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TECHNICAL INNOVATIONS AND IMPROVEMENTS IN PROFESSIONAL LOUDSPEAKERS

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1. General Introduction

The term 'electrical transducers' refers to devices that cause a transformation between electrical signals and acoustic pressure. The origin of any sound is due to the vibrations of a body that compresses and expands the springy medium in which it is immersed (in this case, the air). **See figure 1.**

The perturbation thus created is transmitted through the medium in the form of sound waves which move away from the source and strike our ears, where the sound sensation is produced with another transducing mechanism (vibration of the ear drum).

The study of sound reproduction and its technical solutions is certainly not new. The idea of the moving coil loudspeaker first appeared in 1898 (Oliver Lodge) and the first of these was constructed by Jensen-Pridham in 1913, applied to the mouth of phonograph horn.

The theoretical study of horns began in 1919, and in 1924 Hanna and Slepian published an article on the subject which remained valid for 50 years.

The idea of the bass-reflex was first proposed in 1932, and that of sound columns in 1928. The improvement of transducers over the years, and still today, is primarily related to the construction technology and materials used. Some new materials, in fact, have enabled the application of technical solutions already theorised in the past but never actually realised, including: improved magnetic materials, glues and adhesives that are more durable and resistant of high temperatures, and cone materials that are more rigid and lightweight. The consequence has been a progressive increase in power and sound pressure, following the demands of the market.

In particular, over the last few years we have seen a marked increase in the performance of amplifiers in terms of peak power and headroom, as well as the advent of digital sound sources. This means that loudspeakers are now subject to heavy mechanical stress to which, however, they must not be overly resistant to prevent false reproduction of the sound. Moreover, the introduction of electronic processors has led to a rise in the average operating level of the loudspeaker, with a consequent increase in thermal stress.

We would like to examine a number of improvements that have been made on recent loudspeakers with the aim of increasing overall quality, specifically in the terms of reliability and resistance to thermal and mechanical stress.

The characteristics of sound and the levels of amplification reached have determined a sort of natural selection on the market, and the average lifetime of the transducer has inevitably become shorter.

It should be pointed out that the sound produced by musical instruments is different from one instrument to another even when the same note is being reproduced. This is due to two facts: firstly, instruments generate different harmonics in different ratios, while the reproduction of a pure tone is very difficult (flute); and secondly, the beginning is the result of extremely rapid variations with many high frequency harmonics, and this phenomenon is called a TRANSIENT. The beginning and end of a note contribute 50% to its correct comprehension.

The most damaging distortion for the sound derives from an incorrect response to the transients, as this means a loss of information (non-coherent distortion).

If a peak is to be followed and this is done with a high time constant, the rise time varies and part of the signal is lost. **See figure 2.**

2. MOVING-COIL LOUDSPEAKERS

This type of loudspeaker not only represents the majority of the components on the market, but various construction solutions used ensure that the entire range of sound frequencies is covered.

Sound generation can be carried out by means of :
- direct radiation loudspeakers, in which the vibrating diaphragm is directly coupled with the surrounding medium;
- horn loaded speakers, in which the horn functions as an impedance transformer, presenting a different acoustic load to the vibrating diaphragm.

The vibrating diaphragm can be a cone or a dome. **See figure 3.**

Referring to **figure 4**, we will examine some of the constituent parts of the loudspeaker and describe some of the more recently developed solutions.

3. DIAPHRAGMS

The diaphragm must transmit the vibrations to the air, acting as a rigid piston; i.e. as a flat, circular, and non deformable surface. This definition indicates the ideal behaviour for a loudspeaker, in which the RADIATION IMPEDANCE Za (composed of the resistive and reactive components) occurs as shown in **figure 5**.
If acoustic power Pa is:

$$Pa \text{ prop. } Za * U^2$$

where U is the volume velocity (in cubic metres per second).
It can be seen how, in zone A. Za=Ra is constant with the frequency; thus, the acoustic power emitted is also constant.

In zone B, RA decreases with the frequency, while the reactive component Xa appears (energy storage phenomena), and the acoustic power decreases by 12 dB/octave. The loudspeaker eventually no longer emits any sound, as it does not cause air to vibrate but only compresses it (springy medium).

f1 is the point at which the wavelength of the sound is equal to the circumference of the cone. In real loudspeakers, however, we must consider a variety of phenomena.

