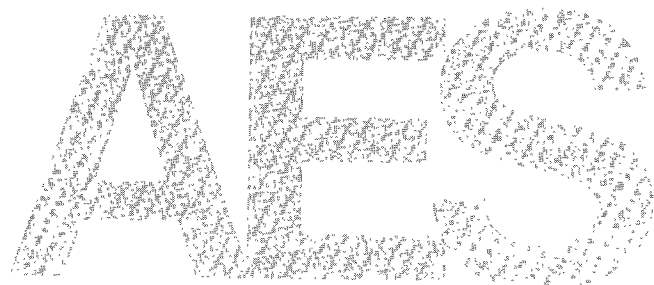


CCIR/ARM: A PRACTICAL NOISE MEASUREMENT METHOD

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CCIR/ARM: A PRACTICAL NOISE MEASUREMENT METHOD

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In 1972 Dolby Laboratories investigated techniques for measuring noise in professional and consumer audio equipment. We needed a method giving agreement with subjective assessments for use within the company and for exchanging information with outside organizations such as licensees. Our study revealed that existing methods were unsatisfactory but that the use of the CCIR weighting characteristic with unity gain at 2 kHz in conjunction with an average-responding meter (ordinary millivoltmeter) gave appropriate results. Practical details, circuitry, and applications are discussed.

1. Introduction

Historically there has been little practical standardization in the measurement and presentation of signal-to-noise ratios in professional and consumer audio equipment. The reason is that the simple methods (unweighted, NAB A-weighted) do not produce meaningful results, so that their use is avoided by critical workers. On the other hand, the more sophisticated methods (DIN 45405, CCIR 468-1) are expensive to implement, thus restricting their application to broadcast organizations and the like.

Working in both the professional and consumer audio environments, we at Dolby Laboratories were concerned for some years by this confusion in noise measurements. In 1972 we decided to review the whole question. A method was needed which would be suitable both for the company's internal engineering investigations and for exchanging test results with outside organizations such as customers and licensees. The need was for a method of measuring and comparing normally encountered noises in professional and consumer audio systems -- especially amplifier noise, tape noise, and FM noise. We felt that, as a practical matter, such a method and the equipment to implement it could come about only if several conditions were fulfilled:

- a) To be purchased, it must be inexpensive.
- b) To be technically useful, it must give relative numbers which correlate well with subjective noise comparisons made under real listening conditions.
- c) To be commercially acceptable, it must yield absolute numbers which are familiar sounding (e.g. it would not be acceptable to have a method which gives a dynamic range of 50 dB for a professional tape recorder).

Only if these conditions are met does any method stand a chance of being accepted and used widely, regardless of the degree of official standardization.

Generally, a noise measuring system comprises three parts: a weighting filter, a metering system, and a definition of the absolute dB number scale. First, therefore, we investigated weighting networks and concluded that the CCIR noise weighting characteristic, on which a considerable amount of work had already been done by others, was the best available one to use from the point of view of obtaining comparative results which are numerically

correlated with the effects noticeable under actual listening conditions. However, the complete CCIR noise measurement system was originally devised for broadcast use, in which the noises to be measured are sometimes impulsive; the resulting complex metering requirements place a heavy cost penalty on users who are not normally concerned with impulsive noises.

To overcome the metering cost problem, we made tests to see whether an ordinary AC millivoltmeter could be used in conjunction with the CCIR filter network. These tests confirmed that for normal non-impulsive noises the results were as desired, namely numbers which agreed with the audible effect.

Next it was necessary to establish an absolute number scale such that the method would give results which would be commercially acceptable. This was done by setting the frequency at which the weighting filter has a gain of unity at 2 kHz. Typically this gives an answer about the same as the unweighted number. A 1 kHz unity-gain frequency produces a result about 6 dB worse than the unweighted figure; such a measuring system might be of use in pure research, but it would not be accepted by the others involved -- equipment manufacturers, tape manufacturers, dealers, and consumers.

We decided to call the resulting noise measurement system CCIR/ARM, in order to distinguish it from other CCIR practices. ARM refers to Average Responding Meter, the property of an ordinary AC millivoltmeter, and, in this context, to the 2 kHz reference frequency used for the weighting filter.

