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SOUND LEVEL LIMITERS FOR HEADPHONES

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1. INTRODUCTION

In the domestic environment headphones are a very convenient method of listening to reproduced sound. They offer a generally good sound quality with the potential of a very high sound level, without the difficulties of irate neighbours.

In the broadcasting environment these same features of good quality sound constrained to just the headphone wearer are equally desirable if not vital. However the high reproduced sound level does pose a potential health risk in that temporary or even permanent hearing damage may occur.

There are several solutions to the problem of potential hearing damage. These include the use of very inefficient headphones which cannot generate high sound levels, sound level indicators to tell the listener to turn the level down or active sound level limiting using electronic limiters. This paper focuses on the last example.

2. ACTIVE SOUND LEVEL LIMITING

Active sound level limiting implies the use of a limiting device in conjunction with a pair of headphones. In order to adequately protect the wearer's hearing this device must act to limit the sound level at the ears. One possible technique is to detect the sound level directly using a microphone placed between the ear and the headphone. The detected level can then be used to reduce as necessary the reproduced level. Whilst this is a very valuable method for collecting data concerning the sound level at a persons ear, it is neither practicable nor, thankfully, necessary in every day use.

All headphones require an electrical signal to generate a sound. The reproduced sound characteristics (ie. pitch, level etc.) are directly related to the electrical signal by the headphone transfer function. This function is sufficiently linear, up to the power handling limit of the headphones, that the electrical signal can be used as a measure of the sound level at the ear.

Having recognised that the electrical drive to a headphone may be used to determine the reproduced sound level it is then possible to use an all electronic device to limit the sound level. All that is necessary is to sense and as required, reduce the level of the electrical signal. The device then need only be programmed with the headphone transfer function and the required sound level to act as a protective limiter. The programming, as will be shown, turns out to be quite simple.

3. NOISE AT WORK REGULATIONS [1]

The Noise at Work regulations stipulate two sound limits to ensure adequate hearing protection. These are:

i) a peak sound pressure limit of 200 pascals (ie. 140 dB with respect to 2 micropascals).

ii) a daily personal noise exposure (L_{EP},d) of not greater than 85 dB(A).

Where headphones are used the BBC, as a mater of policy, applies lower limits than those mentioned above.

4. HEADPHONE SPL MEASUREMENTS

The Noise at Work regulations give a permitted sound exposure specified in terms of A-weighted SPL (Sound Pressure Level) at the operator's head measured in the absence of the operator. Whilst being an easy measurement to perform this approach is not directly applicable to a headphone where the 'operator's' head and ears form a part of the sound reproduction system.

Measurements of the sound level between the pina and headphone cup have been performed, and transfer functions [2],[3],[4] and [5] have been developed to translate the measured level into the equivalent diffuse field level. This technique whilst probably being the most accurate relies on the use of an expensive KEMAR manikin fitted with Zwislocki ear-canal simulators.

A more simple system in use at the BBC is the flat-plate jig shown in cross section in figure 1. Work within the BBC [6]

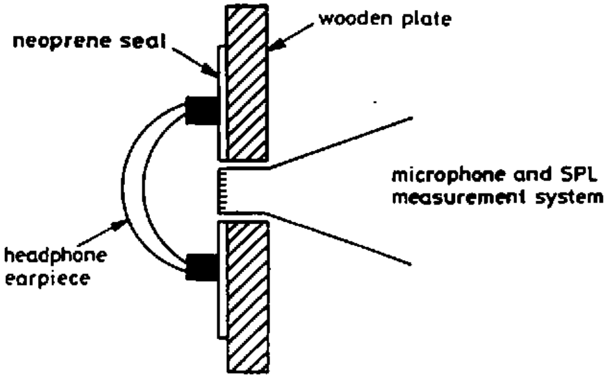

Figure 1

has shown this to have a transfer function which compensates for the measurements not being diffuse field. In addition the jig gives high SPL readings and thus, we believe, is inherently safe.

5. A PRACTICAL LIMITER

Before going on to look at practical limiters it is first necessary to state the practical constraints on the design. The chief features are:

* device to be small
* lightweight
* self powered, no batteries or power supply
* controlled minimum impedance
* adjustable to suit a range of headphones
* less sensitive to low frequencies
* considered as a part of the headphone

Because of the two constraints placed upon sound levels by the Noise at Work regulations any practical limiter is most easily implemented in two sections as shown in figure 2.

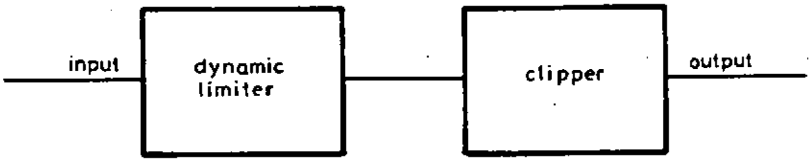

Figure 2

The dynamic limiter is responsible for the day-to-day level reduction. The clipper is present to trap fast transients which may otherwise exceed the peak limit.

Dynamic limiting may be performed using either of the circuit topologies shown in figure 3.