As the frequency increases, the mass (and the inertia) of the loudspeaker gradually becomes excessive to let the loudspeaker vibrate faster and faster. Thus, the excursion gradually decreases. (To maintain the same excursion, the speed must increase, i.e. there must be more power. As the loudspeaker is driven at constant power, this is not possible). As a result, the volume velocity (and acoustic power) decrease again.

The vibrating surface of the cone, however, is gradually reduced (due to the axial flexure of the material), thus reducing the mass in motion. In addition the sound is concentrated on axis (increase of directivity), which compensates for the decrease in sound power, and thus the loudspeaker has its own frequency range.

We must also consider the phenomenon of break-up: starting at a certain frequency, the surface of the cone no longer vibrates entirely in phase, but vibration modes begin to appear and multiple zones are created which vibrate out of phase. The sound emitted is the result of multiple harmonics out of phase (irregular response and cancellations).

To overcome this problem and return to ideal conditions, very rigid materials are chosen (which may also be treated to improve damping) and a curved dome or cone shape is used. The material must not have its own resonance that accentuates certain frequencies in the sound spectrum, and must provide progressive damping of the vibrations that move from the centre outward in order to prevent reflections.

Finally, as the material has its own resonance in any case, it should be out of the useful frequency range, or at least as low as possible.

Given that:

$$fs = \frac{1}{2\pi\sqrt{MC}}$$

then the mass or compliance must be as high as possible, but we loose efficiency. This is obtained by means of surface treatments or concentric corrugation.

The basic problem is to find materials that are extremely rigid but at the same time very lightweight. We can use single components, which may be treated or impregnated, or mixing of multiple components, as well as two overlapping layers or matrix.

The most widely used material for woofer diaphragms is paper combined with various materials kevlar), with the advantage that the excellent acoustic characteristics of cellulose are not altered (dull sound, with the resonance of the material at a very low frequency).

For the midrange and driver diaphragms, a material that offers very interesting characteristics resin-impregnated carbon fibre, which is pressed at a relatively low temperature to prevent vitrification of the material and for a long time to ensure even distribution of the resin and elimination of excess resin. This process significantly lightens the material. **See figure 6.**

Carbon fibre features high rigidity, with break-up that occurs at well over 10kHz. By varying the number and diameter of the fibres, and mixing the resin with ceramic powders or other components, the weight of the diaphragm can be controlled, thus producing a extremely rigid yet lightweight component.

For example: for high frequency units of 1", a weight in the vicinity of 0.4 grams is obtained. A further improvement is achieved by creating greater homogeneity in the carbon fibre cone, which traditionally presents a succession of micro-areas of carbon and resin (as can be seen in the figure); in other words, the Young module is not uniform from point to point.

In addition, the weight of the diaphragm is in large part determined by the quantity of resin that remains in the spaces between fibres, given that carbon as raw fibre is particularly lightweight.

Samples have thus been produced using two pieces of carbon overlapped in such a way that the threads intersect and the carbon is spread into two parts previously occupied by the resin.

The pressing method, with controlled temperature and pressure, was then optimised to ensure the perfect interpenetration of the two layers without the material losing its consistency.

The result can be seen by examining the two graphs below which refer to the same 5" loudspeaker.

The sound decay is uniform, the sound is less coloured, and break-up is shifted forward. See **figure 7-8**

4. COILS

The coil consists of copper or aluminium wire wound on a cylindrical support made of rigid material. This cylinder must have a structure that is lightweight for efficiency but rigid for the transmitting the force to the diaphragm without deformation and therefore energy loss.

The formula that defines the theoretical efficiency of a loudspeaker is as follows:

$$Eff = \frac{2\pi}{C^3} x \frac{Vas * f^2 s * (B * I^2)}{M * \mathrm{Re}}$$

where RE is the resistance of the coil.

The number of turns is determined on the basis of the impedance desired and the length necessary for obtaining an adequate BL. Moreover, the length of the winding must account for how much it moves outside the magnetic flux and that is, from the resulting distortion.

In addition, the material used for the support and the construction of the coil are defined in such a way as to enable efficient heat dissipation (varying between paper, nomex, aluminium, kapton, fibreglass, etc.), which is important because excessive heat has three negative consequences:

- It modifies the dimensional characteristics of the coil (expansion) which can thus touch the walls of the air gap and eventually be destroyed.
- It limits the power that the loudspeaker can withstand (eventually burning the coil).
- It progressively reduces the sound pressure generated by the loudspeaker according to the "power compression" phenomenon.

As the temperature increases, the resistance of copper increases according to the formula

$R=R1*(1+0.004\ T)$

and thus the Re of the coil increases, causing a decrease in efficiency and in the sound power delivered.

