Radio interference —a review

International standardization of measurement and limits: methods of investigation and suppression

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Dealing with radio interference is, perhaps, one of the less well-known aspects of radio engineering and yet it is one of considerable importance. It has a direct bearing on the enjoyment by many millions of listeners and and viewers of sound and television broadcasting; it is an important factor in the provision of accurate telegraphic and intelligible telephonic communication; and it can be a matter of life and death in connection with the radio aids upon which aircraft and ships rely for safe navigation.

Interference with a radio signal can be caused by radio-frequency energy coming from natural or man-made sources. The former include thunderstorms, charged precipitation and other natural phenomena and there is nothing that can be done to eliminate these sources of interference. Their effect can only be ameliorated by attention to the design of the radio system concerned, by providing an adequate transmitted signal strength to over-ride reasonable levels of noise and by carefully designing the receiving system to make the best use of the available signal.

It is with man-made interference that this article is primarily concerned and its sources can be divided into four classes:

(i) Interference from other radio systems operating on the same frequency channel; this can generally only be eliminated or minimized by careful frequency assignment planning to provide adequate geographical separation or time sharing between co-channel stations. This aspect of interference is a subject on its own and is not covered by the present article.

(ii) Interference from spurious out-of-hand radiation produced by radio equipment used for communication purposes. This type of interference can be caused by both transmitting and receiving equipment and can affect other, quite unrelated, radio systems.

(iii) Interference caused by electric equipment in which radio-frequency energy is deliberately generated for heating purposes, e.g. diathermy, plastics welding and cooking equipment.

(iv) Interference caused by electric equipment of many different kinds in which radio-frequency energy is an unwanted by-product and plays no part in the proper functioning of the equipment, e.g. motor car ignition systems, electric motors and switching devices.

The abatement of radio interference is partly a social, partly an economic and partly an engineering problem. In a society in which economic considerations were secondary to social conscience, equipment and appliances could be designed from the outset so that however they were used they would not cause radio interference. In a practical society, however, a policy such as this would impose unacceptable restrictions on the design of equipment, leading, in many cases, to costs which would be prohibitive. Compromise is thus necessary and equipment is generally suppressed to a degree which, in "normal" use, will not cause "harmful" interference to receivers of "reasonable" quality in "good" working conditions with suitable aerial systems in areas of "adequate" field strength. To define these various terms objectively and precisely is difficult and it has been the concern of various national and international bodies over the years to arrive at fair and economic solutions, so that the burden of responsibility is shared equitably by the equipment manufacturers and the providers of radio systems. In all of these considerations it is of paramount importance to ensure that suppression measures applied in no way render any item of equipment less safe or less able to perform the function for which it is intended.

Regulatory powers

In the United Kingdom, until the passing of the Wireless Telegraphy Act 1949,[1] the abatement of interference was on an entirely voluntary basis. The Post Office, as the licensing authority at that time, had set up and operated a country-wide radio interference service with specialised headquarters and laboratory facilities in London. The object of this service was to deal with specific cases of interference to sound and, later, television broadcasting reception and to give advice and guidance on technical problems as they arose. Broadcasting organizations and various branches of the electrical and radio industry co-operated in the study of radio interference problems and the overall effort was co-ordinated primarily in appropriate committees set up by the Institution of Electrical Engineers and the British Standards Institution.

Under the 1949 Act the Postmaster General was empowered, after due consultation with an advisory committee set up for this purpose, to make regulations concerning the manufacture and/or use of specific items of electric equipment which might cause undue radio interference.

Up to the present time a number of regulations[2] have been made covering electric appliances the use of which has been shown by experience to give rise to the most frequent complaints of interference. They lay down limits to be met when the level of interference is measured in a stated manner using measuring equipment of specified essential characteristics. The introduction of regulations in the U.K., by encouraging manufacturers to suppress equipment and appliances at the time of manufacture, has been a contributory cause of the fall in complaints of interference from a peak of 170,000 in 1955 to around 57,000 per annum at the present time.

When, in 1969, the office of the Postmaster General was abolished and the Post Office became a Public Corporation, responsibility for spectrum management in the United Kingdom, including the control of radio interference, became the responsibility of the newly-created Minister of Posts and Telecommunications. The headquarters organization and the development laboratory from the Post Office were incorporated into the establishment of the new Ministry. However, it was not considered practicable for the Ministry to take over the field organization dealing with the interference complaints from the general public. Clearly the Post Office, with its extensive country-wide engineering organization, was in a better position to carry on with this work. Consequently field engineers of the Post Office continue to undertake the investigation of day-to-day complaints, acting now as agents of the Minister. The Ministry, for its part, takes an active role in the work of national and international committees dealing with interference problems and, on the basis that prevention is better than cure, assists manufacturers of a wide range of apparatus to meet the requirements of regulations and standards by giving advice on suppression techniques.

International aspects

There is another and perhaps less obvious aspect of radio interference suppression. This is its effect on trade between countries. Different requirements in legislation on radio interference suppression in different countries, while allowing electric goods to flow in one direction, may make it difficult for them to move in another direction. This constitutes a technical barrier to trade and it is one of the objects of the major trading countries of the world to eliminate such barriers. International standardization of the methods of measurement and limits for radio interference is the means of achieving this aim. The need for such standardization has long been recognized, and since the mid-1930s the U.K. has participated in the work of the International Special Committee on Radio Interference (C.I.S.P.R.) which operates under the aegis of the International Electrotechnical Commission (I.E.C.). The aims of the C.I.S.P.R. are the establishment of internationally agreed methods of measurement and limits of radio interference. To a large extent these aims have been achieved with the realization of agreed specifications for interference measuring receivers for the frequency range from 10kHz to 1000MHz[3] and recommendations for methods of measurement and limits for a wide range of appliances and equipment. A specification for a measuring receiver and recommendations for a method of measurement and limits for the frequency range 1 to 18GHz have now been agreed in the C.I.S.P.R. but these have not yet been published. Limits of interference and methods of measurement laid down in U.K. Regulations and British Standards[4] are in most cases in close agreement with C.I.S.P.R. Recommendations.

Within the Common Market the need for harmonization of interference legislation is recognized and directives setting limits on the interference generated by a wide range of electric equipment are likely to be introduced in the near future[7] as part of the E.E.C's programme designed to eliminate technical barriers to trade. They relate to equipment such as domestic appliances, radio and television receivers, semiconductor control devices and fluorescent light fittings. Goods manufactured in one member state and certified as conforming to the technical provisions of the relevant directive will be acceptable for marketing in all other member states. The technical provisions will be based on C.I.S.P.R. recommendations.

In June 1972, before the U.K. became a member of E.E.C., the Community adopted a directive relating to the suppression of radio interference from ignition systems on certain petrol-engined vehicles. Under this directive new vehicles which conform to its technical provisions will have a certificate to that effect. These technical provisions include the limits of interference contained in C.I.S.P.R. Recommendation 18/2 which were also adopted by the Economic Commission for Europe (E.C.E.) of the United Nations in its Regulation 10 (Uniform provisions concerning the approval of vehicles with regard to radio interference suppression). The U.K. accepted E.C.E. Regulation No. 10 in 1969, and is making its observance by vehicle manufacturers mandatory on and after 1 April 1974. Vehicles which conform to it will bear an approval mark. At a later date when type approval to the E.E.C. standard[6] (which is similar for all practical

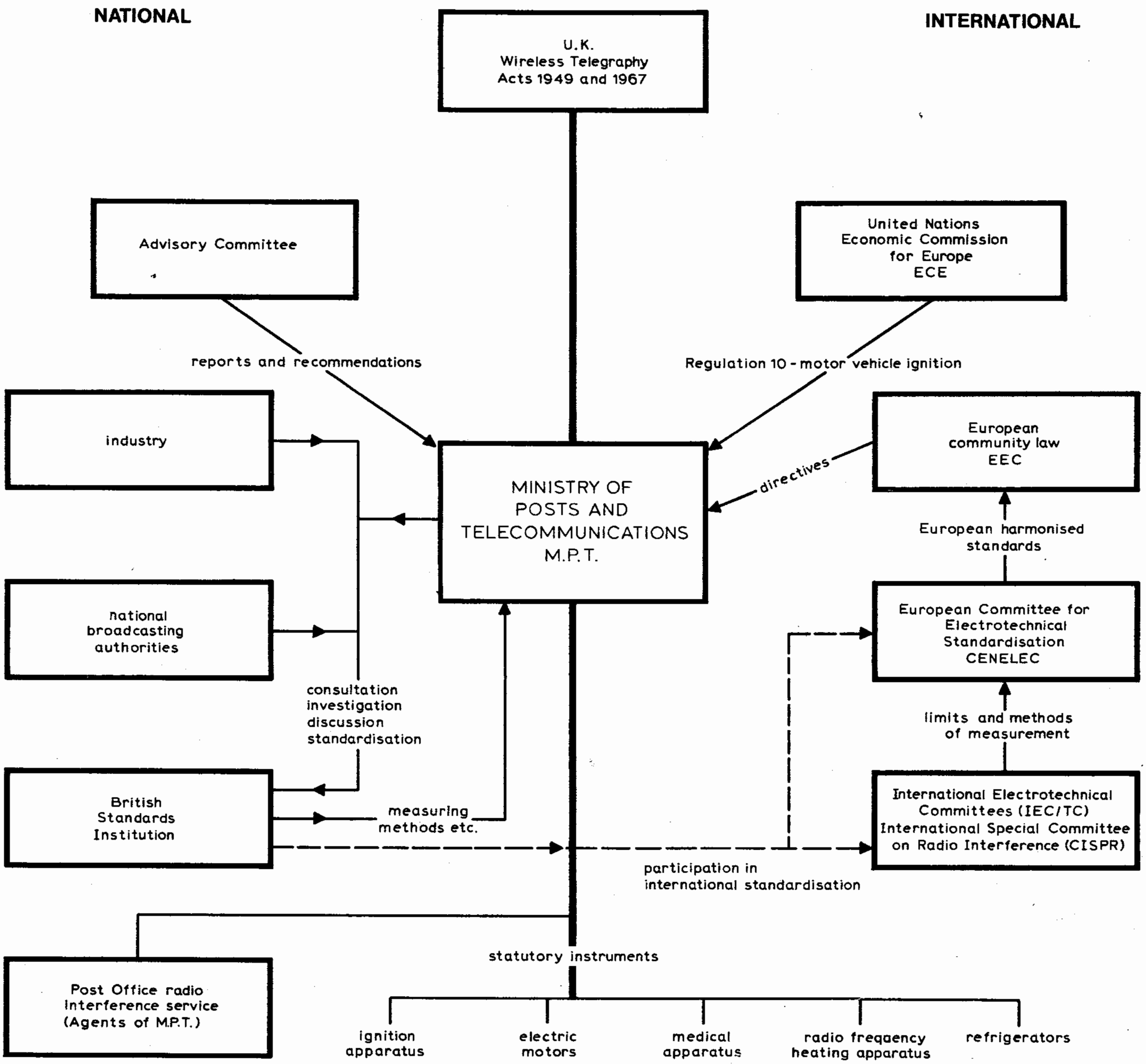

Fig. 1. National and international organization for the control and abatement of radio interference.

