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OVERLOAD PROTECTION
Power limitations of the Loudspeaker/Amplifier combination

In the early days of Hi-Fi, the efforts of loudspeaker designers to achieve extended bass response with enclosures of modest dimensions were frustrated by the limitations of the low-power amplifiers then available. In the last decade, however, developments in amplifiers have made it possible to obtain much higher power ratings within a range of size and price acceptable to the domestic user, and loudspeaker manufacturers have been quick to translate this extra power into improved performance*.

With the wide-spread use of high-power amplifiers, increasing attention is being directed to the power-handling capabilities of the associated loudspeakers and of the amplifier/loudspeaker combination as a whole. As with all equipment operating at high power levels, precautions have to be taken in design and operation to protect the system from the consequence of accident or abuse, and so to ensure a high degree of reliability in service.

The power-handling capacity of a loudspeaker is limited by the onset of distortion arising from non-linear action of the moving elements, and by the possibility of mechanical or thermal damage resulting from overload. Amplifiers on the other hand are subject to damage if operated into certain types of load impedance, and may require protective devices to prevent overheating. Many of the factors that determine the power limitations of amplifiers and loudspeakers are not generally appreciated — how is it, for example, that a loudspeaker can be damaged by using an amplifier of too *low* a power rating? This issue of KEFTOPICS is therefore devoted to a general discussion of the causes and prevention of distortion and damage through overload of various kinds.

Amplifier/Loudspeaker Interface

Although a number of loudspeakers with built-in amplifiers have been produced, the majority of users at the present time still prefer to keep these two items of equipment separate, and thus interchangeable — in principle — with the products of different manufacturers. The pairing-off of amplifiers with loudspeakers however involves other factors besides power ratings and nominal impedances; to ensure satisfactory operation, consideration needs to be given to conditions at the interface.

The rated output of an amplifier refers to the power that can be delivered, with a sine wave signal, into a pure resistance load. Under these conditions, the current and voltage at the amplifier output are in phase; moreover, the current flowing through the output transistors and the voltage appearing across

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them vary throughout each cycle of the signal waveform in such a way that when the current reaches its maximum value, the voltage is at its minimum. The product of the current and voltage values co-existing at any moment represents the instantaneous power being dissipated in the output stage; the average value of this power determines the temperature to which the transistors will eventually rise, and which, if allowed to exceed a prescribed figure, will cause irreversible damage.

Excessive output current, leading to excessive temperatures, can result from over-driving the amplifier for long periods or operating with too low a value of load impedance. Transistors can also be damaged by a temporary heavy overload, caused for example by accidentally short-circuiting the amplifier output, or by transients resulting from switching other equipment on or off, pulling out plugs or dropping the pickup onto a gramophone record. It is therefore common practice to provide a protective circuit to limit the maximum instantaneous current flowing in the output stage, i.e. to clip the current waveform. To allow for the effect of different load impedances on the amount of power dissipated, the limiting value of current is made to depend on the voltage appearing across the transistors at the time, and is progressively reduced as the voltage increases.

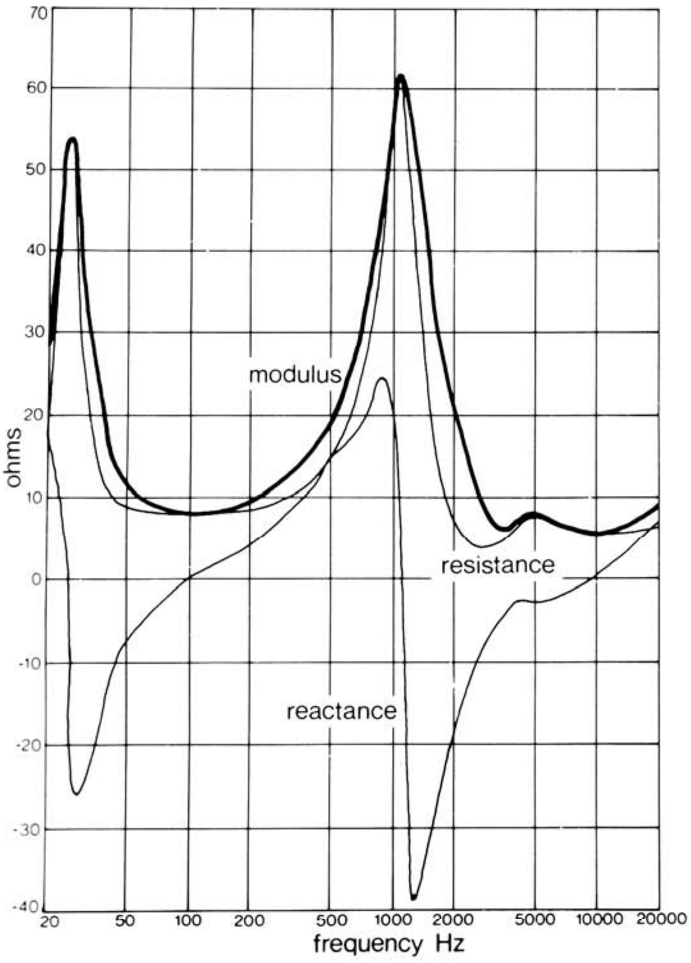

Fig. 1. *Typical impedance variation with frequency for a nominally 8 ohm two-way loudspeaker, showing resistive component, reactive component and modulus (total); in the 3 kHz region, the resistive component falls to only 3 ohms.*

The input impedance of a loudspeaker varies widely with frequency, and in some parts of its working range is largely reactive, with the result that the output current of the amplifier is not in phase with the output voltage. With a predominantly reactive load, the maximum instantaneous current through the output transistors does not occur at the moment when the voltage across them is passing through a minimum, but at some other point in the signal cycle at which the voltage is higher and the power dissipation correspondingly greater. To protect the output stage against damage by overheating with a reactive load, the current-limiting circuit must therefore come into action at a lower signal level than with a pure resistance load of the same numerical value; if, as sometimes happens, the resistive component of the loudspeaker impedance is well below the nominal value for which the amplifier is designed, distortion due to current limiting may set in before the rated output level is reached.

