

Nearly all the oscillators of receivers with an i.f. of 13·5 Mc/s operate at a lower frequency than that of the signal being received, and nearly all the oscillators of receivers with a 16 Mc/s i.f. operate at a higher frequency than that of the signal being received. In modern receivers having the standard i.f. of 34·65 Mc/s the oscillator frequency is invariably higher than that of the signal. V.H.F. sound broadcast receivers employ a 10·7 Mc/s i.f., and the oscillator frequency may be above or below that of the signal being received. At least two television channels may be received in a given area on

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most receivers having either 16 or 34·65 Mc/s i.f.s, and in fringe areas a particular program may be received on two or more channels. Oscillator radiations from television and v.h.f. sound receivers therefore cover a wide frequency spectrum, the range being approximately 29–240 Mc/s.

Receivers tuned to the same signal and having the same nominal i.f. do not radiate at precisely the same frequency. The frequency difference between adjacent receivers may vary from a few kilocycles to several megacycles, depending on the tuning adjustment of the receiver. Owing to oscillator temperature-drift and manual operation of the receiver tuning, the frequency of radiation is not constant, and generally a slow drift can be observed. The electrical coupling between the oscillator and aerial circuits in a receiver is small, and oscillator radiation is mainly caused by chassis currents in the turret tuner and receiver, the short electrical paths favouring the radiation of harmonics of oscillators operating on the lower frequencies. By detecting these harmonics, the frequency coverage needed in a detection system may be reduced considerably.

Field Strengths of Oscillator Radiations

The signal that has to be detected is an unwanted radiation from the receiver, and the radio industry is being urged to reduce such radiation in order to minimize interference. The radiation limits specified by the British Standards Institution[2] at a distance of 3 metres are equivalent to field strengths at a minimum practical detection distance (10 metres) of approximately 20 μV/m in the bands used for television and v.h.f. sound broadcasting and 50 μV/m outside these bands. The figures specified by the British Standards Institution set a limit to the maximum field strength that may occur in any direction on an open test site. The radiation from a receiver that complies with these recommendations may be considerably lower than this in some directions and be further attenuated by the screening effect of a building.

Aerial Performance Requirements

As well as covering a wide frequency band, oscillator radiations are of random polarization. Most direction-finding aerials respond only to signals polarized in a single plane. Two difficulties arise when an aerial that responds to polarization in a single plane is used to locate the sources of signals of random polarization:

(*a*) Since the aerial tends to reject signals polarized at right angles to its plane of maximum response, its sensitivity is low to such signals. Experiments have shown that this reduction in sensitivity, which is very large in free space, may still be as great as 26–30 db when reflections are present. Under these conditions, secondary signal pick-up becomes important. Any metallic components of the aerial structure having appreciable dimensions in the plane of polarization of the direct or reflected signal may re-radiate to the aerial elements and cause bearing errors.

(*b*) Signals usually suffer some rotation of the plane of polarization on reflection, and a linearly polarized aerial may be more sensitive to a wave that has been rotated in this way than to the direct radiation. Thus, the reflected signal may appear to be stronger than that which arrives by the direct path, and a bearing error may result.

These difficulties may be avoided by the use of an aerial that responds to signals of random polarization. The ideal aerial would be circularly polarized, but negligible errors result from the use of an elliptically polarized aerial with a small axial ratio. Many aerials of this type exist, but to be effective in the required application the aerial must also have a wide frequency band, good directivity and gain, small size, and freedom from beam splitting and tilting (i.e. the electrical and mechanical axes of the aerial must bear a constant relationship to each other when the frequency and plane of polarization are varied). Such a specification leaves a very limited choice in the type of aerial that can be used for the detection system being described.

PRINCIPLE OF OPERATION OF NEW EQUIPMENT

The new equipment consists of a steerable v.h.f. broadband, elliptically-polarized, direction-finding aerial mounted on the roof of an estate car and feeding a sensitive and highly-stable panoramic receiver. Location of unlicensed receivers is achieved by taking bearings from different positions. Thus the room in the house in which the receiver is operating may be determined readily. This differs basically from the existing system, which can normally give only one bearing because the loop aerials used are not steerable. This has not been a serious handicap owing to the low sensitivity of the system, but signals may often be detected at several hundred yards range with the new system and a steerable aerial is therefore essential.

In order to make maximum use of the directional properties of the aerial, a combined periscope and optical projector are mounted on the roof of the car and mechanically coupled to the rotating aerial.

