Earthing, shielding and filtering problems

3—Pick-up problems in electrically-adverse environments

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Problems resulting from ineffective or insufficient grounding, shielding or filtering are not easily anticipated or understood, yet this is one of the least-taught aspects of the electronic engineer's art. Difficulties arise from components not shown on circuit diagrams, modes of operation not contemplated by the designer and, worst of all, several such modes operating at the same time. Cure of one mode may not eliminate the symptom — only when all spurious couplings are removed at the same time will correct operation occur.
This month, the problem of obtaining good performance in electrically adverse environments is considered. Here, the major effects are capacitive and electromagnetic pickup. Some precautions are so simple that they should be taken as a matter of course.

Case 6

Situation: Subassembly amplifier.

Symptom: Hum or high frequency signals, which may have been demodulated by non-linearity due to overload, appear at the output. In some cases these vary if people or non-ferrous objects move nearby.

Problem: Stray capacitance from input to other circuits or objects, or wiring acting as an antenna.

Cures: Reduce source resistance; increase source capacitance; or reduce amplifier bandwidth.

Put a grounded non-ferrous shield or box around the input circuit. The situation is very likely that of Fig. 4(b) (September) and the same cautions apply.

Ensure that there are no nearby ungrounded conductors such as spare cores in multicore cables or structural hardware.

Comments: A closely related problem is that due to stray capacitance from a supply transformer secondary to ground. Despite the existence of the usual electrostatic shield a spurious current can flow along power supply output wires, as shown in Fig. 6(a).

The principal component of C in a conventional transformer is between the inner end of the secondary and the electrostatic shield. It can therefore be minimized at near-zero cost by turning the secondary winding inside out, with one of the centre-tap points next to the shield as shown in the winding section Fig. 6(b). Alternatively, a second shield may be used, connected to the output, as in Fig. 6(c).

These precautions are usually required only if the supply frequency is high or the load at a high impedance to ground. However, if the return resistance is open circuit, in Fig. 6(a) a potential appears on the load even if it is switched off by the switch shown. This can result in damage to semiconductor devices in the load if it is then serviced with a grounded soldering iron.

In the real world completely isolated pieces of electronics such as case 6 are rare, so consider next case 7.