Published curves of loudspeaker impedance against frequency usually give only the numerical value or modulus, which does not distinguish between resistance and reactance. It is then impossible to tell whether the resistive component is too low at some part of the frequency range to allow satisfactory operation with certain types of amplifier. Preferably therefore the curves should give, not only the modulus, but the resistive and reactive components as well. Figure 1 shows the impedance of a nominally 8 ohm loudspeaker presented in this way, and illustrates the kind of danger sign to be looked for. Although the modulus of the impedance is never less than 6.4 ohms, the resistive component in the frequency range around 3kHz falls to 3 ohms, and this could lead to premature distortion through waveform clipping by the protective circuit in an amplifier.

To check whether voltage-dependent current limiting is occurring with a particular amplifier/loudspeaker combination, a gated sine wave, i.e. a tone-burst signal, can be used, the on/off time ratio being so adjusted that when the amplitude of the signal corresponds to the maximum output of the amplifier, the average power fed to the loudspeaker does not exceed the safe value for continuous operation of any of the drive units. The frequency is then swept over the working range of the loudspeaker while the voltage waveform is monitored on an oscilloscope to determine the level at which distortion sets in. As a practical example of the method, Figure 2 shows the results obtained with an amplifier rated at 75W into 8 ohms — which with a sine wave signal corresponds to 70V peak to peak. With an 8 ohm resistive load, the output waveform, reproduced in the upper curve, remained undistorted up to this voltage. When however the load resistor was replaced by the loudspeaker referred to in Figure 1, a region around 3kHz was found where severe distortion set in at only 40V peak to peak, as shown in the lower curve of Figure 2; the combination of reactance and low resistance had activated the protection circuit. To remove the distortion altogether, the signal level had to be lowered until only 20V peak to peak appeared across the loudspeaker, thus effectively reducing the amplifier power/output to 1/12th of its rated value at this frequency.

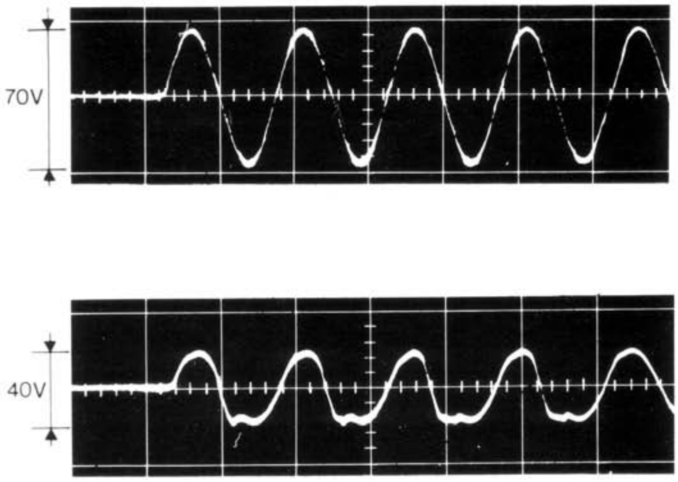

Fig. 2.
(a) *Undistorted sine-wave output, 70 volts peak to peak, produced by 75 watt amplifier with 8 ohm resistive load.*
(b) *Distorted output, 40 volts peak to peak, produced by same amplifier at 3 kHz when loaded with loudspeaker impedance shown in Figure 1; distortion caused by operation of protective circuit on abnormal load.*

Fig. 3. *Old style voice coil showing typical damage due to thermal overload.*

Loudspeaker Overloading

Excessive electrical input to a loudspeaker can lead to distortion and damage of various kinds. Immediate damage can occur if, as a result of high-level hum or low-frequency transients of the kind already referred to in connection with amplifiers, the voice coil or its connecting leads come into collision with the magnet structure — though these effects can be reduced by careful design. In the longer term, damage can result from overheating of the voice coil — a subject dealt with at length in the next section — and ultimately from mechanical fatigue.

Distortion is produced in a loudspeaker if the movement of the voice coil and diaphragm goes beyond the linear limits of the surround or suspension, so that the restoring force is no longer proportional to the displacement. Other sources of distortion are associated with the magnet system. If the voice coil is just long enough to link with all the available magnetic flux, any displacement from its rest position will progressively reduce the amount of linkage and hence the degree of electromagnetic coupling in the system. At the lower end of the frequency range, where the movement of the diaphragm and voice coil is greatest, this reduction in linkage leads to non-linear distortion. The distortion may be asymmetrical, producing a form of electromechanical rectification which tends to drive the voice coil out of the gap[1]*; in addition the cooling effect of the magnet poles is then reduced so that the coil may overheat. Another source of distortion, which is not confined to the lowest frequencies, is associated with the change in voice coil inductance with displacement[2,3,4] Variation in flux linkage with voice coil displacement can be reduced by making the winding long enough to overhang the magnet gap at both ends or, at the opposite extreme, by using a short coil moving within a long gap. Both solutions however reduce the electromagnetic efficiency, since in one case part of the coil, and in the other, part of the flux, is not fully utilised; to achieve a given electroacoustic performance, a more expensive magnet system is therefore required.