The new system operates over a frequency range of 110–250 Mc/s. By detecting harmonics of radiations from receivers tuned to bands I and II and the fundamental radiations from receivers tuned to band III, receivers tuned to any of the v.h.f. channels used for television and f.m. sound broadcasting can be located.

DESCRIPTION OF NEW EQUIPMENT

Aerial

A number of types of aerial were investigated using scale-model techniques at u.h.f. The aerial finally adopted consists of a tilted dipole in a corner reflector (Fig. 1). End screens have been fitted to the reflector to eliminate beam tilt resulting from the presence of the vehicle roof. An optimum angle of tilt for the dipole was determined that gave elliptical polarization over a $2\frac{1}{2}$:1 frequency range without serious degradation of directivity and gain. A useful frequency range from 110 Mc/s to over 250 Mc/s has been achieved, the lower frequency limit being set by the maximum permissible dimensions of the aerial. The gain of the aerial varies with frequency and plane of polarization, but it is approximately equal to that of a resonant dipole. The half-power beam width varies between 45° and 60° over most of the frequency range, but it increases to 90° at the lower end. The ratio of amplitudes of the main response to all other responses (front-to-back ratio) is generally greater than 20 db, but it falls at lower frequencies when the plane of polarization of the signal lies within certain narrow angles.

With a good signal, a bearing accuracy of about 5° may normally be achieved and, even when the signal-to-noise ratio is poor, the mean of several bearings will usually give this order of accuracy. Thus, location is normally within about $3\frac{1}{2}$ ft laterally at a detection distance of 40 ft.

FIG. 1—DETECTOR CAR AND AERIAL

The aerial is constructed of anodized aluminium-alloy tubing and expanded and flattened sheet, the gauge, mesh dimensions and type of alloy being chosen to give minimum weight and wind resistance and maximum screening efficiency. The screen and dipole are supported by a tubular centre spine and transverse tubes of epoxy-resinated woven fibre glass giving great strength and a degree of shock resilience and eliminating electrically-conducting materials from within the screen. Any component of the aerial may be readily removed for replacement in the event of damage, a welded structure being avoided for this reason.

The assembly is mounted on a 2 in. diameter anodized aluminium-alloy mast tube carrying at its upper end a shrunk-on stainless-steel journal running in a self-aligning nylon sleeve. These materials may be run dry, although a grease-groove is provided. The bearing arrangement allows for flexing of the car body and vertical displacement of the roof. A nylon cam mounted on the stainless-steel journal displaces a roller cam-follower as the aerial rotates, and the linear displacement of the follower is transmitted by a steel shaft sliding in lead-polytetrafluorethylene-loaded sintered-bronze sleeves. This shaft rotates the optical system in a periscope that acts as a sighting device. All the bearing surfaces are designed to operate without lubrication or maintenance for a considerable period. A large-diameter shallow ring, integral with the housing of the self-aligning bearing, transfers the wind load on the aerial to the car roof and eliminates the risk of the thin-steel roof shearing at the bolt holes.

Water sealing at the point where the mast tube penetrates the car roof is achieved with a labyrinth of interleaved sharp-edged rings, spaced to avoid capillary action. Any water which is blown in by wind pressure is trapped in a nylon gutter and discharged on to the car roof. Thus the friction and capillary action associated with a stuffed gland are avoided and the movement of the self-aligning bearing is not restricted.

The lower end of the mast tube is supported by a self-aligning ball journal that carries the static load of the aerial and is mounted on a platform welded on to the propeller-shaft tunnel of the car at the point where it joins the rear seat box. The load is therefore carried by the strongest part of the car floor. Integral with the lower bearing is a rotating coaxial joint carrying the aerial feeder to a socket on the bearing housing. This joint permits continuous rotation of the mast, and consists of a doubly-tapered coaxial line with mercury-wetted contacts on the inner and outer conductors at the point of largest diameter; the assembly is shown in Fig. 2. This method of construction was chosen because

(*i*) it avoids variations in coupling when the joint is rotated, such as occur with inductive couplings in this frequency band,

(*ii*) the coupling loss is insignificant, being immeasurable with ordinary measuring equipment, and there is no variation with frequency such as occurs with a practical capacitive coupling,

(*iii*) the joint is free from the contact noise inevitable with metal-to-metal contacts employed at very low signal levels,

FIG. 2—LOWER AERIAL-MAST BEARING AND COAXIAL COUPLING

(*iv*) no contact wear occurs, and

(*v*) it does not restrict the self-aligning action of the lower bearing.