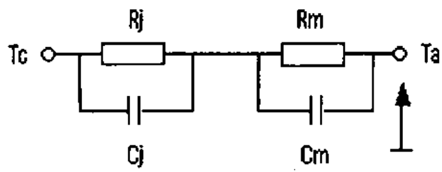
The problem of heat dissipation is especially important for woofers, for two basic reasons:

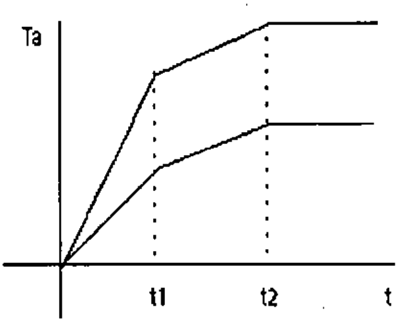
- they are the least efficient transducers, with a sensitivity of about 94-97 dB compared to the 110-117 dB of tweeters .
- the energy content of contemporary music is heavily shifted toward the low frequencies

The basic problem is to improve heat transfer from the coil to the outside through the air in the gap and the metallic parts. See figure 9.
Several types of solutions can be adopted:

- to limit the air gap in order to bring the metal parts nearer (but not too near because of the danger of coil expansion);
- to add a heatsink on the back plate;
- to introduce ferrofluid in the air gap. This substance transfers heat better than air, though it increases damping; moreover the dispersed magnetic flow is limited (less reluctance);
- to force air circulation through the air gap;
- to construct coils that provide greater dispersion.

Let's examine the thermal model of the loudspeaker, which can be defined with R and C.





Tc - Ta = Q*R*[1 - EXP (-t/M*Hs*R)]
Q heat to be dissipated (W)
Tc coil temperature

The thermal resistance of a generic material is described by the formula:

R = D/k*A   k - heat conductivity
A - area
D - length

the thermal capacity (capacity to accumulate heat)is:

C = M*Hs   M - mass
Hs - specific heat

A loudspeaker has a coil immersed in air in contact with the metal of the magnetic unit, which is in turn in contact with the surrounding air

Up to tl, the temperature trend depends on the coil and the surrounding air and, above this value, on the magnetic and basket.

The graph shows that the first part is the most significant (greater and steeper rise = more heat resistance). And thus by reducing the air-coil heat resistance, we obtain the highest gain, while the thermal resistance of the magnetic unit is secondary (the heatsink is often not so useful).

To solve the problem of the effects of heat, coils have been produced with two layers of winding positioned on the sides of the support and not one on top of the other as in traditional coils. See figure 10.

This configuration makes it possible to double the dissipation surface and thus reduce thermal resistance, with less accumulation of heat resulting in a reduction in operating temperature.

Moreover the expansion of the winding is symmetrical and there is less danger that the outermost layer will detach, as it is glued only at the points in contact with the wires.

The following table shows the results obtained:

time	standard coil temperature	inside/outside coil	
30 sec	204	150	
60 sec	225	162	
90 sec	232	166	
120 sec	236	169	
150 sec	237	170	
180 sec	238	170	
210 sec	238	171	
240 sec	240	171	
270 sec	240	171	
300 sec	241	172	-40%

5. SURROUNDS

The purpose of the suspension system which is formed by front and rear parts is to keep the loudspeaker centred by allowing only axial movement, to limit shifting by keeping it restrained, and to accumulate and return the energy of motion.

In particular, the function of the front suspensions (called surrounds) is to ensure that the loudspeaker moves only axially and to damp the vibrations that are propagated from the centre outward, to prevent reflections back toward the centre and thus non-homogeneous cone vibrations(in some loudspeakers for guitar, however these reflections make the sound more metallic and are thus desired).

In general, three categories of material are used for surrounds;
- surrounds in impregnated paper, which do not damp and are used for musical instruments (emphasis of the sound)
- surrounds in impregnated cloth, which are most highly damping (suitable for voice, hi-fi and monitor applications).

In addition to the material, the shape of the surround is also important. There are two basic considerations to be made:
- the contour of the surround must not have its own resonance, so that the frequencies in the vicinity are not emphasised. The treatments applied to the surround must not leave any points of surplus accumulation, as this varies the uniformity of the material and produces "noise".
- the coupling with the basket must permit movement without creating cutting points or sharp edges or in any case points with wide excursions, which are the most frequent cause of loudspeaker breakage.