Thermal Effects

Of all forms of overloading in a loudspeaker, overheating of the voice coil presents the most difficult problems for the designer. Excessive temperature can cause softening, blistering or embrittlement of the materials and adhesives used in the winding and coil former as well as in the adjacent areas of the diaphragm and suspension, leading ultimately to mechanical failure; Figure 3 shows a voice coil that has suffered damage in this way. In recent years however the introduction of improved materials and adhesives has made it possible to operate safely at higher temperatures. As a typical example, Figure 4 illustrates a modern voice coil construction in which the coil is wound directly onto a split aluminium

Fig. 4. *An example of modern voice coil construction having a maximum safe operating temperature in excess of 250°C.*

**Displacement of the voice coil can also result from asymmetrical overloading of the amplifier, producing a d.c. component in the output current (d.c. offset).*

former, using a high-temperature epoxy adhesive; the former in turn is joined to a short spirally-wound tube of high-temperature nylon paper. The aluminium former gives good mechanical stability at high temperatures while the nylon tube isolates the diaphragm and spider from the heat generated in the coil. With this type of construction the maximum safe operating temperature is 250°C to 300°C, compared with 100°C to 130°C for the old-style coil shown in Figure 3.

In a well-designed loudspeaker, however, the maximum allowable temperature for normal operation is limited, not only by the risk of damage, but also by the loss of sensitivity resulting from the rise in voice coil resistance — which with copper wire increases at the rate of 0.4% per degree C. In a multi-way loudspeaker system, the different drive units are affected to a different extent according to the power spectrum of the programme material, causing the overall frequency response to vary with level in an unpredictable fashion. Loudspeakers have therefore to be designed so that in normal operation none of the voice coil resistances ever rises so far as to degrade the response; the risk of damage through the accidental application of abnormally high signal levels is then covered by allowing a suitable margin of safety or by providing some protective device.

The temperature-limited power-handling capacity of a loudspeaker depends on the nature of the programme signal which — in contrast to the steady sine wave used in testing and specifying amplifier power — is a mixture of components having different frequencies and varying levels. The sum of all these components gives a complex waveform in which the average power is much smaller than that of a sine-wave signal having the same peak voltage, so that when the amplifier is just overloading on peaks, the amount of power being delivered is well below its rated maximum. Since in addition the programme level is constantly fluctuating, the long-term average power is still less, to an extent that depends on the dynamic range of the signal and its statistical distribution in time. In symphonic music, the range is large and the periods of maximum level usually represent only a small proportion of the total programme time, so that the average power is low, in contrast to music of the pop or rock type in which the dynamic range is generally small and a consistently high average power is maintained. This variable relationship between peak power and average power has to be taken into account when specifying the required performance of an amplifier/loudspeaker combination, for while an amplifier is rated in terms of its peak output, the listener's judgement of loudness is associated rather with the average.

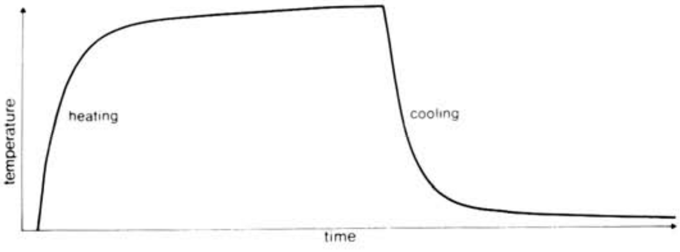

Fig. 5. *Rise and fall of voice coil temperature on application and cessation of steady signal.*

Effect of Thermal Capacity

When a voice coil is fed with a constant signal, it starts to heat up at a rate that depends on its thermal capacity, and eventually reaches a steady temperature when the heat is escaping as fast as it is generated. When the signal is removed, the temperature of the coil returns to that of its surroundings, the whole process — illustrated in Figure 5 — being analogous to the charging and discharging of a leaky capacitor.

With the intermittent or fluctuating signals that constitute normal programme material, the voice coil temperature is constantly rising and falling. However, this temperature does not follow the rapid variations in peak signal level, but rather the mean value, because the thermal inertia of the system produces a smoothing effect like that of an electrical RC circuit. The temperature rise in the voice coil depends not only on the level of the signal but also on the length of time for which it is applied. This relationship is illustrated by Figure 6, which shows how long a given signal may be fed to the voice coil of a typical high-frequency drive unit without the prescribed maximum temperature rise being exceeded. It will be seen that although the continuous power rating of the unit — in this case, for signals lasting longer than 10 seconds — is only 10 watts, an input of 100 watts for 200 milliseconds can be safely handled.