It is interesting to note that severe contamination of the mercury due to amalgamation or to oil films has no measurable effect on the coupling because the self-capacitance of the very thin contaminating films is sufficiently high to provide a low-impedance path at the frequencies employed.

The upper half of the coupling, which is carried by the mast tube, has a balance-to-unbalance transformer attached to it, and a screened balanced-twin feeder connects the transformer to the dipole. The degree of balance is sufficient to reject signals induced in the section of feeder passing up the fibre-glass tube. A rubber piston-ring round the upper half of the coupling prevents moisture that has condensed in the mast entering the coupling, and a drain hole is provided in the mast. Glass-loaded polytetrafluorethylene sliding joints are employed to retain the mercury in the coupling, this material being chosen because of its low friction, low rate of wear and its chemical inertness.

A 12 in. diameter steering wheel is mounted on the mast tube at a convenient height for the operator to rotate the aerial with his right hand. When the car is in motion the aerial rotates initially to the position of least wind resistance. The wind pressure then causes progressive stiffening of the upper mast bearing, so that at speeds in excess of 30 mile/h it needs some force to rotate the aerial. The vehicle is, therefore, stable at speed and no clamp is provided for the aerial.

The size of the aerial has been restricted so that the overall height of the vehicle (9 ft 9 in.) is less than that of commercial vehicles normally using tree-lined residential streets. In plan, the aerial at all angles of rotation remains within the outline of the vehicle.

Panoramic Receiver

In order to resolve the radiated signals, which may have a small frequency separation, a narrow i.f. bandwidth is necessary. The frequency stability of such signals is poor, and to avoid laborious searching with a narrow-band receiver, panoramic presentation is employed. The receiver is a triple superheterodyne employing i.f.s of 35 Mc/s, 30 Mc/s and 450 kc/s and having an overall bandwidth of 7 kc/s. Fig. 3 is a block schematic diagram of the receiver. The input stage is a modified 14-position television turret-tuner employing a low-noise cascode amplifier, frequency-changer and stable oscillator. A high-pass filter is employed in the aerial circuit to prevent i.f. break-through. The tuner, which has continuous frequency coverage from 110 to 250 Mc/s, is followed by a broadband i.f. amplifier having a centre frequency of 35 Mc/s and an overall bandwidth of 8 Mc/s. A buffer stage separates the 35 Mc/s amplifier from the sweep oscillator.

The frequency sweep is achieved by varying the current in an inductor magnetically-coupled to the frequency-determining inductor in the oscillator circuit. This varies the reluctance of the ferrite core and alters the value of the tuning inductance. By this means a constant-percentage frequency sweep is obtained when the centre frequency is varied over a 10 Mc/s range. The amplifier that supplies the biasing current is coupled to the horizontal time-base of the cathode-ray tube (c.r.t.). The drive may be varied so that the frequency sweep may be reduced from a maximum of 8 Mc/s to zero. This enables the operator to select one signal from a number on the screen and expand it as required, filling the screen if necessary. By reducing the sweep to zero the operator may listen to the signal on headphones. Since the overall bandwidth of the receiver is 7 kc/s and the highest input frequency is 250 Mc/s, an extremely low residual frequency-modulation is necessary when zero sweep is required, and the h.t. and heater supplies to the f.m. drive amplifier are derived from an extremely stable source.

The succeeding stages in the receiver are conventional, but extensive filtering and screening have been employed throughout the receiver to ensure the complete absence of internally-generated spurious signals and spurious responses to external signals of the field strengths normally encountered, over the entire sound broadcast and v.h.f. range.

The detected signals are displayed on a 5 in. c.r.t. employing 3 kV e.h.t. The minimum input signal visible above the receiver noise is about 10 db below