purposes) becomes mandatory, the E.E.C. approval mark will be replaced by the certificate. In order to obtain the appropriate E.E.C. or E.C.E. approval for a specific type of vehicle the manufacturer must submit a sample vehicle for test. In the U.K. the M.P.T. has set up a testing station and acts as the test authority on behalf of the Department of the Environment which is responsible for the issue of approvals. When obtained, this approval enables the manufacturer to export his vehicles to other countries in Europe which have accepted the scheme, without separate, national, approval being required. The provisions of C.I.S.P.R. Recommendation 18/2 mentioned above are now embodied in a U.K. Statutory Instrument[2] made under the Wireless Telegraphy Act 1949.

The present national and international arrangements which have evolved as regards control and abatement of radio interference are shown in Fig. 1.

Investigating interference complaints

The large majority of complaints dealt with by the radio interference service investigators in the field are complaints from members of the public of interference with reception of sound or television broadcasting. However, with the rapid growth of mobile radio services in recent years, a small but significant number now arise within this service. The rise and fall of interference complaints is shown in Fig. 2.

In the earliest days of broadcasting, interference to sound radio reception resulted mainly from oscillation in other receivers, and the work of investigation officers consisted mostly of persuading listeners to refrain from advancing the reaction control too far. This problem disappeared as superheterodyne receivers came into general use, but the rapid growth in popularity both of sound broadcasting and the use of electricity in homes and factories resulted in increased interference caused by electric appliances. The Radio Interference Service expanded to meet these problems and by 1939 the field staff totalled some 250 men who in that year investigated about 48,000 complaints of interference to sound radio and 100 to television. During the 1939–45 war broadcasting services were drastically reduced and only a skeleton interference staff was maintained, but from 1947, when television broadcasting was resumed, the pre-war trends continued and the number of complaints of interference increased more rapidly than before. A peak was reached in 1955 when about 500 men were involved and a total of almost 170,000 complaints were investigated, about two-thirds of which related to television. Since that time, despite the continuing growth of broadcasting services and the increasing numbers of radio and television receivers and electric appliances in use, the number of interference complaints has progressively fallen. Although the complexity of some interference problems has increased, it has nevertheless been possible to reduce the staff required and, to deal with approximately 69,270 complaints in 1972, of which 86.3% related to television, about 330 investigation officers were employed.

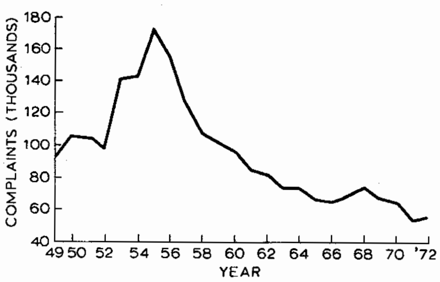

Fig. 2. The rise and fall of interference complaints.

There have been three main reasons for this reduction in the number of complaints. The first is that the coverage given by television broadcasting stations has been improved to provide adequate field strength in many areas where formerly low field strength was a prime factor in interference complaints. Secondly, there is a continuing change-over from v.h.f. to u.h.f. television reception, which is less subject to interference from the more common sources and in general requires the use of more efficient antenna systems which help to give better protection from interference. Thirdly, substantial improvements have resulted from the introduction of the statutory regulations relating to interference from certain classes of electric apparatus, and from the voluntary compliance by manufacturers of apparatus with British Standards containing radio interference limits. One example is that the majority of manufacturers of appliances such as food mixers, hair dryers, and portable tools have voluntarily fitted suppressors to their products.

One of the functions of the M.P.T. headquarters unit is the collection and dissemination of information. Statistics derived from reports by Post Office field staff are analysed to measure the effectiveness of regulations and to identify new sources of interference as they make their effect felt. Periodically, bulletins are prepared for issue to the field staff giving useful information on new forms of interference or new methods of suppression or other information which will assist the investigation officers in their daily work. Often the experience of one officer, reported in a bulletin, will be of practical value to others.

The first step in investigating a complaint from a listener or viewer is to examine the receiving installation to verify that the signal field strength available is adequate, that an antenna suiting the situation is provided, and that the receiver is in good working order and properly adjusted. It may be noted in Table 1, which shows in condensed form the 1972 statistics of interference complaints, that in about one-third of the complaints investigated these conditions were not met.

The interference officer has at his disposal equipment to demonstrate to the owner of an unsatisfactory installation the effect of putting his house in order, at least in those situations where the signal is adequate. This includes a telescopic mast and antenna, to demonstrate the effect of an efficient antenna, and a small portable television receiver for use if the complainant's receiver is suspected of being faulty.

When the receiver is found to be in good order the investigator will proceed to observe the effect of the interference. This may be more easily said than done, for interference is often of an intermittent nature and it may be some time before it makes its presence apparent. There are no set rules of procedure from now on; a brief observation of the interference may be sufficient to indicate, to the investigator with a wealth of experience, the probable cause of the trouble, and perhaps even to locate the source without the use of other special equipment. For instance, short bursts of interference to both sound and vision on a television receiver might be characteristic of a sewing machine in use nearby and a few enquiries at neighbouring houses may quickly identify the source.

However, if the simple approach does not produce the desired result it is necessary to resort to more scientific means, and a number of special interference tracing receivers are available to the investigating officer. Separate models are available for the l.f./m.f., the v.h.f. and the u.h.f. bands re-

TABLE 1
SIMPLIFIED 1972 STATISTICS OF INTERFERENCE COMPLAINTS

Sources	No. of complaints per service					Approximate % of all complaints
	Sound		Television		Private mobile radio	
	l.f./m.f.	v.h.f.	v.h.f.	u.h.f.		
Inadequate signal	57	36	874	1001	6	3.00
Inadequate antenna	637	436	5867	2735	43	14.00
Receiver faults or maladjustments	611	594	6499	3945	208	17.00
Contact devices	1170	250	7528	791	16	14.00
Radio transmitters in U.K.	220	256	2053	979	435	6.00
Broadcast receiver radiation	323	14	1485	1472	23	5.00
Electric motors	275	83	2585	178	15	4.00
Overhead powerlines	86	14	2324	65	15	4.00
Discharge lamps and signs	301	25	1001	63	3	2.00
Industrial and medical r.f. heating equipment	18	10	728	74	22	1.00
Identified sources other than those above	582	154	3294	857	103	7.00
Unidentified	1561	357	9527	2043	324	20.00

spectively, together with a light-weight readily portable combined v.h.f./u.h.f. model for general use. All the receivers have directional antennae so that they may be used to take rough bearings on interference sources, together with facilities for measuring field strength. These two facilities, in the capable hands of an experienced officer, will usually lead to identification of the source of the interference, provided of course that the interference remains on for a long enough period.

Where it is immediately practicable the investigating officer will demonstrate how the interference can be cleared by means of suppressors or filters, and may supply and fit these components provided that the complainant or the owner of the offending apparatus agrees to bear the cost. In some cases, however, the co-operation of a manufacturer may have to be sought, for instance in providing additional screening in an appliance to reduce radiation.

Suppression of interference

Basically, radio frequency interference can be generated in two ways: by switching an electric current on or off, or by means of an oscillator. The transient change of current when a switch is operated contains components the magnitudes of which depend upon many factors such as current switched, the instant of switching in relation to the alternating current cycle (if the supply is a.c.), the capacitance of the wiring across the switch contacts, and dirtiness or bounce in the switch contacts (either of which may cause a single operation of the switch to give rise to multiple interruptions of the current). Resonances in the circuits connected to the switch may cause some frequencies to predominate in the interference produced.

If the switch is a simple on-off device each operation will generate interference in the form of a "click" and this may not be very serious; however, continuous switching operations occur in, for example, commutator motors, motor car ignition systems, dimmer or speed control devices and gas discharge lamps. Such devices will generate continuous broadband interference which is characterized by the presence of high amplitude, short risetime pulses having a repetition rate which is dependent on the switching rate. There are also many multiple switching devices in use nowadays, such as lift controls and automatic washing machine programmers which generate a succession of broadband disturbances in more or less rapid succession. This is generally referred to as discontinuous interference.

The second type of interference generator is the device in which radio frequency energy is deliberately generated by means of an oscillator. Examples are industrial, scientific, medical, or cooking equipment and radio receivers of the superheterodyne type. The r.f. energy produced ranges from many kilowatts in some industrial r.f. heaters to a few milliwatts in a small radio receiver, but both can be serious sources of interference.

There are four basic ways of combating interference:

(i) in oscillating devices, by arranging that the frequency of the oscillation is one which does not interfere with radio services in the vicinity;

(ii) by enclosing the offending device in a screened enclosure which does not allow the r.f. energy to escape;

(iii) in switching devices, by introducing, capacitive, inductive or resistive components to reduce the r.f. content of the current transients;

(iv) in some cases by modifying the receiving equipment.