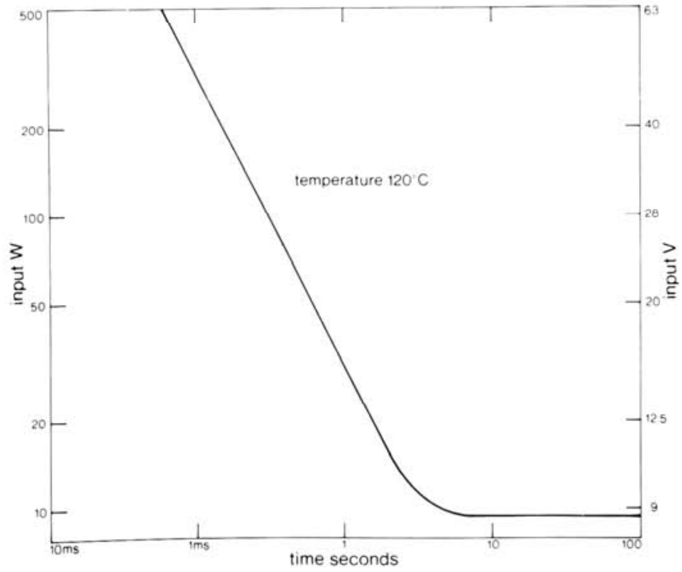

Fig. 6. *Isothermal curve for typical high-frequency drive unit, showing length of time for which a given signal level can be applied without exceeding the prescribed voice coil temperature.*

To minimise the temperature rise for a given signal, the thermal capacity of the voice coil should be high and the heat generated should be able to escape freely. The thermal capacity of the coil is directly related to the combined mass of the wire and the former; its upper limit is therefore set by considerations of frequency response, and high-frequency drive units, which must of necessity have light-weight coils, are at a disadvantage. The principal escape route for heat from the voice coil is by conduction through the air gap into the magnet structure; high-frequency units are again at a disadvantage because of the small surface area of the coil, although this is to some extent offset by the fact that the radial gap between coil and poles can be made narrower than that of a low-frequency or mid-range unit.

A recent development offers the possibility of improving the heat conduction from the voice coil to the poles by filling the intervening space with a fluid containing ferromagnetic material in colloidal form; the viscosity of this fluid also contributes some mechanical damping which may be advantageous in certain cases. The maximum continuous operating temperature of such materials is currently around 100°C to 130°C; operation at higher temperatures can cause progressive deterioration due to evaporation of the liquid base.

Attempts have also been made to improve the heat dissipation from loudspeakers by blackened cooling fins on the outside of the magnet structure. But the temperature rise of the magnet is usually so much smaller than that of the voice coil that the additional cooling has little effect on the transference of heat from one to the other. Special measures for more effective cooling of the magnet system may be advantageous in cases in which the loudspeaker is operated at maximum level for hours at a time, but such devices cannot protect the voice coil against short-term overheating.

Effect of Programme Spectrum

For the reasons given above, the high-frequency drive unit of a multi-way loudspeaker system has a lower power-handling capacity than the associated low-frequency and mid-range units, and cannot be expected to accept without damage a steady signal corresponding to the peak power rating of the system as a whole. For design purposes therefore it is necessary to consider what proportion of the programme power falls within the region above the relevant crossover frequency.

Much of the published data on programme spectra[5] relates to symphonic music only and is not applicable to pop or rock, in which the proportion of high-frequency components is increased by the use of compressors and other electronic devices*; the information is in any case based on average figures from which it is impossible to tell whether a particular set of components appeared intermittently or were so concentrated within a short period as to be potentially damaging. Modern loudspeaker designs are therefore based on practical tests, using a prototype model, in which the voice coil temperatures are measured under working conditions with a variety of traditional and contemporary programme material.

The same method is used to determine the factor of safety against accidental overload by signals having an abnormal spectral content, which can cause damage out of all proportion to their audible effect. Such signals may be generated by acoustic feedback (howl-round) from a microphone in the same room as the loudspeaker, or during rapid spooling of a tape recording with the replay head in contact; in the latter case, high-level components normally confined to the middle of the audio-frequency band are transposed, through the high tape speed, into the upper-frequency region. Another cause of potentially damaging signal abnormalities is overloading of the amplifier on peaks, resulting in clipping distortion and in some cases instability at frequencies above the audible range; the level of harmonics and oscillatory components thus generated at the upper end of the spectrum can far exceed that normally present in programme material, and the high-frequency unit is then in danger of overheating. Such a situation is most likely to arise when attempts are made to achieve a high sound level — requiring a high *average* power — with an amplifier that is incapable of delivering the corresponding value of *peak* power; paradoxical though it may seem, a loudspeaker can in fact be damaged because the associated amplifier is too small.

Specifying Power-Handling Capacity

Ideally, the amplifier power should be the maximum that can be used without damage to the loudspeaker under normal operating conditions, and the appropriate amplifier rating should be arrived at by tests with representative programme material. Such tests, to be comprehensive, must be time-consuming; suggestions have therefore been made that loudspeakers should be rated in terms of their ability to accept safely some arbitrary test signal, such as a continuous or intermittent sine-wave input at various prescribed frequencies, or a continuous random noise having a spectrum weighted to correspond with that of average programme material. To illustrate the application of such methods, Table I shows the results of an experiment in which the voice coil temperatures of the low- and high-frequency drive units in a two-way loudspeaker system were measured with various kinds of test signal and compared with the temperatures produced by typical programme material. The loudspeaker, of 8 ohms nominal impedance and rated at 80 watts (programme), was fed by an amplifier capable of delivering 100 watts of pure tone into an 8 ohm resistor. With each programme or test signal, the two voice coil temperatures were monitored by means of the thermometer system illustrated in Figure 7, which gives dial readings derived from the rise in coil resistance and simultaneously registers the results on a pair of chart recorders; the waveform at the amplifier output was also observed on a CRO. The maximum service temperatures for which the voice coils had been designed were 260°C and 120°C for the low- and high-frequency drive units respectively.