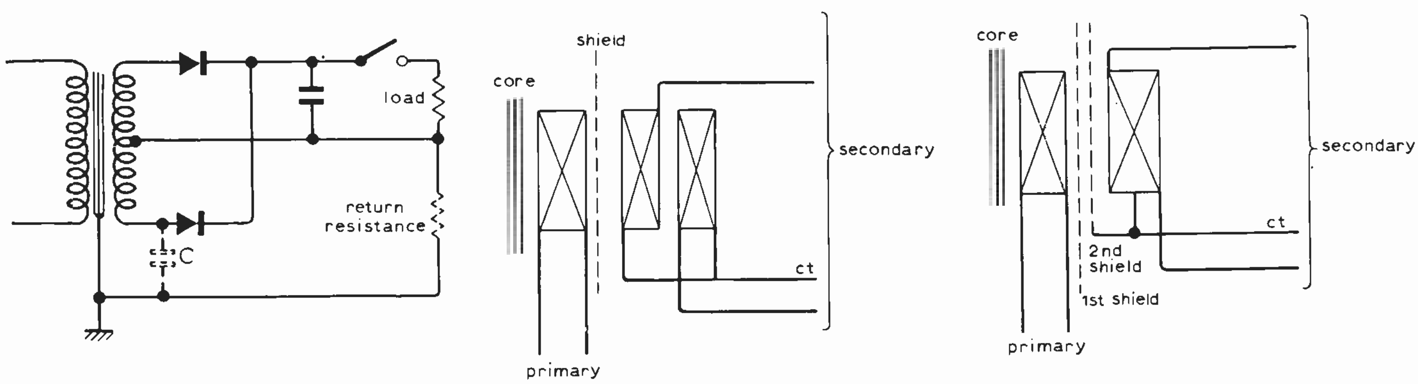
Case 7

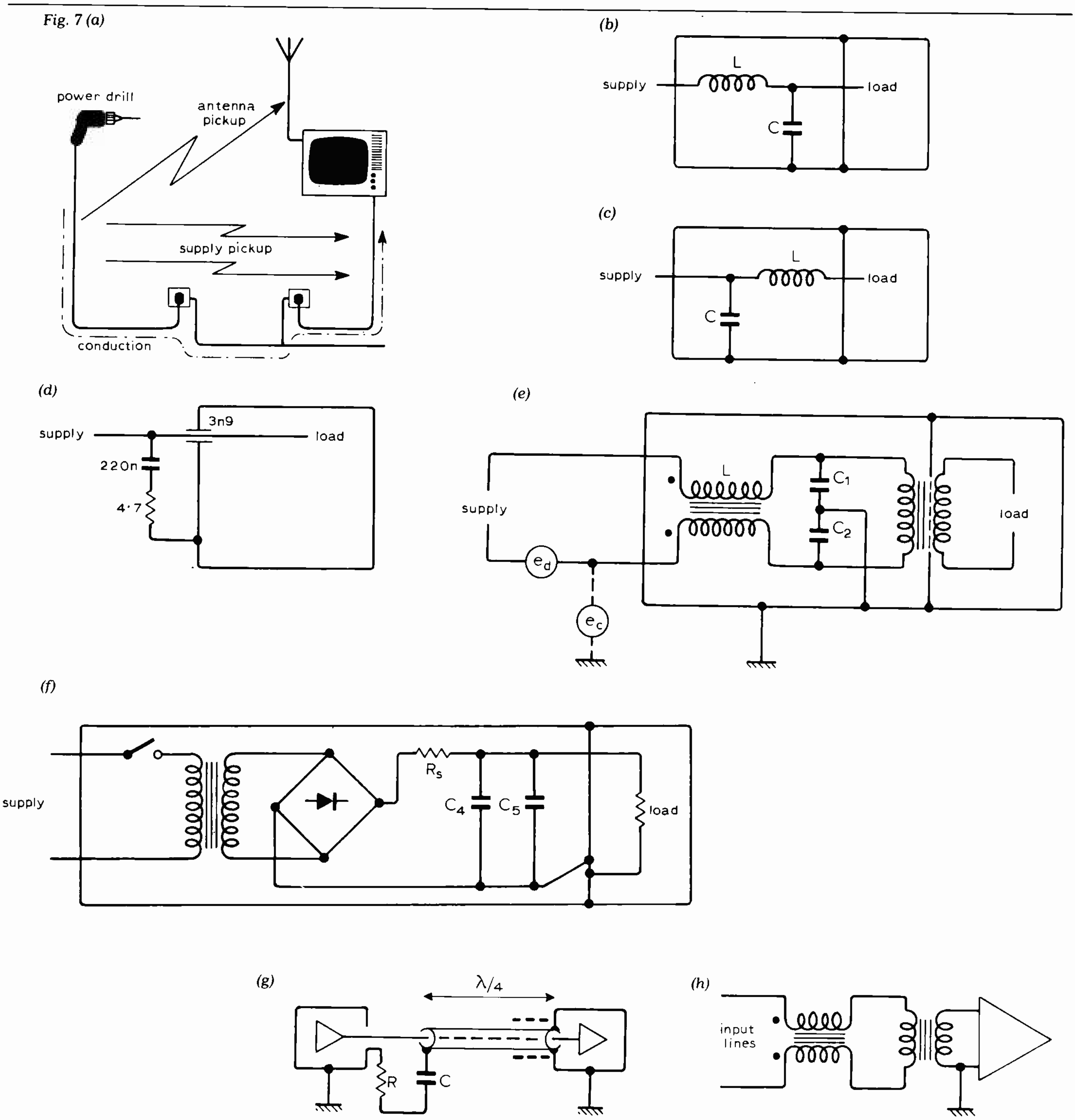
Situation: Subassembly with various cables from it.