For this purpose, a surround with exponential profile has been developed. This improves damping because the surround yields to vibrations in a variable way toward the outside. There is no point of discontinuity, i.e. where the material has sharp edges and interrupts its elastic behaviour with rigid restraints. In addition, movement is limited in the vicinity of the basket and thus mechanical stress is reduced.

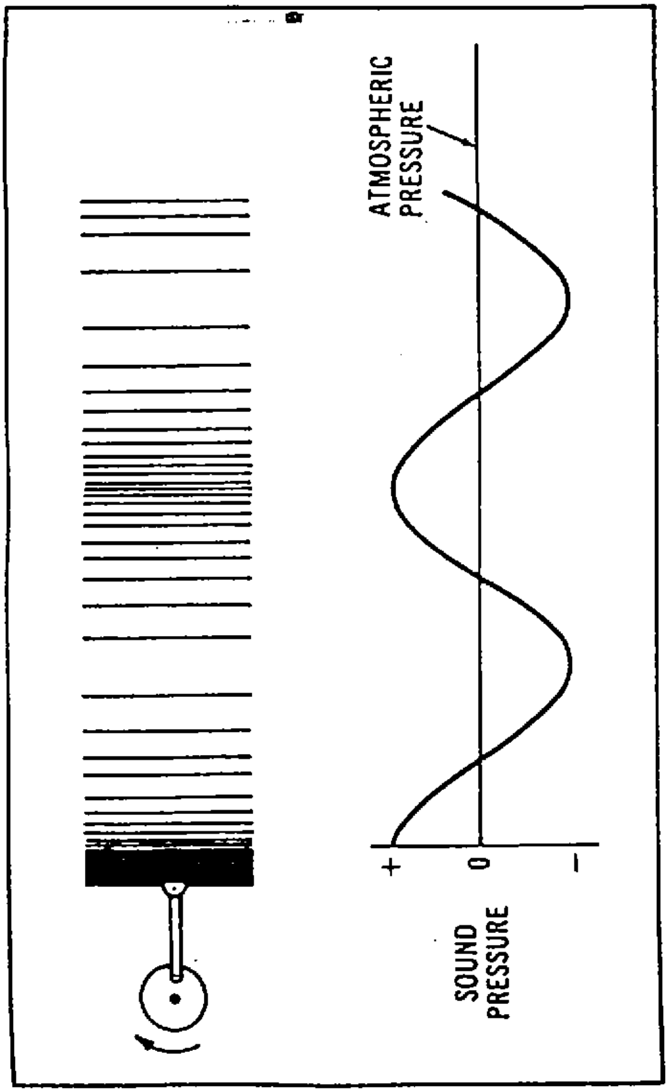


FIG. 1

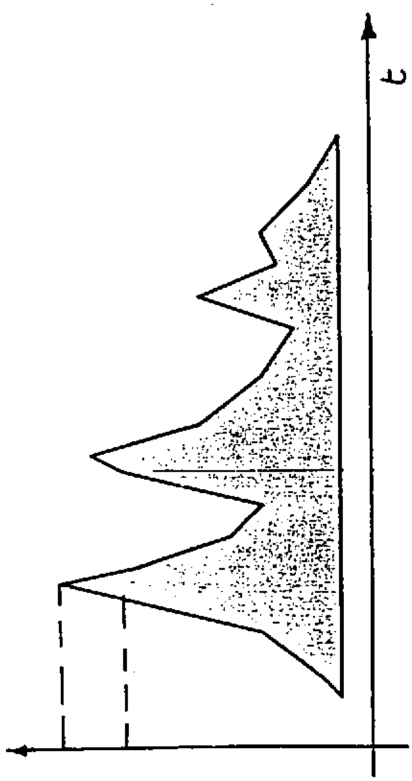


FIG. 2

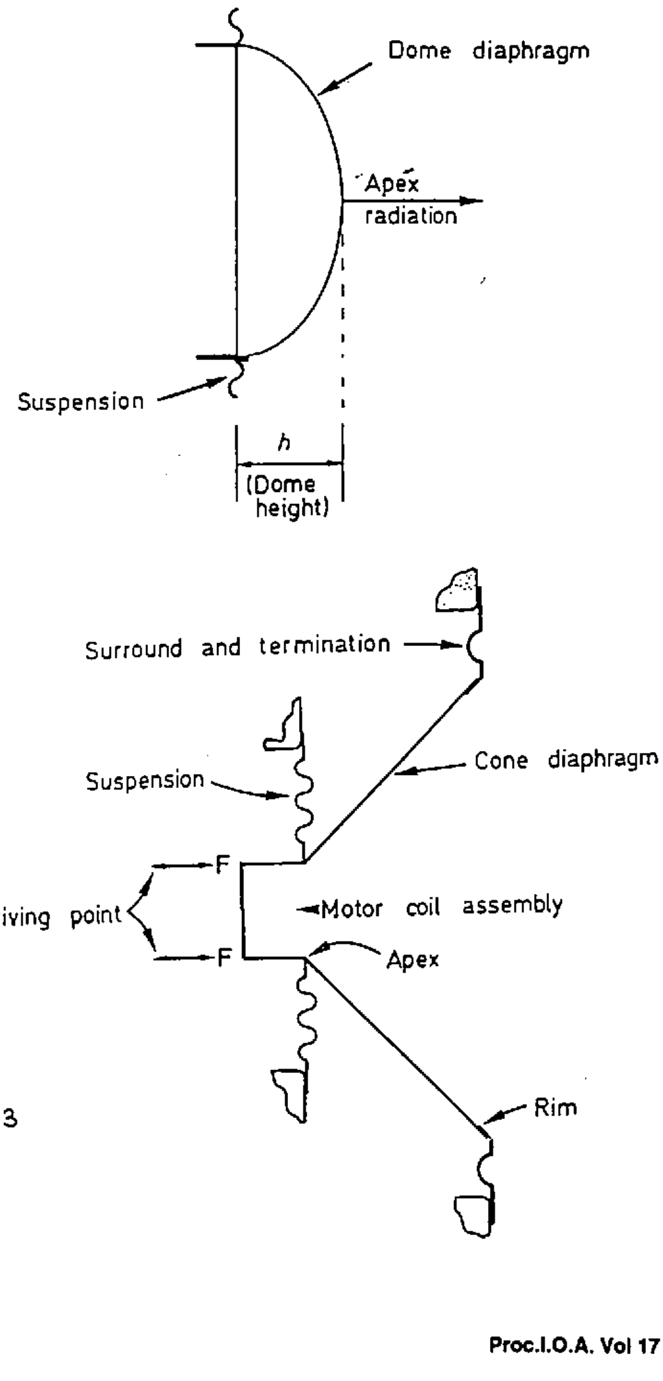
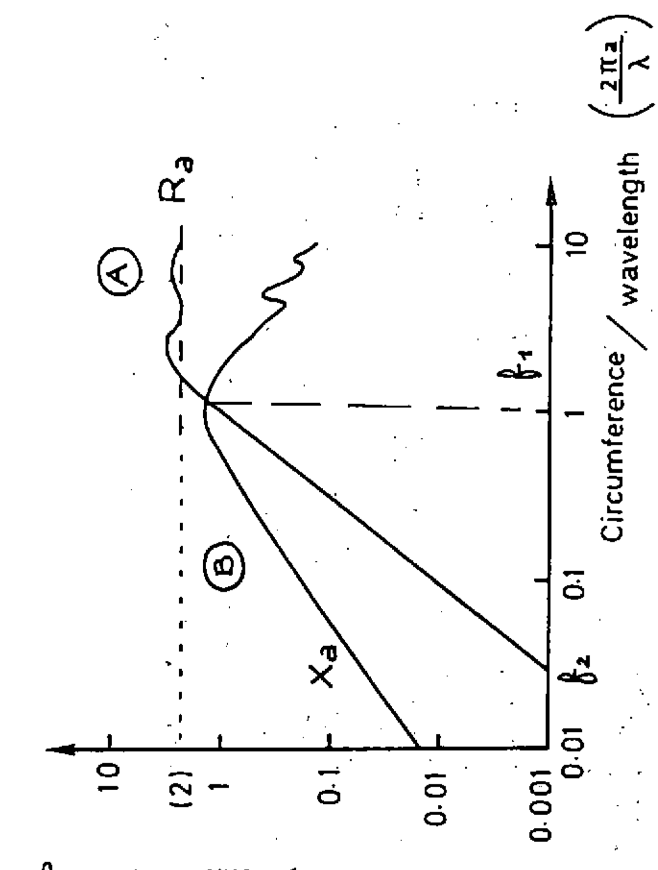

Dome diaphragm
Apex
radiation
Suspension
h
(Dome
height)
Surround and termination
Cone diaphragm
Suspension
F
Driving point
Motor coil assembly
F
Apex
Rim