Most of the available data on the spectra of rock music[6] refers to the sound field measured in the audience area, and does not fully represent the signal appearing at the output of a disc or tape replay system.

TABLE I

INPUT	Max. Temp. °C	
	L.F. Unit	H.F. Unit
1. Music		
(a) Piano: loud solo. Amplifier just clipping	100	25
(b) Orchestra: fortissimo passage. Amplifier just clipping	150	40
(c) Pop: heavy rock with synthesiser. Amplifier just clipping	100	50
(d) Pop: heavy rock with level increased by 6dB boost at 100Hz and 10kHz, producing hard clipping	120	75
2. Test Signals		
Continuous sine wave at 28V peak to peak, corresponding to 12 watts, the signal being adjusted to give the same temperature rise in the high-frequency drive unit as the maximum reached on programme; frequency swept from 50Hz to 20kHz, slowly enough to allow steady temperatures to be reached	70	75
(b) Gated sine wave, 1:10 on/off ratio, 80V peak to peak corresponding to 100 watts during "on" period; frequency sweep as in (a)	70	75
(c) Pink noise (constant power per octave bandwidth) 8V rms. Amplifier just clipping	65	65
(d) Noise weighted to DIN Specification No. 45500 Amplifier just clipping	110	30

Comparing the results from the programme and test signals, it will be seen that the temperatures produced in the low-frequency unit by tests 2 (a), (b) and (c) were well below the maximum values reached during the musical excerpts 1 (a) to (d); test 2 (d) came nearer to simulating the effect of music, but still did not cover the worst case, namely the fortissimo orchestral passage 1 (b). In the high-frequency unit, test signals 2 (a) and (b) produced temperatures equal to the highest reached on programme, and signal 2 (c) a value approaching this; in test 2 (d), however, the temperature was less than the average for the various musical items, and far below the maximum.

This experiment illustrates the way in which the thermal demands on the individual drive units depend on the nature of the programme, and the misleading results obtained with the use of arbitrary test signals. None of the tests described would simulate the thermal effects in both units under all practical working conditions; even a combination of such tests could at best be valid only for loudspeakers of the same general type having the same crossover frequencies. From the user's point of view, therefore, there is still no more reliable guide to the power-handling capacity of a loudspeaker than the programme rating based on the manufacturer's experience with the product and representing in effect the size of amplifier with which the system may safely be used on normal material.

Overload Protection

However high the power-handling capacity of an amplifier/loudspeaker combination, the possibility of the system being overdriven to the point of damage can rarely if ever be ruled out. Most sound reproducing equipment has some amplification in hand and there is nothing to prevent it from being operated at maximum gain; moreover, experience has shown that the distortion produced by peak clipping is not always sufficiently obvious to warn the user that something is wrong. For systems operating at high power, various protective measures have therefore been devised to guard against damage through prolonged operation at excessive levels or through accidents of the kind referred to earlier.

As far as thermal damage is concerned, the most obvious solution to the problem is the use of fuses*; however, this device has to be the subject of careful design if the necessary degree of protection is to be ensured without the risk of false operation. A single fuse at the input to a two-way loudspeaker would be useless, for if it were designed to pass the maximum current allowable for the low-frequency drive unit, it could not protect the high-frequency unit, in which the same value of current would produce serious overheating; similar considerations apply, albeit to a lesser extent, to the mid-range unit of a three-way system. Any form of overload protection in a multi-way loudspeaker therefore needs to be applied to the drive units individually.

Thermal overloading depends on the length of time for which the signal is applied; ideally, each fuse should be able to withstand programme peaks or switching surges that are too short or infrequent to do any damage, but should infallibly operate if long-term heating effects bring the temperature of the associated voice coil to the maximum safe limit. These requirements can to a large extent be met by the use of specially designed delayed-action fuses. The performance of these fuses can be specified by a curve showing how the maximum value of current that they will withstand diminishes with the length of time for which it is allowed to flow; this characteristic is of similar form to the voltage/time curve of Figure 6 relating to a given maximum voice coil temperature, and optimum protection is achieved by matching the thermal characteristic of the fuse to the corresponding characteristic for the drive unit concerned. The fuses must of course be of a type known to have a high degree of consistency in manufacture.

A carefully designed fuse protection system can function extremely well, but can be rendered completely ineffective by an ignorant or careless user who replaces a blown fuse by one of the same nominal rating but of the wrong type or — worse still — by any handy conducting material, such as the metal foil from a cigarette packet. To avoid these difficulties, thermal trips i.e. miniature circuit breakers

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**Zener diodes, which limit the peak signal voltage and are sometimes used to protect electrostatic loudspeakers against damage through arcing, are not applicable to moving-coil drive units, for which the quantity to be restricted is the average power.*