Examples of each of these methods will be discussed.

Industrial, scientific, medical and cooking equipment is required to operate at a wide variety of frequencies to suit various applications, and a number of small frequency bands have been set aside, by international agreement, for this purpose. These are known as "free radiation" bands and there is no restriction on the radiation permitted in these bands. Other services must keep clear or put up with interference. However, in some cases the internationally agreed bands may not fit in with national frequency planning. For example, the i.s.m. (industrial, scientific, medical) frequency 40.68MHz is rather close to the frequency of 41.5MHz used for the sound carrier associated with the lowest v.h.f. television channel of the 405-line system used in this country, and is a potential source of interference to channel 1 viewers. To avoid this particular form of interference 40.68MHz is not used as a free radiation frequency in this country. Instead a system of zoning is used in which the i.s.m. equipment is assigned a working frequency in a television channel which is not in use in the area in which the equipment is installed. Thus, for areas where channel 1 is not used the i.s.m. equipment is allocated 42 ± 0.08MHz; where channel 1 is used the operating frequency is 49 ± 0.98 or 56 ± 0.112MHz. In both cases the radiation is limited to 1V/m at 30m from the boundary of the premises in which the equipment is installed. At frequencies other than the operating frequency the radiation is limited to a much lower level, 30μV/m at 30m from the boundary of the premises being a typical level in the v.h.f. bands.

Another type of interference which was at one time prevalent in the Peterborough area (and came to be known as the "Peterborough effect") occurred when I.T.A. transmissions commenced from Mendlesham on channel 11. Peterborough is at extreme range from Mendlesham and the signals were rather weak. At the same time, receivers in the Peterborough area tuned to the local B.B.C. station on channel 5 produced interference at the second harmonic of the local oscillator frequency of 101.40 ± 0.3MHz right in the middle of the Mendlesham signal and many hundreds of cases of interference occurred. The solution in these cases was to re-tune the intermediate frequency amplifiers in the receivers to a slightly different frequency so that the beating oscillator frequency no longer interfered with the I.T.A. signal. This operation was an extensive one carried out with the co-operation of receiver manufacturers and a number of teams of investigation officers drafted temporarily into the area from other parts of the country. The problem ceased to exist later when a closer I.T.A. transmitter came into operation. In planning the u.h.f. television service care was taken to avoid as far as possible using at the same station pairs of channels which would give rise to this type of interference.

To keep interference to a minimum in the small number of locations where the harmonics of oscillators of v.h.f. receivers are near the frequency of the vision carrier of a u.h.f. channel, limits of oscillator radiation and immunity are prescribed for television receivers.[4]

Enclosing the source within an earthed screen to prevent the radiation of interference is a measure that can sometimes be applied. For example, some industrial and medical equipments can be treated in this way. In the case of microwave ovens, these have to be fully screened to avoid danger to the operator, and linked switches must be provided to cut off the r.f. energy when the door is opened. Careful screening can also be applied in radio receivers to prevent direct radiation of the beating oscillator frequency. However, in this case it may still be possible for some energy to escape via the antenna. Generally speaking, screening is an expensive method of avoiding interference and is only used where there are compelling reasons for it.

The suppression of switching devices,[8] whether of the single-operation type or repetitive, is essentially the introduction of components which will slow down the transient current changes to limit the power generated at radio frequencies and filtering elements to attenuate r.f. energy transmitted along, and to damp down any resonances in, the associated wiring.

At radio frequencies capacitors behave

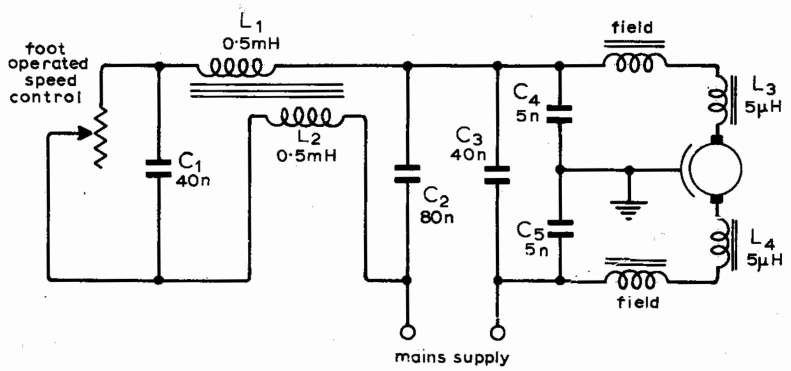

Fig. 3. Typical circuit for suppression of a sewing machine.

electrically as series tuned circuits, the inductance being that of the foil windings, or plates, and connecting leads. Capacitors must therefore be chosen to have a low impedance throughout the frequency range to be suppressed. Inductors behave electrically as parallel tuned circuits, the capacitance being that of the inductor windings. Inductors must therefore be chosen to have a high impedance throughout the frequency range to be suppressed. To meet these requirements it is generally necessary to have one set of suppression components for the l.f. and m.f. sound broadcast bands and another set for the v.h.f. sound broadcast and television bands.

Experience will usually suggest the best form of suppression for a particular equipment but some trial and error must be used to find the optimum values for the components. In many devices the housing of the necessary components in a confined space presents a difficult design problem, and great care must be taken in the choice of components. In particular, some of the capacitors used must be capable of withstanding the continuous application of mains voltage and associated large voltage spikes.

An example of the suppression applied to a sewing machine is shown in Fig. 3. C_1, C_2 and L_1, L_2 suppress the clicks from the foot operated speed control. C_3, C_4 and C_5 suppress the l.f. and m.f. interference from the motor and the small 5μH chokes L_3, L_4 are fitted close to the brushes to suppress v.h.f. interference.

A measure which may be effective in cases where suppression at the source presents difficulties is the introduction of filtering in the aerial lead of the affected receiving equipment. For example, when receiving a wanted signal of normal strength, a very strong signal on some other frequency applied to the input terminals of a receiver may cause blocking or cross modulation or some other non-linear effect which will interfere with reception of the wanted signal. A suitable filter will often solve this problem. *(To be concluded.)*

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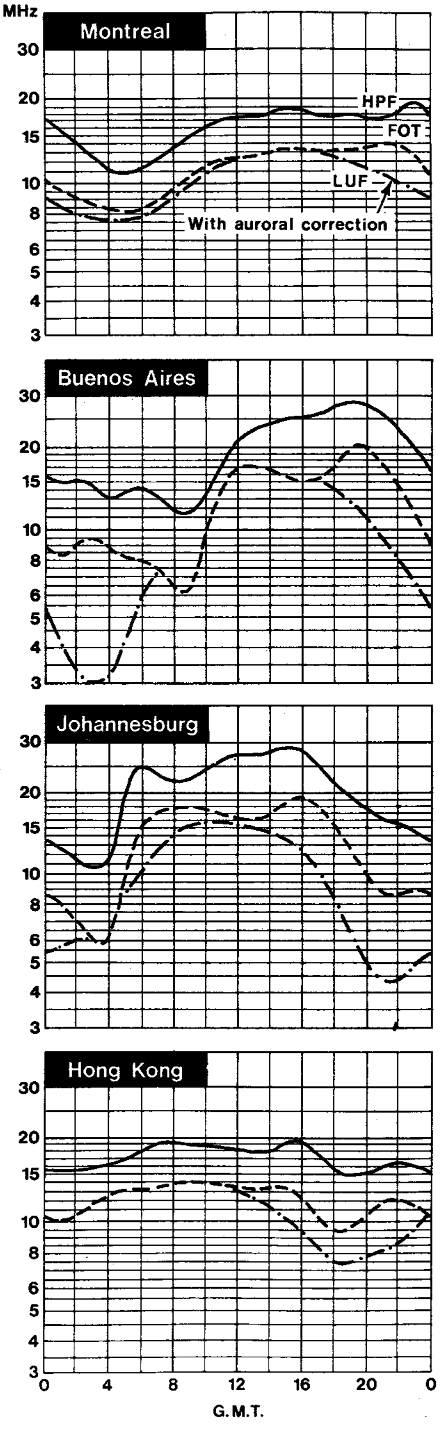
HF predictions for June

Ionospheric Index IF2

	1972	1973	1974
January	58	41	7
February	78	46	12
March	100	41	27
April	90	13	19
May	90	43	10
June	82	37	8
July	94	32	7
August	96	25	6
September	83	40	5
October	80	26	4
November	56	8	3
December	49	4	2

April 1974 onwards are forecast values. Data supplied by Science Research Council, Appleton Laboratory, Slough.



Radio interference

Concluding a review: methods of measurement

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For successful control of interference it is necessary to ensure that the bulk of equipment is suppressed before being placed on the market. Because of the wide variety of equipment which may cause interference and the great diversity in the design of any particular type of equipment it is not possible to prescribe a single physical form of suppression which will meet every case. Instead it is necessary to lay down limits in a particular form for each class of equipment in conjunction with a standardized method of measurement[9] and a method of production control. There are generally four different ways in which interference may be coupled from an equipment to a receiving installation: by conduction along leads such as mains supply wiring, telephone or control cables; direct radiation from the equipment itself; radiation from the leads; or radiation from an aerial connected to a radio transmitter or receiver.

Thus there are requirements for two basic forms of measurement—a voltage measurement at the power supply terminals (and in the case of radio transmitters or receivers at the aerial terminals) of the equipment and a radiated field strength measurement.

For equipment which itself radiates, it is generally necessary to apply both methods in the frequency range up to 30MHz but because power at higher frequencies is poorly conducted along wires a radiation measurement only is necessary at frequencies above 30MHz. For equipments such as small domestic appliances which do not themselves radiate appreciably, a terminal voltage measurement only is necessary in the frequency range up to 30MHz to control conducted interference, with some other form of measurement to control the radiation from the leads in the frequency ranges above 30MHz. The terminal voltage measurement on all equipment with the exception of television receivers is made using a standard V network in which the measured voltages V_1 and V_2 are a combination of the symmetric voltage, e_s, and the asymmetric voltage e_a which are shown in the equivalent circuit in Fig. 4. The 150 ohms termination is chosen to represent the mains impedance which has been shown to have a median value of this order. For television receivers a delta network is used in which the symmetric and asymmetric voltages are measured separately.