FIG. 3



(Acoustic impedance / unit area) ÷ ρ0c
10
(2)
1
0.1
0.01
0.001
0.01
0.1
1
10
Circumference / wavelength (2πa / λ)
Ra
Xa
A
B
β1
β2

FIG. 5

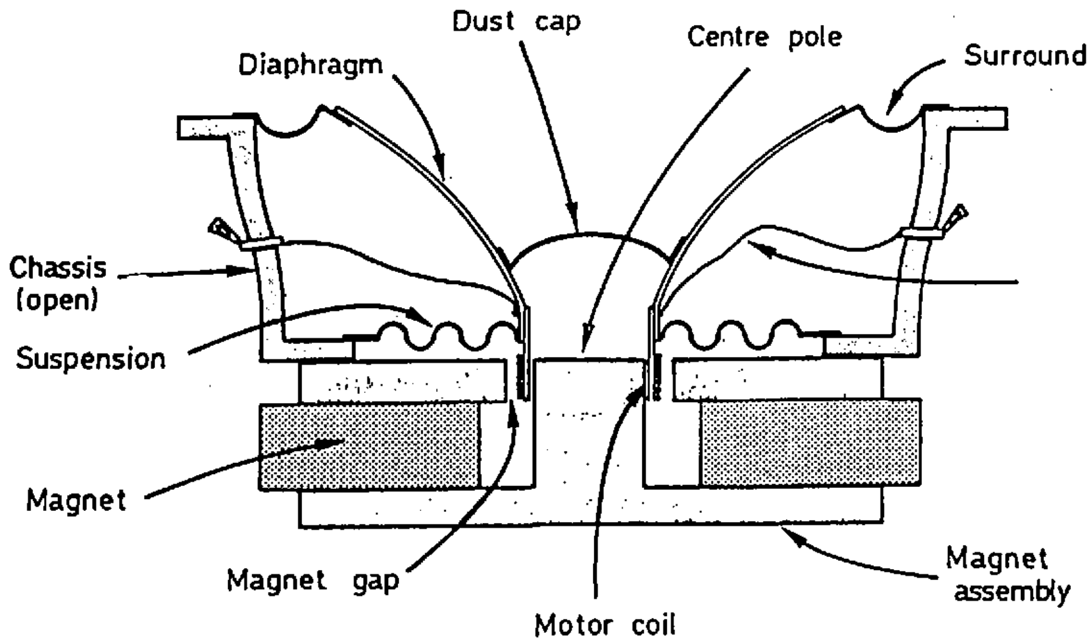

Dust cap
Centre pole
Diaphragm
Surround
Chassis
(open)
Suspension
Magnet
Magnet gap
Motor coil
Magnet
assembly