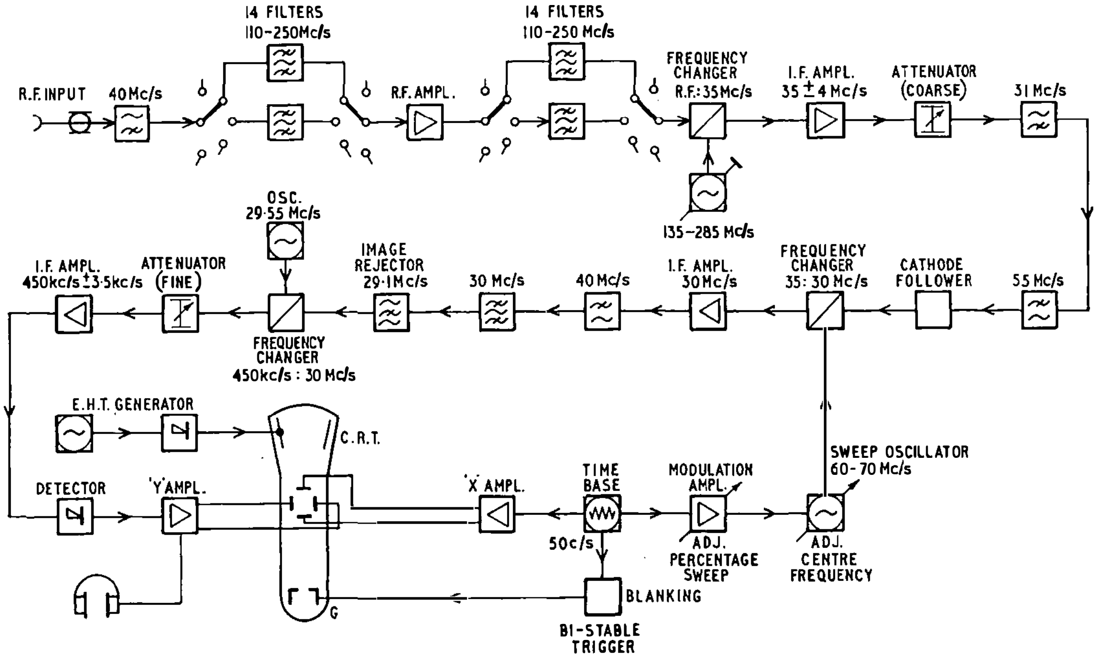


FIG. 3—BLOCK SCHEMATIC DIAGRAM OF PANORAMIC RECEIVER

1 μV, giving the detector system an overall sensitivity in the region of 1 μV/m. The intensity of the trace on the c.r.t. is dependent on the number of times the electron beam follows the same path on the screen, a single sweep of the time-base producing a very weak trace. Impulsive interference, being of random frequency and amplitude, does not produce trace-brightening by repetition, and continuous-wave signals of low amplitude can be easily seen in the presence of high-amplitude impulsive noise. Thus it is possible to operate the detector in the presence of ignition noise at least 20 db greater than the wanted signal.

Illuminated dials are provided on the receiver controls, which are grouped for ease of operation in the dark, and a rubber mask shields the c.r.t. from bright daylight and protects the operator from possible injury in the event of an accident to the vehicle. The receiver is mounted so that it can pivot on horizontal shafts projecting through clearance holes in the case at the centre of gravity. It is normally held at the desired angle by clutches that can be released by rotating external handwheels on either side of the case, but residual friction due to spring-loading prevents damage due to rapid movement, and the range is restricted to about 30°. The handwheels also serve to secure the receiver on a tubular-steel stand that is mounted on ball-bearing slides to give fore and aft movement of the receiver. The slides may be locked in any desired position by a ratchet mechanism operated by a push-button on the stand. Fig. 4 shows the receiver mounted on its stand.