2. Existing Noise Measuring Methods

First we reviewed the available noise measuring methods and the extent to which they satisfied the necessary conditions for success described previously.

a) Unweighted

Unweighted measurements are useful as a means of comparing different noise levels only when it is certain that the spectra of the noises are identical and the bandwidths within which the measurements are made are identical. Since neither of these conditions is met in general, unweighted measurements are essentially useless, except as a very rough indicator.

b) A-weighted (NAB)

A-weighting (1), also adopted by the NAB, is based on the inverse of early measurements (Fletcher-Munson) of the ear's sensitivity at the fairly low sound pressure level of 30 phons. This characteristic, shown in Fig. 1, does not correspond closely to the ear's sensitivity at the acoustic level of the noise normally encountered during high quality sound reproduction; neither does it take into account that the annoyance of a noise in the presence of wanted sounds does not necessarily correlate accurately with the audibility of the noise in the absence of signal. For example, the high frequency hiss of low speed tape recording is much more obtrusive than A-weighted measurements would imply.

A-weighting in conjunction with an rms meter (or frequently, without thought to the written standards, an average-responding meter) has been used fairly widely in the specification of professional studio equipment, but very rarely at the time of the investigation in the consumer field. In comparing noises of such different spectra, A-weighting gives poor correlation with subjective impressions, particularly when some of the noises have a preponderance of high frequencies.

c) DIN 45405 method

At the time of the study (1972) the DIN 45405 method (2), now officially obsolete, was in common use in Germany for specifying consumer equipment performance. There was much confusion over the specified meter, an elaborate quasi-peak indicating instrument whose characteristics permitted the assessment of impulsive noise as well as random broad spectrum noise. Not infrequently, equipment specifications were quoted as DIN 45405 even though the measurements had been made with the DIN filter and an rms or average-responding meter, such results being optimistic by roughly 6 dB. The weighting curve itself, developed in the 1940's, was originally designed for use in communications systems having sharp cutoff properties; it therefore contained a very sharp 9 kHz low-pass characteristic (see Fig. 1). However, DIN-weighting took into account not only the audibility but also the obtrusiveness of noise; it therefore gave good correlation between subjective impressions and measurement provided the noise did not contain much energy above 8 kHz or so. Unfortunately today's professional and consumer equipment produces irritating noise at very high audible frequencies.

The DIN 45405 method did not achieve widespread usage because the numbers yielded were unappealing (some 6 - 8 dB worse than unweighted) and also because of the high cost of the complex meter required. For many years it was available from only one manufacturer (Sennheiser).

Subsequently a further DIN standard has been introduced to bring the DIN noise measurement method into line with the IEC standard (A-weighting with rms meter); this seems unfortunate in light of the technical inadequacies of A-weighting in comparison with old DIN weighting.

d) CCIR

At the time of our investigation in 1972, it happened that the whole subject of noise measurement in audio equipment was under review by the CCIR. The evidence presented in study program 2A/10 (3) included the results of measurements using various techniques on different kinds of noise in comparison with their obtrusiveness. This information led to a fairly clear-cut optimum system, that which the CCIR subsequently adopted unanimously (Recommendation 468-1). This system is very satisfactory technically and for research purposes but retains the other disadvantages of the DIN 45405 method; it uses the same expensive quasi-peak instrument and gives figures apparently inferior to those being published in the specifications of audio products (by 10 or 12 dB). The CCIR was of course trying to standardize on a technique applicable not primarily to commercial audio equipment but to broadcasting, including landlines and multiplex carrier systems. The method therefore had to give accurate results on impulsive noises, distorted crosstalk, dialing clicks, whistles, etc., and required the quasi-peak meter to do so.

e) Conclusions

Thus our 1972 review of the available methods showed that none of them fulfilled our requirements for a practical system. Both DIN and CCIR weighting essentially met the technical requirement of correlation with subjective assessment but notably failed the other conditions, being expensive and giving answers which sounded commercially disastrous in comparison with unweighted ones.

3. CCIR/ARM Method

In choosing a method which we felt would be workable, we decided to start with and accept unaltered the CCIR weighting characteristic, since it had been designed for modern, wide-range audio systems, was well documented, and already had a history of acceptance by critical workers in the field.