At frequencies above about 30MHz conducted interference ceases to be important and coupling is mainly by radiation from the equipment and its leads. When radiation takes place from the equipment itself, e.g. from motor vehicle ignition systems and large radio frequency heating devices, measurement of radiated field strength must be made. This is done in a standard manner usually at a distance of 3m, 30m, 100m or 300m from the appliance, depending upon the frequency range and size and power of the source. The measurement of ignition interference at a distance of 10m is shown in Fig. 5.

Field strength measurements are difficult and expensive; their accuracy and repeatability with normal equipment and techniques tends to be low and the measurements usually have to be made outdoors. To overcome the drawbacks of the direct measurement of field strengths the CISPR has developed substitution methods of measurement in which the results are quoted in terms of c.w. power from a signal generator to give the same output on the measuring receiver as the equipment or appliance under test.

Two different methods are in use. In the first, which is used for battery operated appliances with self-contained batteries in the frequency range 30–300MHz and for microwave ovens in the frequency range 1 to 18GHz, the equipment is placed on a turntable at a convenient distance from a measuring aerial and rotated for maximum indication on the measuring receiver. The equipment is then replaced by a half-wave dipole fed from a standard signal generator which is adjusted to give the same output on the measuring receiver. The interference power of the equipment is then quoted as the power (pW) at the terminals of the dipole. The second method utilizes a ferrite current transformer and associated power absorbing ferrite rings arranged in a manner to be described later.[10] The transformer and associated ferrite rings are moved along the supply lead to obtain a maximum indication on the measuring receiver. The interference power of the equipment is quoted as the c.w. power from a standard signal generator to give the same output on the measuring receiver under defined conditions. This method is used in the frequency range 30–300MHz for domestic and other appliances which radiate mainly from the supply leads.

At present in the UK and a number of other countries the greatest number of complaints from a single source of interference are those caused by contacts, mainly of thermostats. Measurement of the discontinuous interference caused by contacts presents difficult problems. The solutions in current use are not entirely satisfactory and the resultant methods of measurement which have developed over a great number of years are very complicated and not readily understood. Originally discontinuous interference ("clicks") was distinguished from continuous interference ("buzzes") by listening in the audio circuits of the measuring set. Clicks, which were disturbances

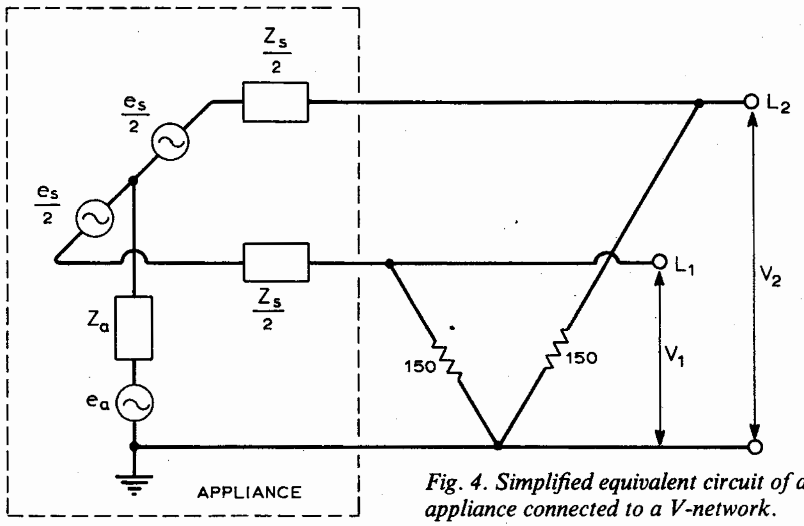

Fig. 4. Simplified equivalent circuit of an appliance connected to a V-network.

judged to last less than 200ms, were counted by the operator and a weighting factor of $20 \log_{10} 30/N$, where N equals the number of clicks per minute, was added to the limit for continuous interference to arrive at that for the discontinuous interference for the appliance under test. The appliance was then judged to pass or fail the test by the application of the upper quartile method in which if more than 25% of clicks exceeded the limit the equipment was rejected.

This method is extremely tedious and time consuming and, relying as it does on the judgement of individual operators, yields results which are far too inconsistent for use in modern conditions. Recently, as an interim measure to enable test houses and laboratories to speed up measurements and achieve more consistent results, especially on programmed appliances such as automatic washing machines, the CISPR has rationalized its recommendations on discontinuous interference and has produced a more rigid definition of a "click" to enable the measurement of duration and repetition rate to be made using a special electronic counter specified in CISPR Recommendation No. 41. Fig. 6 shows the block schematic of the method of measurement in the v.h.f. range.

A click is now defined as a disturbance which lasts not more than 200ms and is separated from a subsequent disturbance by at least 200ms. If more than two of these clicks appear in any two-second interval the limit for continuous interference applies. For clocks which are repeated less often than twice in two seconds the weighting factor $20 \log_{10} 30/N$ applies as before.

The method of counting the number of clicks during the observation time is important and where possible, i.e. in general for simple appliances, the number of openings and closings of the switch or thermostat is used. For programmed appliances and other complex equipment where it is impossible to count the number of openings and closings of contacts the number of clicks which exceed the limit for continuous interference is counted by the interference analyser and the upper quartile analysis is then applied as before.

The input to the disturbance analyser is taken from the i.f. stage of the measuring set which retains the function of the measurement of amplitude. The disturbance analyser's functions are the counting of clicks and the assessment of duration and repetition rate. The operation is semi-automatic in that the apparatus may be set up and left unattended for the duration of each test which may last as long as several hours.

Fig. 5. Measurement of ignition interference.

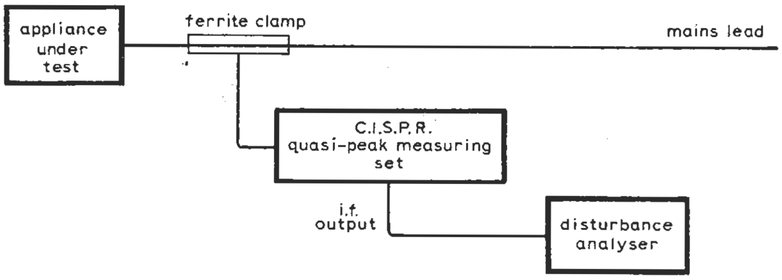

Fig. 6. Measurement of discontinuous interference in the frequency range 30–300MHz.

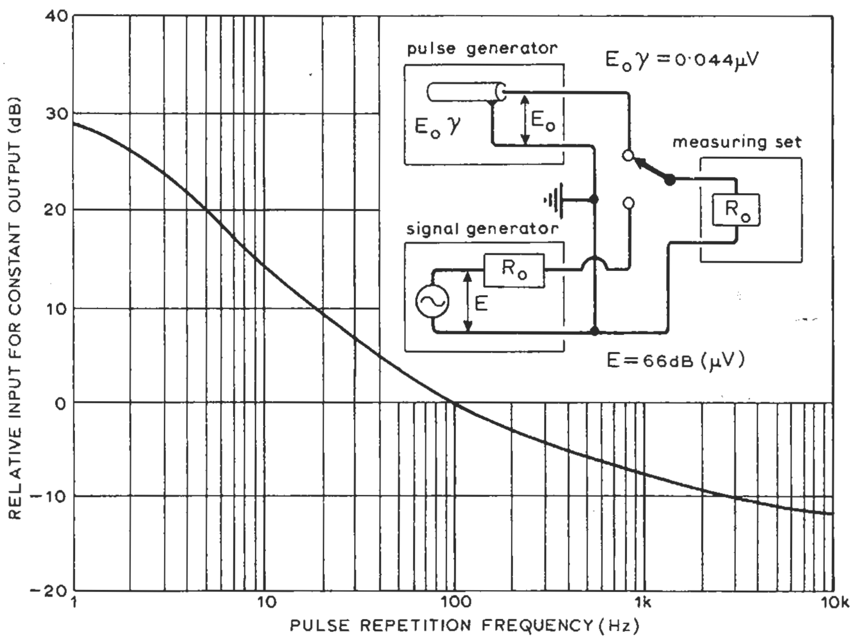

Fig. 7. Pulse response curve 25–1000MHz of CISPR interference measuring receiver

Limits of interference

When suitable methods of measurement have been developed it is then possible to fix limits of interference. To a large extent these are a compromise between that which will give protection in all circumstances and that which it is possible to achieve economically without affecting the operation or safety of appliances to be suppressed. For the broadcasting bands the limits are based on calculations which take into account the minimum field strength at which a particular broadcasting service is expected to provide satisfactory reception, the median value of the measured decoupling factor between an appliance and sound radio or television installations in homes, the protection ratio required for satisfactory reception and the effective length of the receiving aerial. It is then common practice to monitor the effectiveness of these limits by analysing the statistics of complaints as described earlier. Limits used in the UK are in general in accordance with the recommendations of the CISPR which are based on compliance in production of 80% with a confidence of 80% assuming a gaussian distribution.

Measuring apparatus

Measuring receivers. Interference measuring equipment was first designed for use in the protection of amplitude-modulated sound broadcasting in the l.f. and m.f. bands. Extensive testing was undertaken to determine the electrical characteristics required to give measured values corresponding to the subjective effect of disturbances. For the l.f. and m.f. bands this resulted in a specification for an r.f. value voltmeter having a bandwidth of 9kHz and detector time constants of 1ms charge and 160ms discharge. The bandwidth of 9kHz was, of course, chosen to represent the bandwidth of the a.m. sound broadcast receivers in use at the time. For the protection of other type of services it would be ideal to have measuring apparatus specially designed to correspond to each service. Unfortunately for general use this would be uneconomic and also there would be a difficulty in correlating the results of measurement by different apparatus to achieve a common limit to apply to interfering equipment. The CISPR therefore decided to standardize on fixed bandwidth receivers with specified time constants. There are three specifications for the frequency range 0.15–1000MHz, the essential characteristics of which are shown in Table 2. The use of the specified characteristics in a CISPR receiver has the effect of requiring a larger amplitude input to give the same output as the pulse repetition rate decreases. Fig. 7 shows the pulse response curve for the frequency range 25–1000MHz. A measuring receiver built to the CISPR specification is essentially of the superheterodyne type with solely manual gain control by means of calibrated attenuators and a built-in calibrator for setting the receiver gain to a standard value.