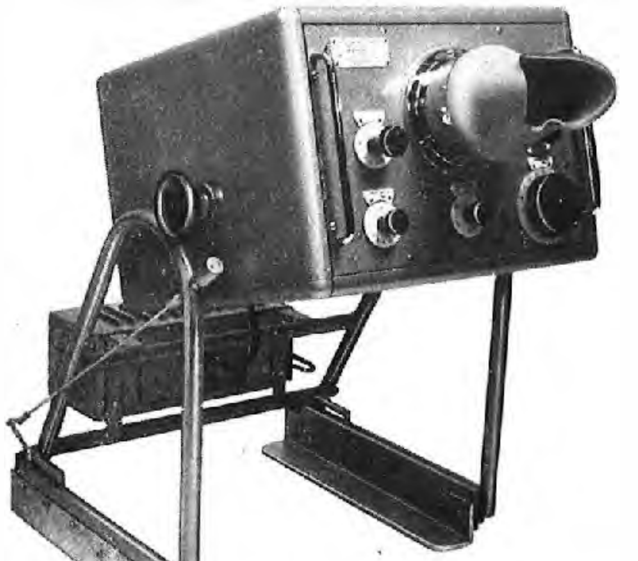


FIG. 4—PANORAMIC RECEIVER MOUNTED ON ITS STAND

Periscope and Optical Projector

In order to utilize fully the directional properties of the aerial a sighting device is necessary. A simple sight attached to the aerial mast inside the car would be unsatisfactory because of the low roof height, the obstructions caused by roof pillars and the occupants' heads and the fact that the sight would rotate with the aerial, requiring the operator to follow suit. Also, such a device would be ineffective in poorly-lit streets. This problem has been solved by mounting a rotating periscope through the roof of the car and coupling it mechanically with the aerial mast. Scanning periscopes of the submarine type are well known, but these suffer from the disadvantage that the viewer must rotate with the periscope. This rotation may be avoided by interposing a Dove prism in the optical path and contra-rotating it at half the speed of the viewing head. If a useful angle of view and long optical path are required this leads to a complicated and expensive optical and mechanical system, and an alternative system has been devised.

The scanning element of the periscope is a "Prismor"[3] consisting of two right-angled prisms with their hypoteneuses cemented and silvered at the interface. The prism is rotated about a vertical axis parallel to the interface at half the speed of the aerial mast. The angular position of the viewer's line of sight remains constant as the prism scans, and the view is transferred to the operator by two mirrors and four achromatic lenses, all the optical elements being anti-reflection coated. A masking drum with a viewing aperture is rotated round the prism at the same speed as the aerial mast, to exclude extraneous light. The operator views a 25° arc of the external scene with a vertical line superimposed, indicating the direction of propagation of the signal received by the aerial. The magnification of the periscope is slightly greater than unity.

When the ambient-light intensity is too low for effective viewing, a stage carrying a 48-watt projection lamp may be rotated into the optical path by means of an external knob, the eyepiece being simultaneously masked. By means of a switch biased to the off position, the operator may momentarily project a very narrow beam of light on to the house in which the detected receiver is operating. Internal masking prevents the light beam being projected on the offside of the car. The principle of the optical system is illustrated in Fig. 5.

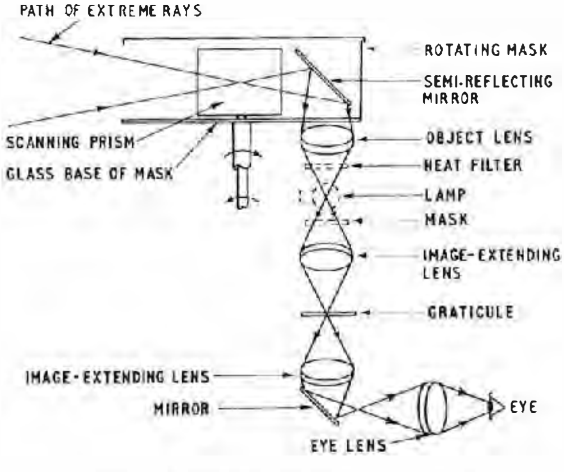


FIG. 5—PRINCIPLE OF OPTICAL SYSTEM

A fully-geared mechanism coupling the aerial mast to the periscope would use large-diameter gears, owing to the large diameter of the mast. These would be bulky and it would be difficult to reduce backlash without introducing excessive friction. However, since it is not possible to mount the periscope coaxially with the aerial mast, there is a blind spot on the offside of the car (a direction not normally used for detection). The cam drive, already described in the aerial section, has therefore been employed, the return stroke of the cam taking place at the blind spot. The cam-follower imparts linear motion to a sliding rod carrying a brass rack. The rack engages with a molybdenum-disulphide-loaded nylon pinion, the first in a train of alternate brass and loaded-nylon gears driving the masking drum. The drive to the prism is direct from the first pinion, and the train is loaded by a clock spring on the second pinion, which eliminates backlash and ensures continuous contact between the cam and follower. Miniature ball-journals and lead-polytetrafluorethylene-loaded sintered-bronze bearings are used throughout, and no lubrication or maintenance, apart from occasional replacement of the lamp, are necessary.

Effective water-sealing of the periscope, which is shown in Fig. 6, has been achieved by avoiding an exposed rotating head, the rotating mechanism being enclosed in a fixed glass dome projecting through the roof of the car.