Next it was necessary to examine the question of metering; we suspected that complex and expensive metering such as rms and combinations of peak-average or peak-rms were unnecessary for the everyday measurements of practical audio. Indeed, the CCIR evidence itself reveals that for the "smooth spectrum" noises produced by amplifiers, tape recorders and other equipment, the choice of measuring instrument is very uncritical. Our experiments of 1972 confirmed that the relative readings for different (non-impulsive) noises measured with the CCIR weighting curve of Rec. 468 using average-responding, rms, and quasi-peak meters are essentially the same. Expressing this differently, the results with one type of meter differ by a constant factor from those with a different meter. It is of course possible to construct waveforms which after passage through the CCIR filter do not conform to this observation, but such waveforms are highly artificial and do not normally occur in real life.

Table 1 reproduces some of our measurements on different noises. Clearly it is an important advantage if existing millivoltmeters can be used for making noise measurements.

Difference in meter readings in dB	Flat	50 us pre-emphasis	300 us de-emphasis	Rising 6dB/octave	Falling 6 dB/octave	300 Hz band centered on 3 kHz
Quasi-peak - average	+5.9	+6.0	+5.9	+6.1	+5.8	+5.5
Rms - average	+1.1	+1.1	+1.1	+1.2	+1.1	+1.0

Table 1 *Effect of Different Meters on Noise Measurements. All noises derived from white noise band-limited 20 Hz - 20 kHz.*

Having satisfied ourselves that an average responding meter gives consistent results with a variety of noise spectra, we then tried such metering with the CCIR curve to measure the noise in typical audio equipment. We found that the answers were in the order of 6 dB worse than unweighted results. Thus this technique, promising from the technical and economic standpoints, was still not workable, because the resulting numbers would not be acceptable to the industry and consumers alike.

We considered whether the 6 dB discrepancy could be remedied by specifying that a 6 dB compensation should be made when stating results. Unfortunately, confusion would be likely, since 6 dB would have to be subtracted from noise levels but added to signal-to-noise ratios. This approach did not seem promising.

We then looked at the possibility of changing the specified frequency at which the CCIR weighting curve has a gain of unity. In so doing, we recognized that there would be acceptance problems, since most engineers have a longstanding and deeply ingrained emotional attachment to the frequency of 1 kHz. However, there seems to be no technical reason for putting the zero gain (0 dB) point of noise weighting curves at 1 kHz. Although

1 kHz is often used as an audio reference frequency because it is in the middle of the spectrum, and therefore in a region relatively free from edge-of-band performance irregularities, a more likely reason for its popularity is graphical tidiness and drafting room convenience. According to a comment in the CCIR documents (3), the CCIR working group apparently had an inconclusive discussion on whether 1 kHz was an appropriate reference; in any event, the published graph was drawn with a 1 kHz reference. Nonetheless, many other frequencies are in use in the audio field: 315, 333, and 400 Hz in low-speed tape; 700, 850, and 1000 Hz in professional tape; 1, 1.58, 3, and 3.15 kHz in various other applications.

It is worthy of note that it is slightly undesirable from an operational standpoint for the 0 dB frequency of a noise weighting filter to be the same as the nominal frequency of the tone providing a reference level for signal-to-noise ratio measurements, since this practice leads to the possibility of feeding the reference tone through the filter. Usually the filter does not have as tight a tolerance at this frequency as at higher frequencies, and more importantly the reference tone may not have a precise frequency; since a practical noise weighting filter will have a slope in the 1 kHz area of around 6 dB/octave, an error of 10% in the reference frequency will lead to an error of 10% or roughly 1 dB in the measured signal-to-noise ratio. Hence a network with its 0 dB point at the nominal reference frequency can be misused to give answers which are inaccurate but not so dramatically as to make the error obvious. If, however, the network has a pronounced gain or loss at the reference frequency, the incorrect procedure leads to answers which are sufficiently different from the expected ones for the error to be noticed.

The various considerations discussed led to our setting the 0 dB point not at 1 kHz but at 2 kHz, thereby reducing the sensitivity by the required amount in an unambiguous way (Fig. 1). The particular shape of the CCIR curve results in a change of 5.6 dB, which brings the answers into line with typical unweighted figures.

Our resulting technique, measurement via a network with the shape of the CCIR curve and the zero gain, zero loss frequency at 2 kHz, together with an average-responding meter*, we designated CCIR/ARM.