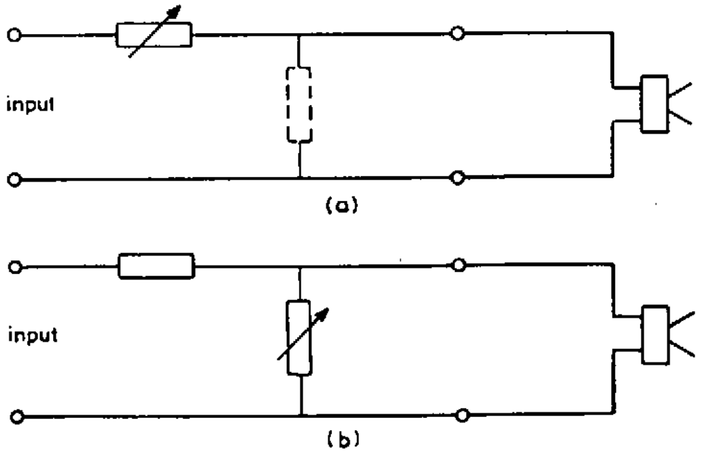

Figure 3

Both topologies use a variable impedance element which changes its value in response to a control signal. This control signal has to be derived from the input and hence most naturally creates a rising control signal with rising input level. The control chain is not shown for clarity.

The topology of figure 3a), above the limiting threshold, exhibits a rising impedance at the input in response to a rising level. This acts not only to limit the signal level at the headphone but also leads to reduced power dissipation in the limiter and ensures a minimum impedance no lower than the headphone impedance. However most active electronic devices have a falling impedance with a rising control signal and hence require a battery to be usable within this circuit arrangement. This has so far ruled out the use of this arrangement within the BBC.

The topology of 3b) is much better suited to the currently available technology and three limiters have been developed to date. Two of these limiters cover low impedance headphones at different sensitivities and the third covers the high impedance ranges.

The major drawback of this topology is with the low impedance versions. These suffer high power dissipation at limiting. To overcome this problem positive temperature coefficient devices are used as the series element together with power devices as the shunt element, where dissipation is a problem.

Control of the shunt element is performed by a side chain. This performs the same functions for all three limiters and is shown schematic form in figure 4.

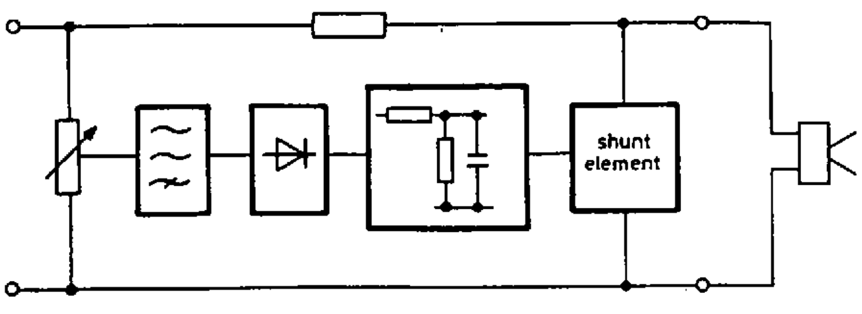

Figure 4

The three centre blocks in figure 4, the filter, rectifier and attack/decay network form the heart of the side chain. The filter is a high pass first order network which reduces the sensitivity of the limiter to low frequencies. The 3dB frequency is placed in the range 450 Hz to 850 Hz. This conforms approximately to the reduction in sensitvity of the human hearing at low frequencies.

The attack/decay network sets the dynamic characteristics of the limiter. The attack time is the critical figure. If it is too short, typically less than 3 ms, the action of the limiter causes loud clicks as it functions. If on the other hand the attack time is too long (greater than 100 ms) the limiter allows through loud bursts of sound prior to limiting which may cause hearing damage over a period of time. The decay constant is set reasonably long, typically 1 second, to avoid excessive pumping of the audio signal.

To cope with modern very sensitive low impedance headphones the side chain has been modified by the inclusion of a step-up audio transformer before the high pass filter. This sets a much lower minimum threshold of limiting of around 50 mVrms. In addition power MOSFETs are used as the shunt element. These are used as a variable impedance, which means this third limiter acts to compress the sound rather than simply chop the level down by a scaling factor. The other two designs act in the later manner with a minimum threshold of 2 Vrms.

Clipping of excessive peaks is performed at the output of the limiter. For the high impedance design, where the circuit current is low, zener diodes are used to catch the peaks at the output. In the low impedance designs a diode network is used to by-pass the side chain and to turn on the shunt element directly.

To enable the limiters to be used with a range of headphones, it was found to be necessary to pad the output of the limiter with resistance and hence reduce the apparent sensitivity of the headphone earpiece. To this end a resistor ladder is provided at the limiter output which is brought into circuit by cutting links which normally short out the sections.

Once proven, all the limiter designs have been manufactured as a thick film hybrid. This has ensured that all the limiters are small, the largest being 54.0 mm by 14.5 mm. The heaviest limiter is less than 15 grams in weight. All three limiters are packaged in a tough moulded plastic case for protection, with strain relief grommets and cable clamps as part of the packaging.

6. LIMITER SETUP

The limiter is setup by attaching the headphone to the flat plate jig. The headphone limiter combination is then fed with pink noise and the acoustic output level measured on the jig. The limiting level is set by adjusting the potential divider shown at the left of figure 4. For two of the limiters this is a resistor chain with links. The links are cut to set the potential divider to give the nearest lower limit level to that required. For the high sensitivity limiter the level is set using a trim potentiometer. If found to be necessary the headphone sensitivity can be padded down using the output attenuator.

The limiting level required is determined by the anticipated use of the headphone and varies from department to department within the BBC. However the limiter design has assumed a minimum limiting level of 85 dB(A). All the limiters can comfortably meet this figure.

Because of the use of the flat plate jig and a noise source to set the limit level it can be seen that the limiter need not be programmed with the exact headphone transfer characteristic. This greatly simplifies the design of the limiter and its consequential setup.

7. SUMMARY

To date three limiters have been developed for hearing protection when using headphones. All three types of limiter have been in use within the BBC for some time, two for about 6 years and the third for 4 months. All the limiters have been shown to give good hearing protection under constant level and high peak level conditions.

8. ACKNOWLEDGMENTS

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