Impulsive interference is unlikely to be a problem at frequencies above 1GHz. At present the only likely major source of interference at these frequencies is the microwave oven which is designed to operate at a frequency of 2450±50MHz or 5280±100MHz but which also generates energy at other frequencies not necessarily harmonically related to the fundamental but extending throughout the spectrum from the l.f. band up to the s.h.f. bands. Experience has shown that each such spurious radiation may occupy a bandwidth in excess of 50MHz and that the energy is not uniformly distributed over this bandwidth. Thus measuring receivers with different bandwidths may give different results and it is not possible to apply accurate correction for bandwidth in order to correlate them.

It has been argued that the best correlation with the disturbing effects of this type of interference would be obtained with the use of a measuring receiver having a very wide bandwidth and an r.m.s. detector. The CISPR, however, has taken the view that the construction of a special receiver for the measurement of interference from microwave ovens would be so expensive that very few would be built and that effective control would be much more likely to be achieved if it were based on a commercially available receiver which is already in widespread use. It has therefore recommended the use of a spectrum analyser having the characteristics shown in Table 3.

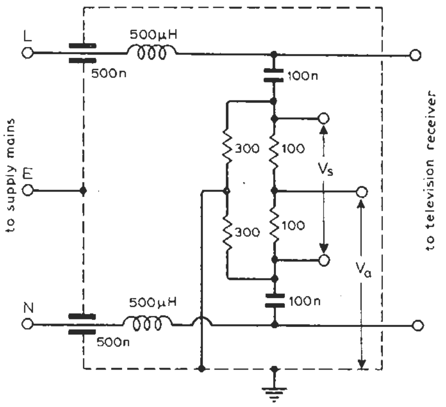

Fig. 8. Basic circuit of a delta "artificial mains" network.

TABLE 2
CHARACTERISTICS OF CISPR QUASI-PEAK MEASURING APPARATUS

Characteristics	Frequency range (MHz)		
	0.015 to 0.15	0.15 to 30	25 to 1000
Bandwidth at 6dB	200Hz	9kHz	120kHz
Charge time constant	45ms	1ms	1ms
Discharge time constant	500ms	160ms	500ms
Mechanical time constant of meter	100ms	100ms	100ms
Overload factor (r.f. and i.f. amplifiers)	24dB	30dB	43.5dB
Overload factor d.c. amplifier	12dB	12dB	6dB

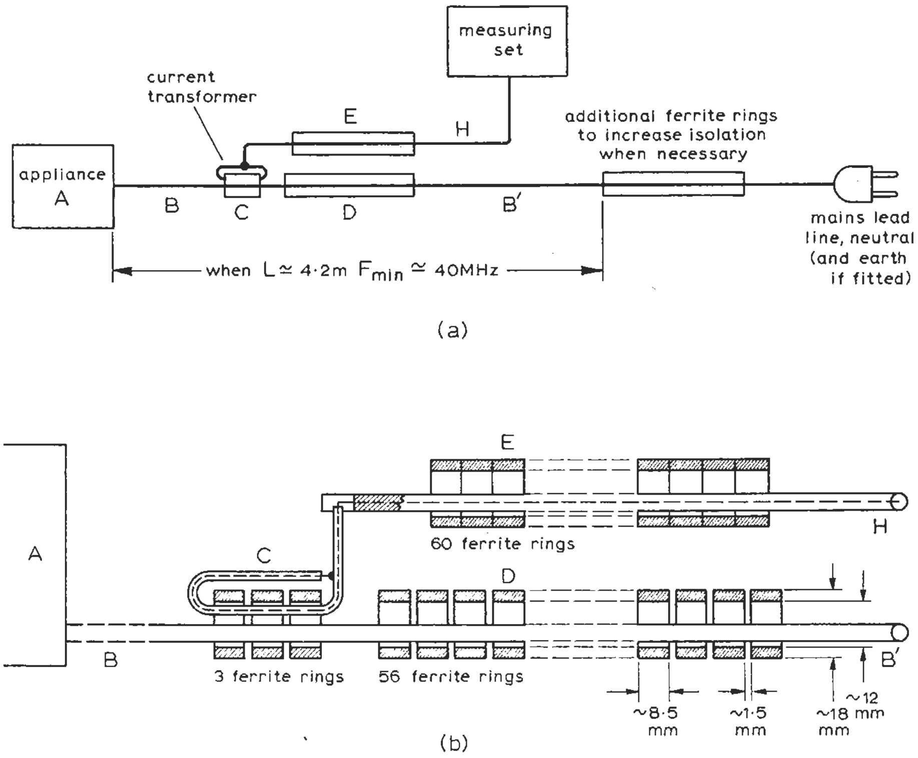

Fig. 9. Construction and use of the CISPR ferrite clamp.

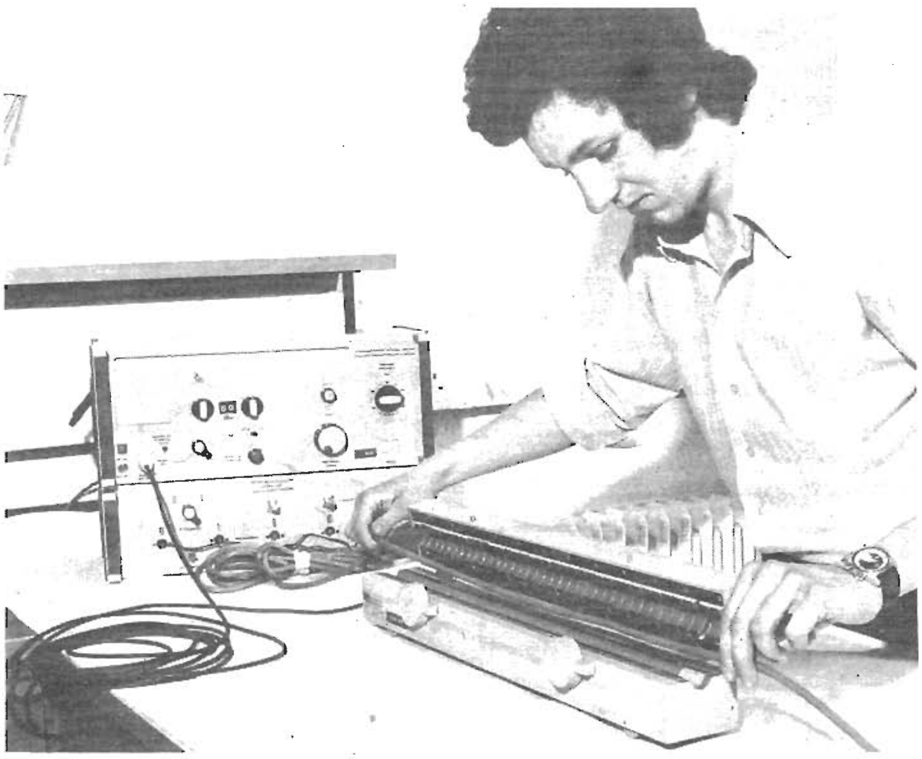

Fig. 10. The CISPR ferrite clamp.

TABLE 3

Characteristics of a spectrum analyser for use in the frequency range 0.3–18GHz

Spurious responses: 40dB below response at the instantaneous tuned frequency. (A pre-selector may be used.)
Bandwidth: 125±25kHz.
Variable attenuation in both r.f. and i.f. sections of receiver.
Screening effectiveness: 60dB.
Sweep time: variable from at least 0.1 sec. to 10 secs.
Display tube: storage type (or other means of storing information).

Note: During measurements a filter shall be provided at the input of the analyser, having at least 30dB attenuation at the operating frequency of the equipment under test.

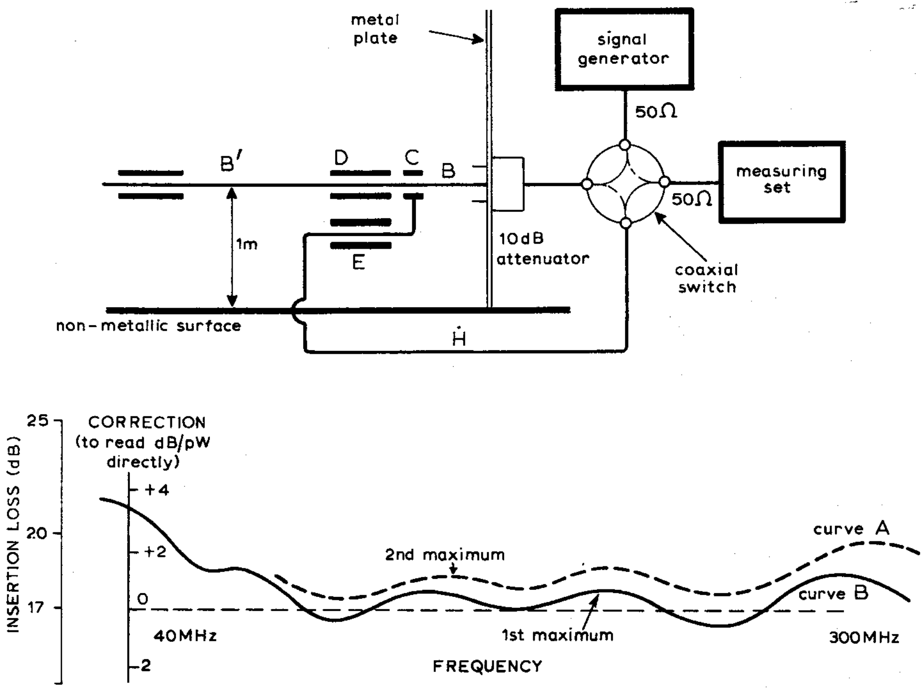

Fig. 11. Method of calibration of CISPR ferrite clamp.