Symptom: Switching clicks or radio frequency signals appear despite all the cures so far suggested.

Problem: Interference is conducted along cables, incoming, outgoing, or power supply and thence coupled through real or stray circuit elements into the circuit. Interference may appear on these cables by direct con-

Fig. 6 (a) (b) (c)





duction from other apparatus[5], or by pickup onto the cable acting as an antenna. Fig. 7(a) shows a typical situation.

Cures/Preamble: The working environment is usually defined by explicit specifications only in military situations[6] although maximum emission from electronic equipment is defined by a variety of national and international standards. Generally these limit conducted interference from apparatus to 1 to 6mV per 10kHz bandwidth in the h.f. range, but allow rare clicks up to 1V. The commercial radiation environment will depend on the proximity of both deliberate transmitters and unintended sources such as r.f. welders and fluorescent lamps, and in the absence of direct information can only be assumed to lie somewhere between 1mV and 100mV/metre/kHz. White noise signals increase as the square root of bandwidth, so that one hundred times greater signals will appear in a 10MHz bandwidth system. With single-frequency signals it is just the probability of their occurrence that increases. The choice of design figure requires knowledge of the working environment and of the consequences of trouble; occasional clicks in a programme of music are acceptable, but occasional corruption of a computer program is not.

Susceptibility to an r.f. interference field depends on cable length in relation to the wavelength of the interfering signal, reaching a maximum at a quarter wavelength, and thereafter fluctuating between this value and zero due to cancellation. To assess pickup, first ascertain the maximum frequency to which the system will respond, then calculate the quarter wavelength. If the cable lengths associated with the system are shorter than this, the voltage pickup will be given by *length* × *field*, and, very approximately, will be frequency independent. If the cable lengths are much longer, the pickup will be that corresponding to a quarter wavelength, and will thus increase at lower frequencies.

Actions: Shorten cables.

Output, control and power cables for example should be arranged so that they cannot couple interference into more sensitive circuits. Use isolated transformer windings and careful layout. Ensure that out-of-band signals cannot be coupled from output to input via negative feedback components. Though not strictly interference, bias voltage at the output of a magnetic tape record amplifier is such an out-of-band signal.

Filter power and control cables where they pass through the shield box wall. The design of filters for this purpose is overshadowed by the uncertainty as to terminating impedance, for this will vary with frequency and application. This results in apparently anomalous behaviour, as a shunt capacitor alone is useless as a filter element if the source impedance is zero, but effective if the source impedance is high. The reverse is true of a series element, such as an inductor, so the two should always be used in combination, as in Figs. 7(b) & (c).

Current flowing through C in Figs. 7 (b) & (c) will add to the circulating current in the ground wire and make the problem of case 3 in Part I worse. This can be avoided, though probably only at high frequencies, if the capacitor is on the load side as in Fig. 7(b). If greater series-mode attenuation is required, filters with three to six elements are used. Very low impedance to the correct ground point is essential; special capacitors are usual[7].

Resonance of the filter due to the mismatch is a problem which can be avoided by deliberately adding loss to the elements[8]. A simple example of this is encountered in the distribution of low voltage supplies to a number of separately shielded stages using feed-through capacitors for high-frequency decoupling[9]. If low-frequency decoupling is provided by a larger capacitor in parallel, its lead inductance will form a parallel resonant circuit with the feed through at some higher frequency. This can be damped by the use of a series resistor as in Fig. 7(d).