The CCIR/ARM method could in due course be made part of a unified measurement standard. This would entail redefining the quasi-peak reading instrument required by CCIR recommendation 468-1 so that it is scaled to give an apparent sensitivity 11 dB lower; the CCIR method would then give the same answers as CCIR/ARM on the types of noise for which the latter is intended. Note that the scaling of the peak meter is arbitrary since it is only used for this noise measurement; It would then be possible, for example, to relate directly the signal-to-noise ratio of an FM tuner measured in the manufacturer's laboratory, or by a reviewer, with the signal-to-noise ratio of the land line feeding the FM transmitter, measured by the broadcasting authority using much more costly equipment.

4. A Practical Noise Weighting Filter

In measuring signal-to-noise ratios, the normal procedure is to feed a reference level signal through the equipment and measure the output level, v_1 say. Then the reference is removed, the weighting filter is added before the meter, and the weighted noise level v_2 is measured. The ratio v_1/v_2 is the required signal-to-noise ratio. Most commonly v_1 and v_2 are read off the meter in decibels (for example with respect to 0.775 or 1 V), and the signal-to-noise ratio in dB is arrived at by subtraction, a process in which it is easy to produce error -- especially if the reference v_1 is on one side of the '0' of the meter and the noise v_2 on the other.

* calibrated as such meters usually are, to read the rms value of a sine-wave.

The procedure described above bears a strong resemblance to the measurement of total harmonic distortion. Here again one measures firstly a reference level, (the fundamental), and then adds a filter (a notch at the fundamental) before measuring the signal remaining, (the distortion components). The distortion factor is the ratio of one measurement to the other. In equipment for measuring distortion it has become conventional to provide means for adjusting the meter sensitivity so that the fundamental reads at some fixed point on the meter scale, usually 100%; this is not necessary but is a great operational advantage.

It is surprising that this convenient feature has not become equally commonplace in noise measuring equipment. The output levels of consumer equipment vary widely, and to be able to make the reference tone register 0 dB on a meter greatly eases the measurement of frequency response as well as signal-to-noise ratios.

In moving from the measurement of the reference tone to that of the noise, the weighting filter has to be added. It is important, therefore, that adding the filter does not introduce unwanted changes in gain or frequency response. In particular, the loading on the equipment under test, which may not have a very low output resistance, must not change, and should be substantially independent of frequency in both the level setting and noise reading modes.

These considerations lead to the practical device shown in Fig. 2, with the block diagram of Fig. 3 (Dolby Cat. No. 98A). A rotary switch selects one of three operating modes:

- | | |
|---------------|--|
| a) Bypass | Direct connection from input to output. |
| b) Set Level | Addition of a fixed gain input buffer amplifier and a variable gain output amplifier; the two together have a gain of approximately unity, ± 6 dB, so that any input level can be made to read 0 dB on a meter which has 10 dB gain steps. |
| c) Read Noise | Addition between the input and output amplifiers of a CCIR weighting network with its 0 dB point at 2 kHz. The input and output impedances of the unit remain the same as in the set level mode. A Standard Gain mode is also provided (unity gain at 2 kHz), permitting the measurement of absolute noise levels. |

The full circuit schematic is shown in Fig. 4. The input amplifier is an emitter follower Q1 giving an input resistance of 100 k ohms in the Set Level and Read Noise modes. The CCIR filter consists of a 7-pole low-pass filter (Q2 to Q5) with a small amount of feed forward via resistor R8 to increase the attenuation in the 9 kHz area, together with a single pole high-pass filter (R27, C10). During manufacture a small adjustment of the effective value of R27 compensates for component tolerances. In the output amplifier (Q6, Q7), switch S2 is the end-stop switch on the gain adjusting potentiometer RV1. With the pot fully counterclockwise (S2 open), the overall gain in the Set Level mode is unity (Standard Gain), permitting the measurement of absolute noise levels in the Read Noise mode. With the pot turned up (S2 closed), the overall gain is adjustable over a range of approximately 12 dB, making relative measurements much more convenient. The components around RV1 are arranged so that the gain varies logarithmically with linear rotation of the potentiometer.

The power supply is a noteworthy part of the circuit. For convenience we decided to try to design so that the product would operate on virtually any AC supply from the nominal 100 V in Japan to the 240 V in some European countries. The precise voltage applied to the circuitry is uncritical, so accurate regulation was unnecessary, but fairly low ripple

was needed. Remembering that we were designing a low cost and physically small item, power supplies involving high dissipation to accommodate the large range of input voltages were unacceptable. The solution was to use a current source (Q8, Q9) feeding a zener diode ZD1, and then to employ small incandescent lamps (LP1, LP2) in the primary of the power transformer; these lamps act as positive temperature coefficient resistors introducing very little voltage drop when the power input supply is 80 volts, but glowing with perhaps 20 or 25 volts drop each when the input supply is 240 volts. The lamps also serve as fast-acting low current fuses protecting the transformer and other components.