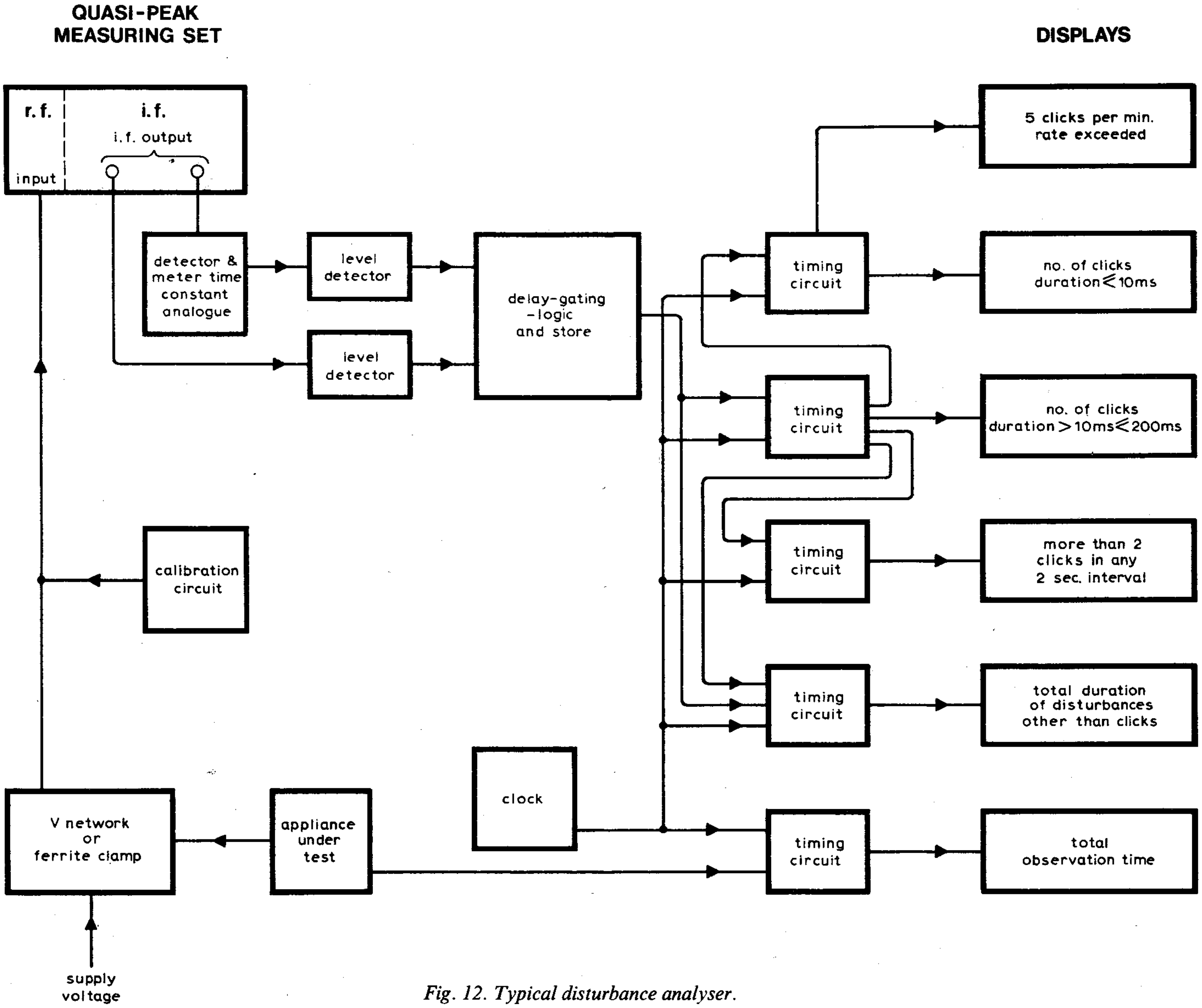

Fig. 12. Typical disturbance analyser.

Auxiliary apparatus. As already stated the interference measuring receiver is essentially a valve voltmeter and has to be used in conjunction with certain auxiliary apparatus including antennae and terminating networks. For field strength and substitution measurements the use of a half wave dipole antenna is normally specified with the proviso that broadband and other types of antenna such as horns may be used where these can be shown to give the same results.

For measuring terminal voltages in the frequency range up to 30MHz terminating networks of specified form are used. These range from simple attentuators for antenna terminal voltage measurements to V and delta[11] "artificial mains" networks for measurement on mains supply and other lines. Fig. 8 shows an example of a basic delta network for measuring r.f. voltages on the supply terminals of television receivers. The network is required to provide a defined impedance, at radio frequencies, between the mains input terminals of the television receiver and between each of these terminals and earth. In addition a suitable filter is incorporated to isolate the measuring receiver from radio frequency voltages on the supply mains. In practice this is somewhat difficult to use and a modified version using a balun is employed.

For the assessment of interference radiated from the mains lead of an appliance in the frequency range 30–300MHz a ferrite clamp is used. The construction and use of a typical CISPR ferrite clamp[10] is shown in Fig. 9. It consists basically of a ferrite cored current transformer in which the mains cord of the appliance under test is one winding and the lead to the measuring set is the other. To stabilize the impedance at the point of measurement and provide some r.f. isolation from the mains, a large number of ferrite rings, usually between 50 and 65, are placed over the mains lead as shown in Fig. 9(b). A like number of rings are placed round the lead to the measuring set to reduce standing waves on the screen. In practice the rings are split and mounted in a hinged plastic case as shown in the photograph in Fig. 10. This allows appliances having mains leads with moulded-on plugs to be measured without cutting or changing the lead. At each frequency of measurement the clamp is moved along the stretched out main lead to give maximum reading on the meter at the current antinode closest to the appliance. At this point the clamp presents to the appliance a substantially resistive impedance of between 100 and 250 ohms.

The clamp method of measurement is essentially a substitution one in which the appliance is replaced by a standard signal generator. The interference power is taken to be that from the generator at the input to the clamp. To avoid the tedious process of substituting the signal generator on every measurement a calibration curve is prepared for each clamp under defined conditions. Fig. 11 shows the details of the calibration in which the clamp is placed 1m above a non-metallic surface and connected to a signal generator and a measuring set to enable a measurement of insertion loss to be made. Radio interference measuring receivers are usually calibrated to give voltage readings in dB (μV) (i.e. decibels relative to 1μV). To convert a voltage across a 50-ohm resistor expressed in dB (μV) to power in the *resistor* expressed in dB (pW) (i.e. decibels relative to 1 pW) it is necessary to subtract 17 (i.e. $10 \log_{10} 50$). Quite fortuitously the insertion loss of a well-made clamp connected between 50-ohm impedances is nearly equal to 17dB, thus for many purposes it is possible to read the interference power in dB (pW) directly from a measuring receiver which is calibrated in dB (μV). For greater accuracy the calibration curve for the particular clamp can be used.

The clamp has been developed empirically and the precise theory is not yet well understood. For instance the selection of the correct grade of ferrite presents a difficulty and is essentially a matter of trial and error. Nevertheless the performance of correctly constructed clamps has been checked in many different countries and it has been confirmed that it provides a most satisfactory method for the measurement in the v.h.f. bands of interference from equipment which radiates mainly from the supply leads.

For the measurement of discontinuous interference an automatic analyser has been developed. A schematic diagram of a typical analyser is shown in Fig. 12. The function of the disturbance analyser is the recognition and recording of different durations and repetition rates of interference generated by switching devices. Measurement of the amplitude of these disturbances remains the function of the quasi-peak measuring set. The disturbances which are being measured are of fairly high amplitude and comparatively long duration and there are thus none of the problems of coping with short duration, fast risetime pulses of low amplitude. The main problems have been the difficulty, because of the varying delay times, of associating each pulse in the intermediate frequency stage with the corresponding meter deflection, and the precise interpretation of the various, sometimes conflicting, requirements which had been laid down at different times in different CISPR recommendations. The CISPR, as already mentioned, has rationalized the requirement for the measurement of discontinuous interference and included all of them in one recommendation. This has removed one difficulty. The other problem has been tackled in different ways in different countries and it will require further work to standardize the analysers to ensure reasonable correlation of results.

Conclusions

A large measure of success has been achieved both nationally and internationally in the control of radio interference. There is still much to do, however, and the rapid changes which are taking place in every facet of modern life make it essential to keep existing equipment and practices under review.

For the present, the emphasis, from a standardization and regulatory point of view, has shifted to the treatment of radio interference measurement and suppression requirements so that they no longer form a possible barrier to trade. In the UK this will mean a change from a predominantly voluntary system of co-operation to one in which almost all equipment will be required by law to be suppressed at the time of manufacture. This in turn may lead eventually to the extension to other products of the type testing and conformity marking scheme now in operation for motor cars.

Acknowledgement is made to W. Goldsmith for his contribution on international aspects, to the staff of the Ministry's radio interference laboratory for their assistance in the preparation of the article and to the Director of Radio Technology for permission to publish it.

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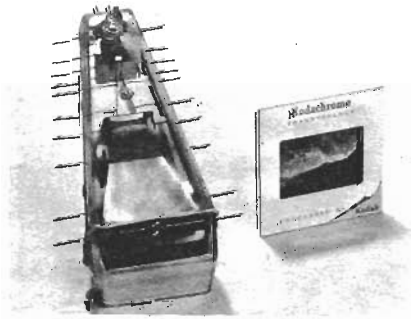
The short view

The cathode-ray tube in the photograph has been designed by A. V. de V. Krause for the Sinclair television receiver, now under development. The tube is 100mm long and presents a picture which is about the same size as a 35-mm slide. The directly-heated filament, working at 0.75V, consumes 30mW. Electrostatic deflection is used, requiring 100Vp.p. per 1000V on the third anode, which is run at 1–2kV (beam current 35μA). Grid voltage for cut-off is −20V per kV of first anode potential. Novel techniques are used in the tube construction, the body being made in two parts, split longitudinally. No graphite coating is applied, a metal shield being used to collect the beam current—screening has not been found necessary. It is intended that the tube should be mounted directly on a p.c. board by its lead-out wires.