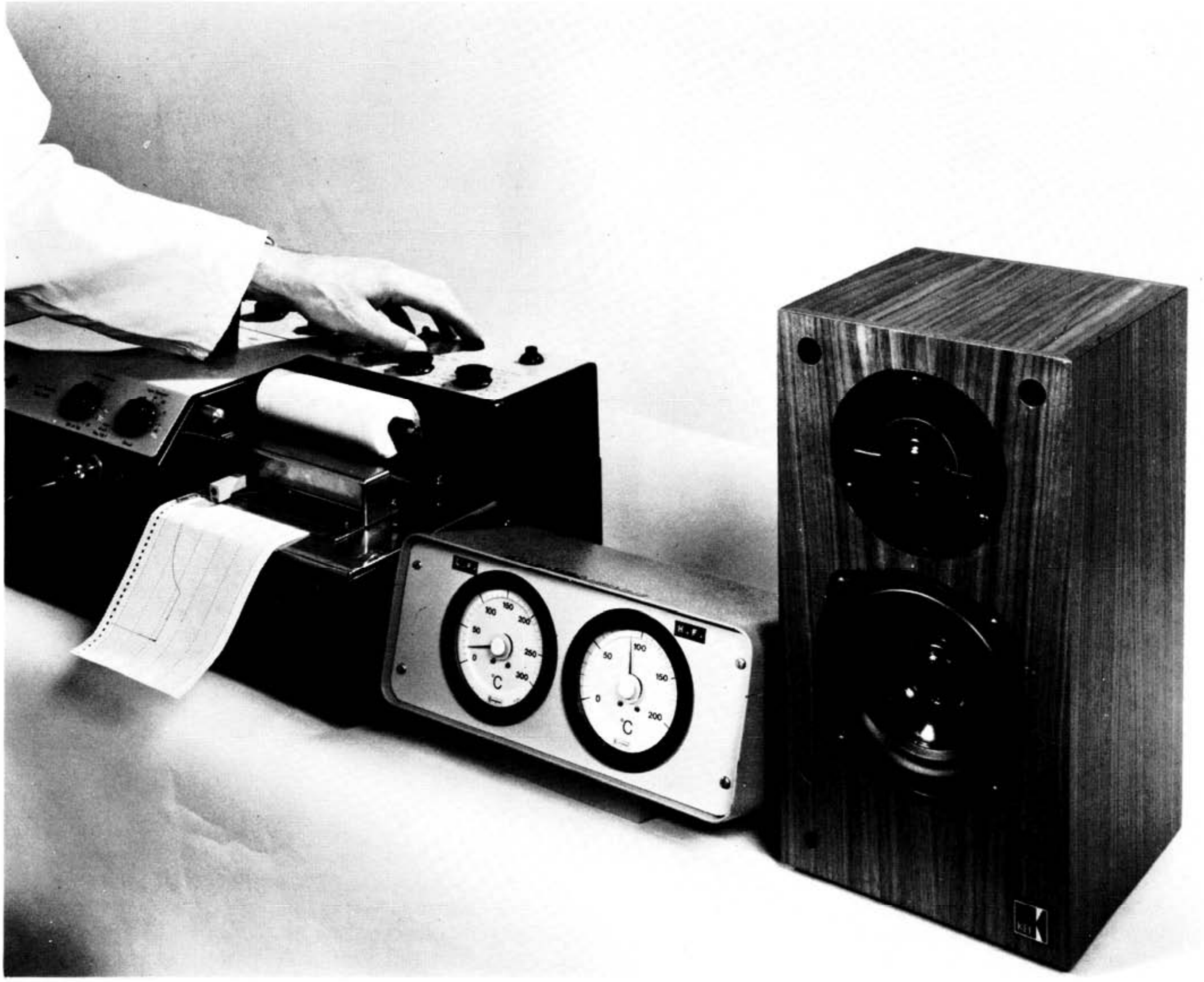


Fig. 7. *Thermometer system and chart recorder used to monitor and record voice coil temperatures of low- and high-frequency drive units fed with various signals.*

actuated by the temperature rise in a heating element, have been tried, but it is difficult to make them match the thermal time constants of the drive units without absorbing too much of the signal power. They are certainly more convenient than fuses, but have to be re-set manually.

Electronic Overload Protection

Where some increase in cost can be justified, electronic overload protection systems can be used; these are designed to monitor the temperature of each voice coil — or some other quantity proportional to this — and to interrupt or attenuate the input to the loudspeaker if the safe limit for any of the coils is in danger of being exceeded. The inconvenience of having to replace a fuse after an accident is thus avoided, and the operating point can be very accurately preset.

A device of this kind was incorporated in the KEF Model 5/1AC monitoring loudspeaker which is still in service in many recording and broadcasting studios. Figure 8(a) shows, in simplified form, the essentials of the system. The voltages applied to the high- and low-frequency drive units are sampled by a temperature sensor module. This is in effect a miniature analogue computer element, which simulates the thermal characteristics of each unit under working conditions, and by taking into account both the amplitude and duration of the incoming signals, reproduces in electrical form the rise and fall in voice coil temperature. If at any time the temperature of either voice coil exceeds the maximum permissible value, the sensing module generates a level-correction signal; this signal is applied, via a d.c. amplifier, to a voltage-controlled attenuator, which reduces the input to the power amplifiers by an amount sufficient to save the loudspeaker from damage. Normal conditions are automatically restored as soon as the voice coil temperature has returned to a safe value. In professional work, the danger of accidental overload is often greater than in domestic use; at the same time, it is particularly important to minimise any departure from normal operation. An overload indicator lamp is therefore provided to warn the user when the protection system is beginning to operate.