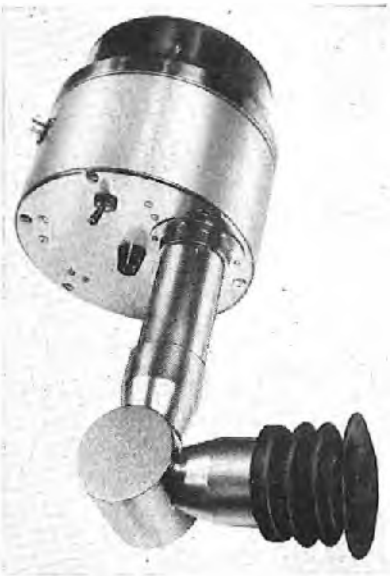


FIG. 6—PERISCOPE

Power Unit

The power supplies are derived from the vehicle battery, and wide variations in supply voltage can occur in service. In order to keep the receiver oscillator drift and residual frequency modulation within acceptable limits it is necessary for the receiver h.t. supplies and some of the heater supplies to be stabilized, a minimum stability of 1 part in 1,000 being required. Also, the efficiency of the power unit must be high because of the limited capacity of the vehicle battery and generator. These considerations preclude the use of a rotary converter or carbon-pile regulator, and, similarly, neither an electronic-valve series stabilizer nor shunt regulator is suitable.

In the power unit described below (Fig. 7), the very low voltage-drop between emitter and collector of a transistor in the current-saturated condition has been exploited, resulting in a regulator and voltage converter of very high efficiency. The high-voltage power supplies are generated by a push-pull self-oscillating transistor inverter, operating at a frequency of 475 c/s and employing a saturated low-hysteresis transformer. The square-wave output from the transformer secondary windings is rectified by bridge-connected, silicon-junction rectifiers, and filters reduce the output ripple to a few millivolts. A third secondary winding, insulated to withstand a potential of 3 kV from earth, provides an isolated and stabilized a.c. heater supply for the c.r.t., which operates with a negative e.h.t. supply connected to the cathode.

Owing to the minimum achievable voltage-drop across the control element being large, it is usual to employ a series stabilizer in the high-voltage output of an inverter. This voltage-drop is much reduced when a transistor is used as the control element, but a protective circuit is necessary to prevent a destructive voltage appearing across the transistor in the event of a momentarily short-circuited load. Furthermore, a separate regulator is required for each output from the converter, and an unrectified output cannot be stabilized. These difficulties have been avoided by inserting the voltage-control element in the input circuit of the regulator (Fig. 7) and a low-output impedance has been achieved by deriving the error signal for the feedback amplifier from the 300-volt output. Close control is exercised over those outputs that are not included in the feedback loop because of the very low transformer secondary resistance and leakage reactance and the low-resistance ripple filters. The regulated input to the inverter also provides a stable heater supply for the turret tuner and modulation amplifier in the receiver.

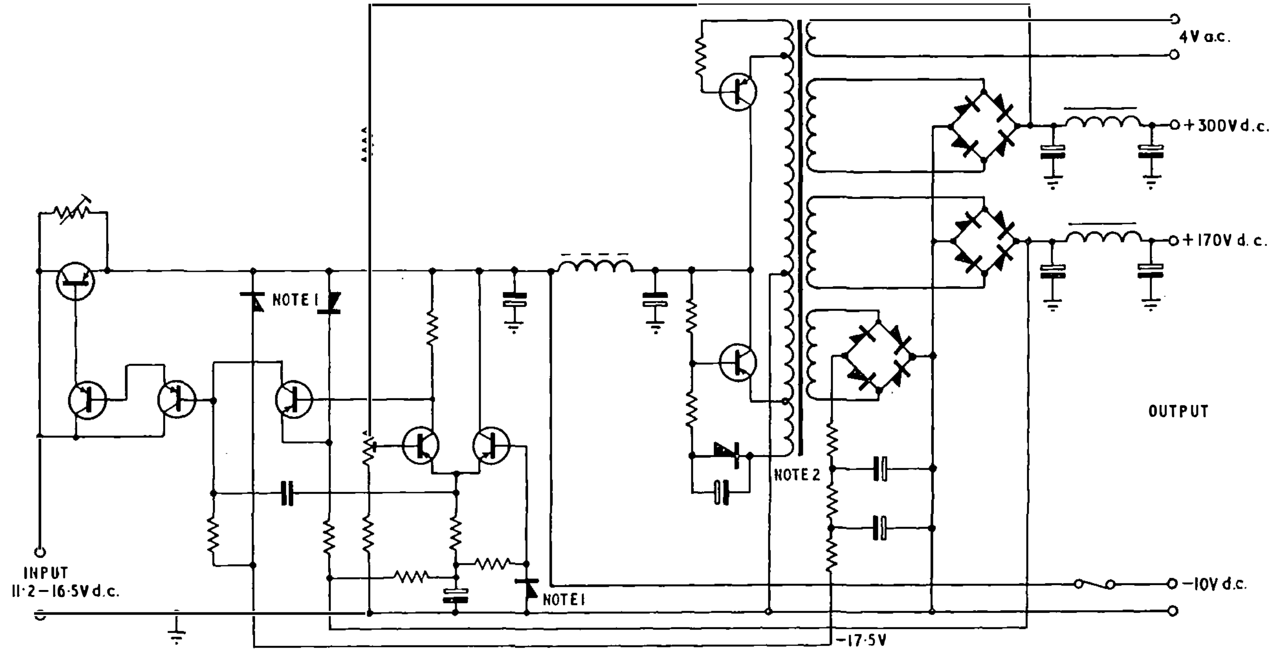
Currents up to 10 amp may be handled by the series-regulator transistor, with a minimum voltage drop of 1·2 volts, and a shunt resistor with a large cooling surface reduces the power dissipated in the transistor to a maximum of 15 watts, although the maximum dissipation of the regulator may reach 60 watts when the battery voltage is high. The minimum power loss in the loaded regulator when the battery voltage is low is 10·5 watts.