Miniature tube for television and applications in other types of display.

Eliminating adjacent-channel interference

by P. L. Taylor, M.A., F.I.E.E., F.I.M.A., *University of Salford*

Adjacent-channel interference between amplitude-modulated signals can be overcome, even when the carrier frequencies are so close together that the sideband of one signal overlaps the carrier of the other.

The problem of adjacent-channel interference has been with us almost since radio communiction began. Fig. 1 illustrates the situation in which it arises: the carrier frequency of an unwanted amplitude-modulated signal *U* is too close to the carrier frequency of a wanted signal *W*. The result is that some of one sideband of *U* intrudes into the part of the spectrum occupied by *W*. A receiver tuned to *W* must have a pass-band sufficiently wide to accept the sidebands of *W*, and so cannot reject the unwanted sideband of *U*. The audible result, after detection, is unintelligible and annoying "sideband splash" or "monkey chatter" caused by the beating of the unwanted frequencies with the carrier of *W*.

If *U* is not too close to *W*, as in Fig. 1(a), then it is possible to design the receiver to accept only the "clean" sideband of *W* (which contains all the modulation information in itself) and to treat the result as a single-sideband signal; but this requires very sharp and precise filtering, which of course is expensive. If the two carrier frequencies are as close together as is shown in Fig. 1(b) it has been generally thought that there is nothing one can do about the situation. In addition to the monkey chatter one must put up with an inter-carrier whistle at the difference frequency between the two carriers.

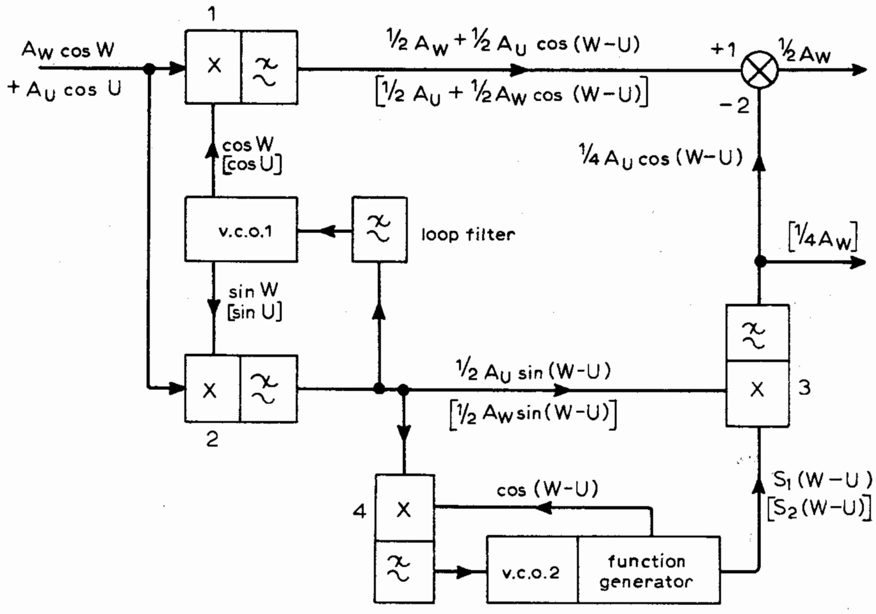


Fig. 2. Block diagram for both methods of overcoming interference.

Here are two methods[1,2] which provide solutions to the problem. Both begin with synchronous demodulation of the wanted signal, as in the homodyne and synchrodyne receivers.† For brevity, the wanted signal will be represented by A_W cos W, where $W = 2\pi f_W t$, f_W being the frequency of the wanted carrier. Similarly, the unwanted signal will be represented by A_U cos U. We want to recover A_W, uncontaminated by A_U.

In synchronous demodulation, the wanted carrier is multiplied by an oscillation having exactly the same frequency and phase. The result is

$$A_W \cos W \times \cos W = \tfrac{1}{2}A_W + \tfrac{1}{2}A_W \cos 2W$$

(Table I may be a helpful reminder).

Thus the wanted signal A_W is recovered, together with an oscillation at twice the carrier frequency, which is easily removed by filtering.

Table I

cos *A* cos *B* = ½ cos (*A*—*B*) + ½ cos (*A*+*B*)
sin *A* sin *B* = ½ cos (*A*—*B*) — ½ cos (*A*+*B*)
sin *A* cos *B* = —½ sin (*A*—*B*) + ½ sin (*A*+*B*)

cos (—*C*) = cos *C*; sin (—*C*) = —sin *C*

First method

Figure 2 is the block diagram, in which the expressions in square brackets should be ignored, since they relate to

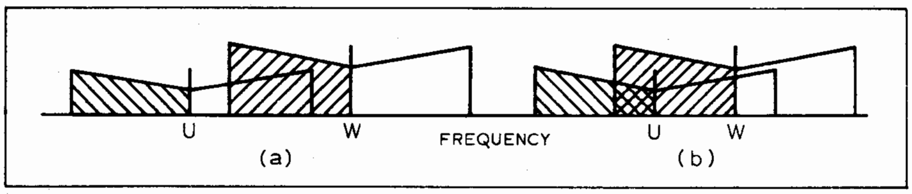


Fig. 1. If the carrier of an unwanted signal U is too close to that of a wanted signal W there is interference. In case (a) it is possible to filter out the "clean" sideband of W. Up to now it has been thought that nothing could be done in a situation such as (b).

† *This is history repeating itself. When Professor Tucker did his work on the synchrodyne he was led to consider the present problem, and suggested an approximate solution. Some while ago the author was casting round for projects for his final-year undergraduate students and thought it might be interesting to see what could be made of the synchrodyne using modern technology. He, too, was led to consider the problem: this time the suggested solution is exact.*

the second method. The combined signals are applied to demodulator 1, where they are multiplied by cos W. The output of this demodulator (after filtering) is now $\frac{1}{2}A_W+\frac{1}{2}A_U\cos(W-U)$. The second term in this expression is the audible interference. The multiplier cos W is obtained from a voltage-controlled oscillator VCO_1 which is phase-locked to the wanted carrier via demodulator 2. VCO_1 produces quadrature outputs. The phase-lock loop will settle itself so that the v.c.o. output which is presented to demodulator 2 is in quadrature with the wanted signal, so this output must be represented by sin W and the quadrature output will be cos W. It is arranged that when capture has occurred the loop bandwidth is reduced to about 1Hz by extra filtering so that the oscillator is not disturbed by the other frequencies present in the signals. Also, the loop includes an integrator so that the phasing is exact.

Now the output of demodulator 2 contains the component $\frac{1}{2}A_U\sin(W-U)$, but no component involving A_W. The clue is too obvious to be missed: if the phase of this oscillation could be changed from $\sin(W-U)$ to $\cos(W-U)$ it could be used to cancel the unwanted component in the output of demodulator 1. This could be done by multiplying, in a third demodulator, by $\sin 2(W-U)$:

$$\tfrac{1}{2}A_U\sin(W-U)\times\sin 2(W-U)=\tfrac{1}{4}A_U\cos(W-U)-\tfrac{1}{4}A_U\cos 3(W-U)$$

Thus the desired phase-shifting has been accomplished but at the cost of introducing a 3rd-harmonic oscillation, and, if $(W-U)$ is small, it may not be possible to filter it out. But if $\frac{1}{2}A_U\sin(W-U)$ is multiplied by the series

$$S_1(W-U)=\sin 2(W-U)+\sin 4(W-U)+\ldots+\sin 2n(W-U),$$

the result is:

$$\tfrac{1}{4}A_U\sin(W-U)\,S_1(W-U)=\tfrac{1}{4}A_U\cos(W-U)-\tfrac{1}{4}A_U\cos(2n+1)(W-U).$$

The intermediate products give rise to sum- and difference-frequency terms which cancel, leaving the interfering oscillation at a frequency which may be made as high as desired by a suitable choice of n; this oscillation may now be filtered out easily. Thus, the desired cancellation signal is obtained, and processing is completed as shown in Fig. 2.

A waveform, whose Fourier series components form $S_1(W-U)$, is obtained from a function generator which is described later. The generator is phase-locked via VCO_2 and demodulator 4 to the beat frequency $(W-U)$. Note that the series S_1 is one in which all the first $(n-1)$ harmonics are equal in amplitude to the fundamental, which has a frequency twice that of the beat frequency.

Second method

If the unwanted signal is stronger than the wanted signal it will probably be easier to lock VCO_1 on to the unwanted carrier, so that (taking the expressions in brackets in Fig. 2) the output of demodulator 2 becomes $\frac{1}{2}A_W\sin(W-U)$. Thus, the unwanted signal is rejected directly at this stage, but the problem now is that the wanted signal is modulated on a carrier frequency that lies within the audio range.

The wanted signal could be demodulated by multiplying by $\sin(W-U)$:

$$\tfrac{1}{2}A_W\sin(W-U)\times\sin(W-U)=\tfrac{1}{4}A_W-\tfrac{1}{4}A_W\cos 2(W-U)$$

but this introduces an interfering oscillation, at twice the beat frequency, which may still be too low to filter out. But if $\frac{1}{2}A_W\sin(W-U)$ is multiplied by the series

$$S_2(W-U)=\sin(W-U)+\sin 2(W-U)+\ldots+\sin(2n+1)(W-U)$$

the result is

$$\tfrac{1}{2}A_W\sin(W-U)S_2(W-U)=\tfrac{1}{4}A_W-\tfrac{1}{4}A_W\cos(2n+2)(W-U).$$

The intermediate products give rise to sum- and difference-frequency terms which cancel, leaving the interfering oscillation at a frequency which may be made as high as desired by suitable choice of n; it is thus easily filtered out. In this method the wanted signal is taken from the output of demodulator 3.