FIG. 4

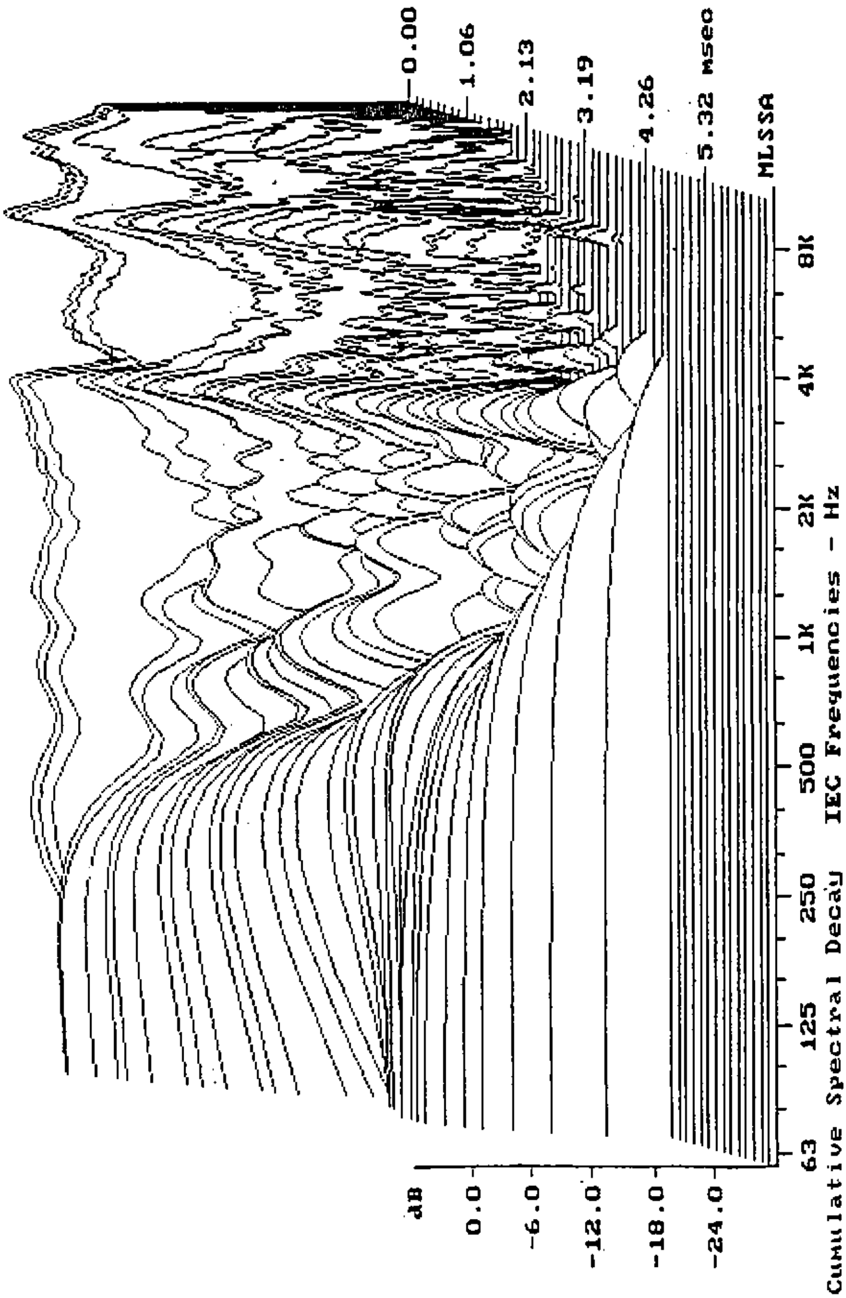
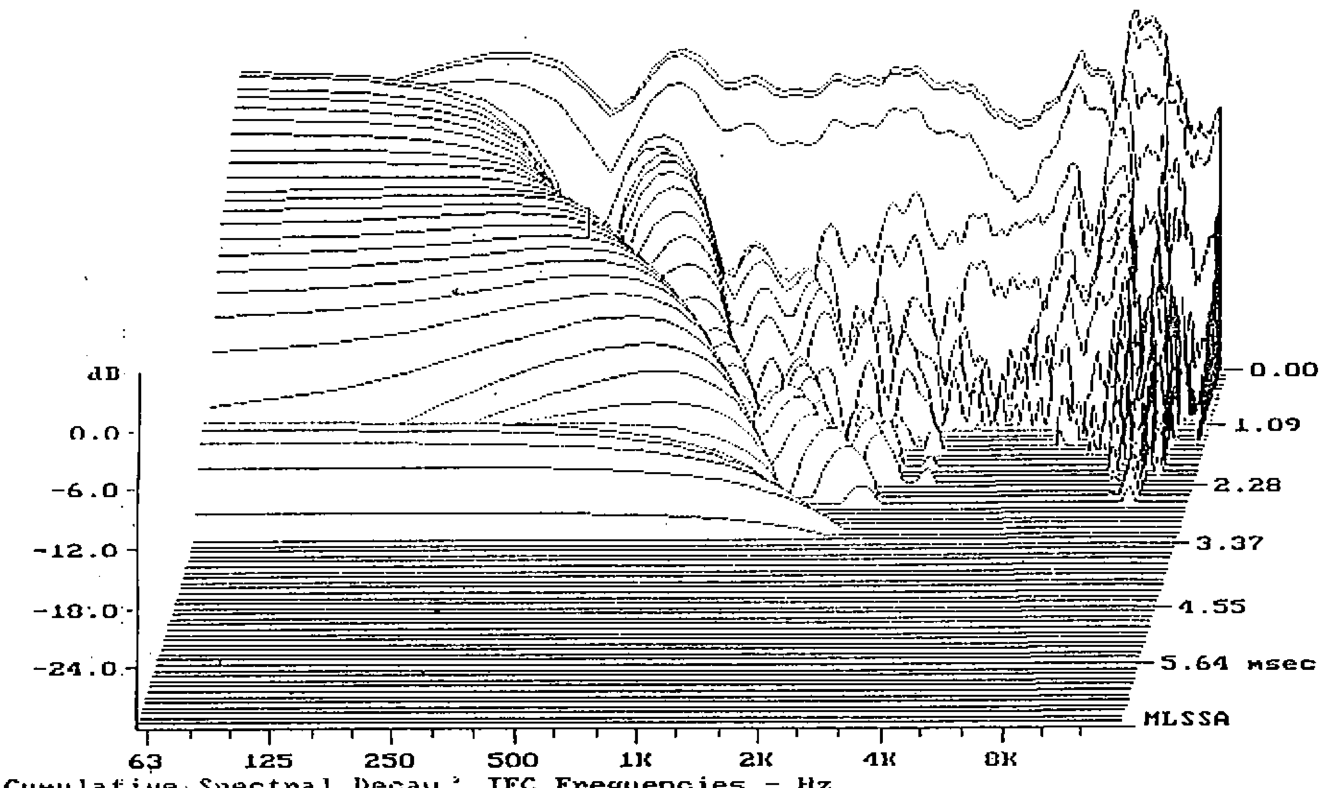