The silicon-transistor differential amplifier (long-tailed pair) ensures a low temperature-drift and reduces the load on the reference diode by a factor of 40. The overall current-gain of the regulator amplifier at low frequencies is about 4½ million, and a secondary internal negative-feedback path maintains stability by reducing the gain as the frequency increases. Owing to the high transfer impedance of the inverter, which is included in the external feedback loop, the regulator does not entirely remove the ripple in the output and an additional ripple filter has been used.

The power unit can operate with an input voltage range of 11·2–16·5 volts and an ambient-temperature range of 0°–45°C, with a short-term stability of a few millivolts. The total power consumption of the receiver and power unit is about 130 watts.

DETECTION VEHICLE

The detection equipment is mounted in a modified Series 5 Morris Oxford Traveller, the panoramic receiver and power unit being in the position normally occupied by the nearside front passenger seat. The operator sits in the nearside rear seat and a Postal and Telegraph Officer occupies the offside rear seat. A shielded map-reading light is fitted to the rear of the driver's seat for the use of the postal officer. The driver's view is unobstructed by the equipment except for the central mast tube and the periscope, which are visible



Notes:
1. Zener diodes.
2. Saturated low-hysteresis transformer.

FIG. 7—CIRCUIT OF POWER UNIT

in the internal mirror. Wing mirrors are provided, the nearside mirror being adjusted to show the clearance between the aerial and roadside trees when the car is tilted by a steep road camber.

A 3-phase, self-excited a.c. shunt generator, belt-driven by the engine and operating at a maximum speed of 11,000 rev/min, supplies a maximum output of 800 watts. The current in the rotating field-winding of the generator is controlled by a transistor-amplified vibrator-type regulator, and the stator output is rectified by bridge-connected silicon-junction diodes and used to charge the vehicle batteries. The two series-connected 6-volt batteries of 110 ampere-hours capacity are enclosed behind the rear seat in sealed cases vented on the underside of the car. The detection equipment is normally operated with the vehicle stationary and the engine idling. Under these conditions the output of the generator is sufficient to balance the electrical load.

A fully-screened and suppressed ignition system is fitted to the vehicle, and radio-interference suppressors have been fitted to the windscreen wipers, petrol pump, heater booster and clock.

The standard fresh-air, heating and ventilating unit of 2·75 kW capacity utilizes waste engine heat.

CONCLUSION

The equipment was designed by the Post Office Engineering Department and to speed the replacement of the previous system, all the panoramic receivers were produced by the Department. To reduce lost time due to maintenance, the individual units of the equipment are designed to be removed with a minimum of dismantling and exchanged with spare units.

It is expected that the new detection equipment will avoid the difficulties experienced with the existing system and provide more accurate location of receivers, particularly in densely-populated areas. The greater sensitivity of the new equipment should also be useful in sparsely-populated areas, where a close approach to a house may cause an unlicensed receiver to be switched off before it is located.

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