Function generation

It would be possible to generate the series S_1 or S_2 by taking a number of oscillators, of appropriate harmonic frequencies, and phase-locking them together and to the beat frequency $(W-U)$. But this would be clumsy, and would also require that the demodulator 3 should be a true multiplier. The simplicity of a switching demodulator may be retained as follows.

In normal use a switching demodulator acts to change the sign of the signal to be demodulated in step with alternate half-cycles of the multiplier oscillation. That is, it effectively multiplies the signal by a square wave switching function f, drawn as the solid line in Fig. 3, which alternates between the values +1 and −1 with the same period T as the multiplier oscillation. As drawn in Fig. 3, the function f is odd (in the mathematical sense), that is, $f(-t)=-f(t)$, and the graph has rotational symmetry about the point $t=0$. Hence its Fourier series consists of odd functions (sine terms) only:

$$f(t)=\frac{4}{\pi}\left[\frac{2\pi}{T}+\frac{1}{3}\sin 3\frac{2\pi}{T}+\frac{1}{5}\sin 5\frac{2\pi}{T}+\ldots\right]$$

Thus, the demodulator does multiply the signal by the required frequency (the first term in the series). It also multiplies by the higher frequencies in the series, but the results are usually filtered out.

Now, suppose that two extra edges are introduced, at t_1 and t_2, to give the dotted wave. Since S_1 consists only of sine terms the rotational symmetry must be preserved, by introducing corresponding edges at $-t_1$ and $-t_2$. Now t_1 and t_2 can be chosen at will; the question is, can we choose them so that the first two harmonics of the new waveform have amplitudes equal to the fundamental? The answer is yes, and the result is quite general: if n extra edges are introduced, then the first n harmonics can be made to have amplitudes equal to the fundamental.

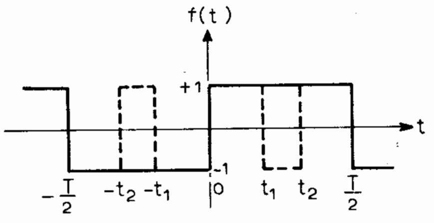
The correct instants $t_1, t_2 \ldots t_n$ are found as follows. The expression for the Fourier series of the new waveform is found in the usual way, and from it the conditions that the coefficients of the first n harmonics shall be equal are found. This results in a set of simultaneous equations in the unknown t. However, the equations are non-linear, so the solution of them is best entrusted to a computer.

Thus a square waveform can be designed such that the first terms in its Fourier series form S_1. A similar argument leads to a waveform the terms of which form S_2. There is a small complication in this case because only the odd harmonics are required. Both series continue with higher-order terms, but these do not matter because the unwanted products to which they give rise will be filtered out anyway.

The waveforms may be generated quite easily by digital techniques. VCO_2 is made a high-frequency oscillator, the cycles of which are presented to a digital counter. The counter output is presented in turn to a number of digital comparators (one for each edge) which are hard-wired with numbers defining the instants at which the edges occur. Whenever a coincidence is detected, an edge is generated by triggering a bi-stable.

In an alternative method, numbers representing the *differences* between successive edges are placed in a read-only memory (r.o.m.). A presettable counter is loaded with the first number, and is counted down to zero by VCO_2. When zero is reached an edge is generated, the number in the next address in the r.o.m. is loaded into the counter and so on until the cycle is

Fig. 3. Illustrating the derivation of the special switching functions.



completed and control is returned to the first address in the r.o.m. This method is more economical of hardware, and more flexible because the numbers for several series can be stored in one r.o.m. Any waveform can be selected simply by choosing the appropriate starting address.

Sidebands

Though the mathematical analysis given above indicates that the methods should work, and experiment shows that they do work, it is not so far clear exactly how it is that the overlapping sidebands are disentangled.

Take as an example the first method. Suppose that initially VCO_1 has not locked on to the wanted signal, but is running at some frequency F higher than W. The output of both demodulators 1 and 2 is a group of signals at the sum- and difference-frequencies, as in Fig. 4(a). Only the lower frequency group is retained; the other is eliminated by the low-pass filter.

Now suppose that F is reduced towards W. The lower frequency group moves towards zero frequency and a stage is reached when some of the sideband frequencies of the wanted signal should become negative, as shown at (i) in Fig. 4(b). The practical effect differs in the two demodulators. In the case of demodulator 1 the product is $\cos W \times \cos F$, and therefore is also a cosine. The cosine of a negative quantity is the same as the cosine of the same positive quantity (see Table I) so the negative frequency components are reflected about zero frequency, without change of sign, to become positive frequency components as shown at (ii). In demodulator 2, which is multiplying $\cos W \times \sin F$, the output is a sine; and the sine of a negative quantity is minus the sine of the same positive quantity, so in this case the reflected components must be shown as negative, as at (iii).

Finally, let F be reduced to equal W so that VCO_1 locks. In the output of demodulator 1 the lower sideband of the wanted signal folds back to reinforce the upper sideband, and both now start from zero frequency, i.e. the wanted signal is demodulated. This is shown in Fig. 4(c). The unwanted signal is modulated on to the beat frequency $(W-U)$ and its lower sideband is folded back. In the output of demodulator 2, Fig. 4(d), the sidebands of the wanted signal exactly *cancel* each other, being of opposite sign, so the wanted signal does not appear in the output of this demodulator.

Now consider the effect of multiplying (d) by the series S_1. The resulting spectrum of the output of demodulator 3 is shown at (e). First, there are sum- and difference-components centred on the frequency of the first term in the series, $2(W-U)$. We are now dealing with a sine × sine product, which is a cosine, so the part of the lowest sideband which is partially reflected about zero is reflected without change

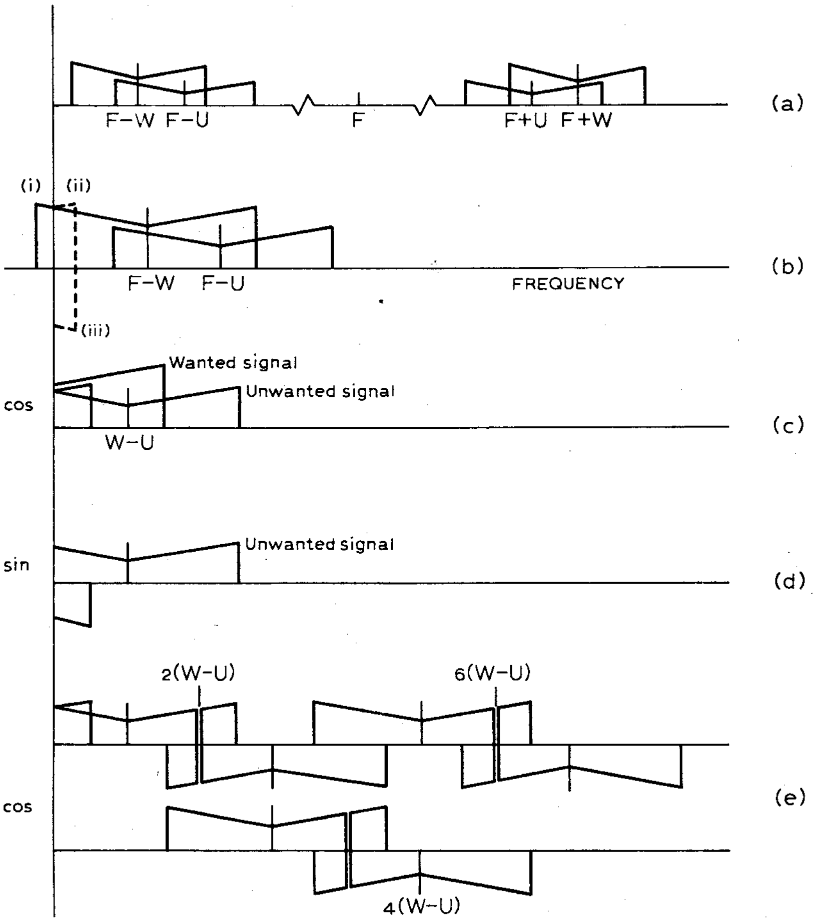


Fig. 4. (a) Result of multiplying the incoming signals by a frequency F greater than W. (b) If F is only slightly greater than W some reflection of the lower sideband occurs. (c), (d) Outputs of demodulators 1 and 2 respectively when F = W. (e) The result of multiplying (d) by the series S_1.

of sign; and the sum-frequency components have a negative sign.

For clarity, the sum- and difference-frequency components centred on the frequency of the next term, $4(W-U)$, are shown on a lower line. The diagram is drawn for the case where it is necessary to go only as far as the third term in the series, of frequency $6(W-U)$. When all the various bands are added together there is a lot of mutual cancellation; there are left only the lowest group of frequencies, which are now of the right form for subtraction from (c), and the highest group; in between there is a big gap, so that filtering out the highest group is easy.

The foregoing description makes it clear that the methods are really exploiting the fact that an a.m. signal has two symmetrical sidebands to effect mutual cancellation of unwanted signals. It is also clear that the cancellation will be less than exact if the sidebands suffer differential gain and/or phase shift in their passage through the r.f. and i.f. stages of a receiver. It is unlikely, therefore, that these methods will form a satisfactory basis for an "add-on" unit for an existing receiver, in which these aspects of performance will probably not have received much attention. It is also clear that, unfortunately, they will not work for s.s.b.!

I am very grateful to Mr L. J. Unsworth for constructing the experimental apparatus in which these ideas were tested.

References

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Space shuttle comms

The Battelle Institute say the communications industry could save millions of dollars in the 1980s if their satellites used the space transportation system of which the shuttle is a part. A NASA funded study is being carried out at Battelle's Columbus Laboratories with five satellite manufacturers to make their systems compatible with s.t.s.