0.00
1.06
2.13
3.19
4.26
5.32 msec
MLSSA
8K
4K
2K
1K
500
250
125
63
Cumulative Spectral Decay IEC Frequencies - Hz
dB
0.0
-6.0
-12.0
-18.0
-24.0

FIG. 7



-7.11 dB, 473 Hz (8), 1.584 msec (16)

FIG. 8 cc1

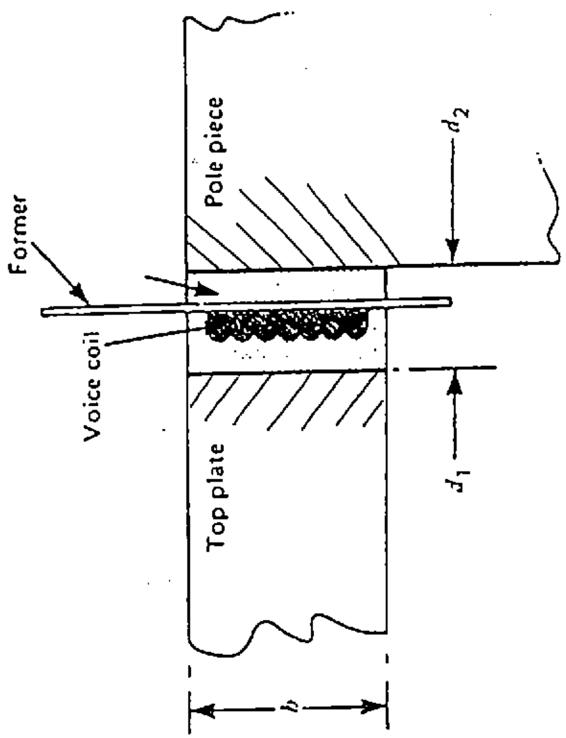
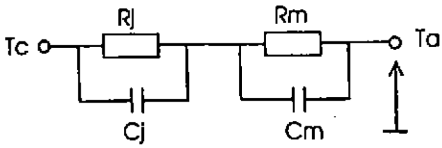
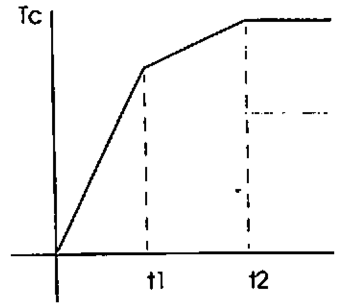


FIG. 9



$$Tc - Ta = Q^{*}R^{*}\left(1 - EXP\left(\frac{-t}{M^{*}Hs^{*}R}\right)\right)$$

Q heat to be dissipated (W)
Tc coil temperature



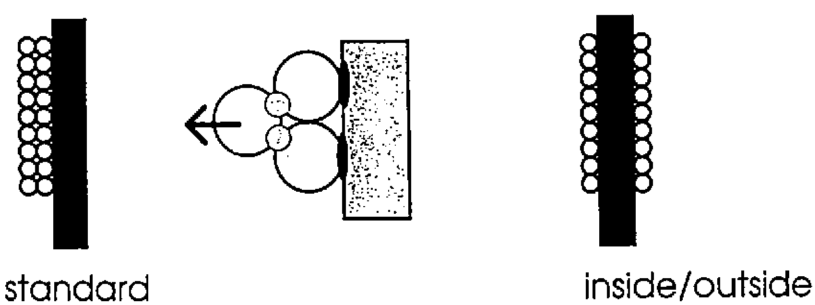


FIG. 10