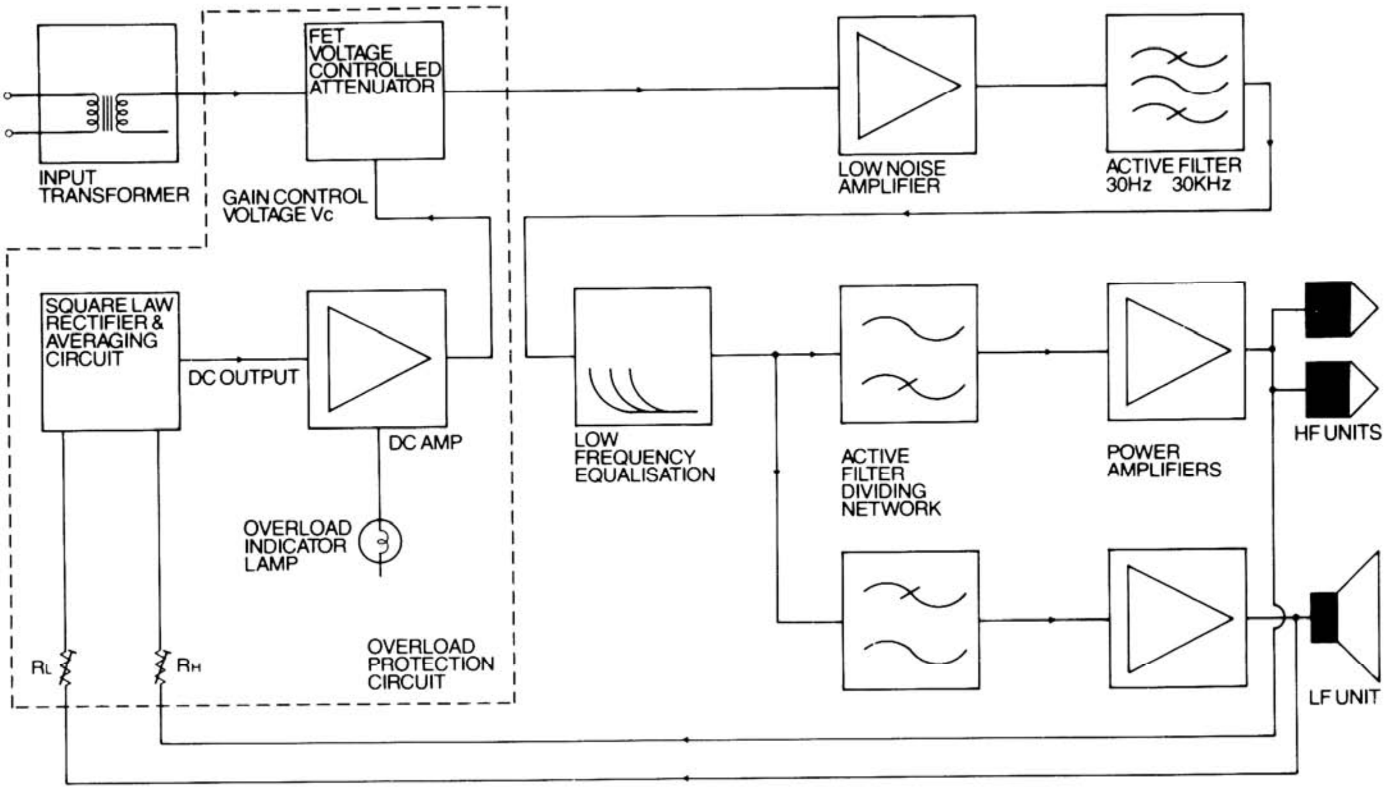


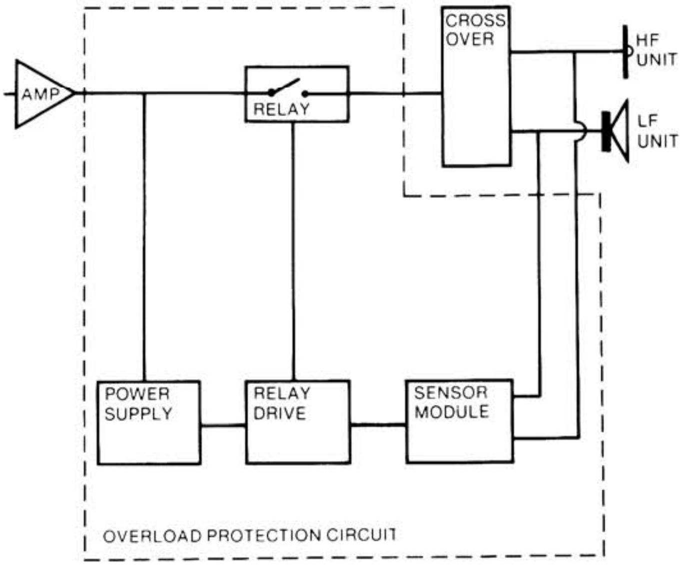
Fig. 8.
(a) *Schematic diagram of overload protection circuit used in professional studio monitoring loudspeaker KEF Model 5/1AC.*

The S-STOP System

In its original form, the system described above was too complicated and expensive for use in domestic loudspeakers; however, KEF have now developed an improved version known as the "S-STOP" (Steady State and Transient Overload Protection) which can be used in both home and professional equipment and is capable of wider application than its forerunner. In the S-STOP system, sensor modules can be designed to monitor other operating variables besides the temperature, giving protection, not only against voice coil overheating, but also against damage through other kinds of overload — excessive diaphragm movement, for example — to which a particular model might be subjected; a high degree of security from accident or abuse can thus be achieved.