The inductor L has to carry the circuit current without saturation of its core. If the current is appreciable, then inductor bulk and cost will be appreciable too. Economies can be made where the go and return wires run together, for most interference will be common mode, that is between the wires taken together and ground as shown by the generator e_c in Fig. 7(e) Here the sense of the two identical windings on L is such that the supply current does not magnetise the core, so it can be smaller. Consequently, the inductor has no effect on the differential mode interference voltage e_d – this will be attenuated only by the supply impedance and C_1 in series with C_2. On the other hand common-mode voltage such as will predominate from radiation pickup and ground potential differences will be attentuated by L and C_1 in parallel with C_2.

Low-cost precautions: Use as filters components already required for other purposes, by careful choice of configuration and layout. For example, in Fig. 7(f) the on/off switch shares a compartment with the supply transformer so that supply wiring is well away from the load. The resistor R_s is required to limit peak diode current, and together with the transformer leakage reactance it forms the series element of a filter. The electrolytic reservoir capacitor C_4 acts as shunt element, augmented at high frequencies by the ceramic capacitor C_5.

Choose the input circuit configuration for minimum pickup. The situation is like that of Fig. 2 (August), the only difference being that the e.m.f. JK arises from a different source: the effect of C_3 is greater at high frequencies so that balanced cable becomes more desirable, and skin effect may effectively separate currents on the inside and outside of the shield so that coax acts as triax.

If the input cables are of appreciable length and particularly at those frequencies where they are an odd number of quarter-waves long, the proposal in Fig. 3(b) (August) is unsatisfactory, as the resulting resonance gives the ungrounded end of the shield a very high impedance, and consequently high potential. These resonances can be damped by loading the outside of the cable with lossy ferrite rings at the grounded end (where the shield current is highest), or by providing shunt damping at the ungrounded end, (where the voltage is highest). Both techniques are illustrated in Fig. 7(g). They have the merit of converting unwanted r.f. energy into heat, rather than reflecting it.

If the subassembly is a receiver, it will have an antenna cable which can often be balanced as in the previous paragraph, but cannot be filtered quite as easily as a power lead! Often there are electronics that can be driven into non-linearity prior to the bulk of the selective circuits. Interference then intermodulates the wanted signal, and no amount of subsequent filtering will remove it. The cure is to design carefully the distribution of gain and selectivity in a receiver, and, in particular, to avoid the use of wide-band preamplifiers[10].

As indicated in Part I (August), balanced inputs distinct from the ground connection are desirable. However, at high frequencies balance becomes increasingly difficult to maintain, and the dominant need is to minimize the common-mode potential by multiple grounding of all box and cable shields using as many parallel paths as possible to lower the reactance. In a sense this is the opposite of the low-frequency technique — changeover should be at a frequency somewhere between 50kHz and 1MHz — but both can be combined if twinaxial or triaxial cables are used as in Fig. 5(c), (September), or if a cable shield is grounded only at r.f. by a capacitor (as in Fig. 7(g) if R=0). A method of improving the r.f. performance of balanced inputs is the common-mode choke[11], already mentioned in connection with power supplies. It is only effective at high frequencies, and is usually used in conjunction with other balancing devices, that take over at low frequencies, as in Fig. 7(h).

Sometimes it is possible to eliminate interference at source, though this is usually difficult and time-consuming. The suppression of thermostat contacts or vehicle ignition systems[12] are examples of this.

Next article discusses the effects of purely magnetic pickup.

References

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Announcements

Customs and Excise have issued a VAT leaflet correcting their earlier list of electronic components attracting a VAT rate of 12½% as opposed to 8%. The substance of the change is that only plastic encapsulated Zener diodes (Section K, sub-section iv) attract the higher rate of 12½%.

BASF (UK) have moved their offices from Knightsbridge to Haddon House, 2-4 Fitzroy Street, London W1P 5AD.

CBS have ordered two automatic Tachos 12 cassette loading machines from Hayden Laboratories for CBS's Aylesbury factory. The Tachos 12 loads up to 50 cassettes at four a minute, say Hayden, and is the fastest yet developed. This is their first sale in the UK.