Figure 8(b) shows the S-STOP system as used in the KEF Model 101 two-way loudspeaker to monitor the voice coil temperatures. Whenever the maximum permissible temperature for either drive unit is exceeded, a signal from the overload sensor module actuates a relay-controlled attenuator connected between the output of the power amplifier and the input of the loudspeaker; at the same time, visual indication of overload is given by a Light-Emitting Diode (LED). The degree of attenuation introduced is such as to protect the loudspeaker from damage, while allowing the programme to be still heard — albeit at low volume. As before, the system returns automatically to normal operation as soon as it is safe to do so. The minute amount of power required to operate the S-STOP system is derived from the incoming audio signal.

Modern developments in solid-state circuitry allow protective systems of this kind to be produced in a very compact form. Figure 9(a), for example, shows an S-STOP circuit designed for a two-way domestic loudspeaker (the Model 101 referred to above), and Figure 9(b) a corresponding device developed for a three-way studio monitoring system.



(b) *Schematic diagram of S-STOP overload protection circuit used in KEF Reference Series Model 101.*

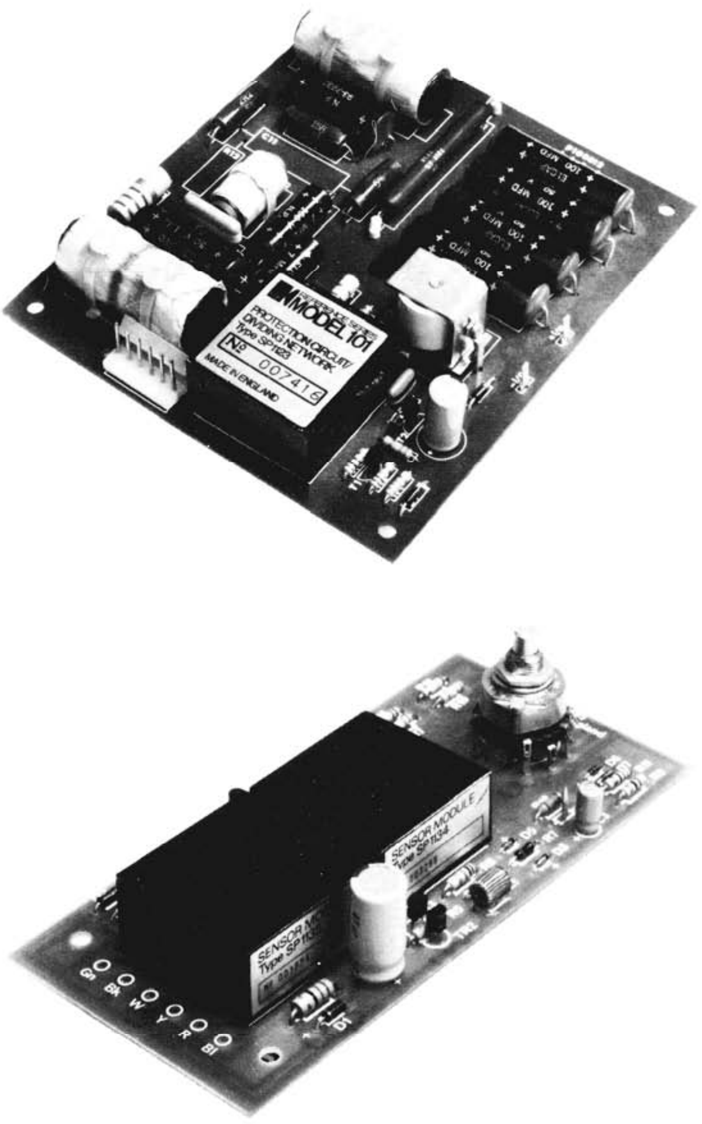


Fig. 9.
S-STOP electronic protection circuit for
(a) KEF Reference Series Model 101
(b) KEF Reference Series Model 105 Series II

Conclusion

Overloading of a loudspeaker, resulting in distortion and possibly damage, can occur in a number of different ways according to the nature of the input signal. The power-handling capacity of the system as a whole depends on the limitations of the individual drive units and the proportion of the total signal power applied to each; it also depends on the statistical relationship between the average power — which in a given environment determines the listener's impression of loudness — and the peak power — which is restricted by the characteristics of the associated amplifier.

Distortion or damage, both in amplifiers and loudspeakers, can arise from incompatibility between the two. The input impedance of some loudspeakers is such as to cause overheating of the output transistors or distortion through premature operation of current-limiting protective devices. On the other hand, the use of an amplifier of either too high or too low a power rating can cause damage to the loudspeaker — in the latter case through overheating of the high-frequency drive unit by the distortion products that result from waveform clipping.

Because of the number of variable factors involved, it has not been possible to devise a standard test signal that would simulate the most severe conditions imposed by *any* kind of programme material on *any* kind of loudspeaker. For comparative purposes therefore the best guide to power-handling capacity is the manufacturer's rating, based on the recommended amplifier power, rather than the ability of the system to withstand, for a prescribed period, some arbitrary form of input.

Loudspeakers, like other electromechanical equipment for professional or domestic use, are engineered to operate reliably under all conditions likely to be met with in normal service, making such allowance for the probability of accident or abuse as experience has shown to be necessary. Where high power levels are involved, protection against accidental damage can be provided by delayed-action fuses designed to match the thermal time constants of the individual drive units in the system. In more recent times, however, electronic protection systems have been devised which allow the safe operating conditions to be more precisely defined and the period of interruption following an accidental overload to be reduced to a minimum; reliable service is thus ensured under the most exacting conditions of professional or domestic operation.

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