5. Applications and Progress in Use of the CCIR/ARM Technique

Having described this noise measurement method and a basic practical device for implementation, we should like to mention that we make no proprietary claims, and have been making the circuits and other information available to interested individuals and manufacturers without charge. We encourage other companies to produce comparable instruments, as we feel that it will be of great benefit to everyone to have a standardized noise measurement method in widespread use.

In reporting on use of the CCIR/ARM method, it is appropriate to begin by commenting on professional acceptance of the CCIR filter shape itself. The CCIR filter has proved itself well, mainly due to the European broadcasters and communications authorities responsible for national and international distribution of programs, who have adopted and used the curve enthusiastically. However, their need to measure impulsive noises (for example, the assessment of automobile ignition interference on FM transmissions, or the determination of signal-to-noise ratio of landlines which are often subject to crosstalk from telephone dialing pulses or data transmissions) has meant that they prefer to employ the quasi-peak responding instrument specified by the CCIR or alternatively one of the peak program meters already in general use in signal level monitoring (the VU meter is little used in European broadcasting). Thus there is already considerable experience which supports the validity of the filter characteristic for use in professional noise measurement.

At Dolby Laboratories we have used the CCIR/ARM technique since 1972. It has been used for investigations of both professional and consumer tapes, tape recorders, FM receivers, integrated circuit design, and audio circuitry of all kinds; the experience has been extremely satisfactory. While not originally envisaged for the purpose, the method has also been used to measure and compare noise levels on optical sound tracks. No problems have been found if the print is in reasonably good condition and is not extremely dirty or scratched; such defects lead to impulsive noise. We do not have any experience of disc noise; it is probable that considerations similar to those of optical noise are applicable.

Following the design of a practical CCIR/ARM circuit in 1972, we disseminated the constructional information to our licensees, in order to facilitate and simplify our communications with them concerning product performance and quality standards. To speed up the adoption process we followed up by designing the Cat. No. 98A unit, which was then manufactured and distributed to all licensees. Units were also loaned to various audio journalists and other relevant individuals and organizations in the audio industry.

For some years now the CCIR/ARM noise measurement method has been used for thousands of interchanges of technical information between Dolby Laboratories and its licensees, now numbering some 80 companies in more than twenty countries. Indeed, it is interesting to speculate that the method could well be the most widely used audio noise weighting and measuring system currently in use in the world. During all this time the consistency, reliability, and usefulness of the results in improving product quality have contributed to our confidence in the technique. The last two years in particular have seen a rapid growth

in use, largely due to our licensees' discovering for themselves that CCIR/ARM is a suitable and practical method of measuring, comparing, and specifying noise levels, and not just a curious requirement of Dolby Laboratories. Several licensees now use noise figures obtained in this way publicly, as part of their product specifications (4, 5).

Meanwhile, the technical press has also been adopting the CCIR/ARM measurement technique. A gradual change from wideband, or possibly A-weighted, measurements is taking place in both England and the USA. Several reviewers regularly give CCIR/ARM results of noise measurement for both tuners and recorders (6, 7), and from their comments to us it is apparent that they support the concept and appreciate its usefulness. For the first time reviewers have felt able to give noise measurements which could be compared from product A to product B in a meaningful way.

We have also had discussions with a number of audio instrument manufacturers planning equipment incorporating the CCIR filter, with the result that several of them now have full CCIR/ARM facilities. The first of such products was introduced in February 1976 by Radford Laboratory Instruments of Bristol, England. Their model ANM1 is a sensitive millivoltmeter with provision for introducing weighting filters, including CCIR/ARM. Two Japanese companies have introduced similar meters; these instruments, from the NF Circuit Design Block Co. Ltd. (Models 174 and 177) and from Meguro Denpa Sokki KK (Model MN445 A), are similar to the Radford instrument in that they are sensitive millivoltmeters, but have the added advantage of a variable gain control which allows reference levels to be set to a convenient zero point on the scale, thus making noise measurements a simple procedure. For absolute noise or voltage measurements, the gain controls have calibrated positions.

The Ferrograph RTS2/ATU1 Test Set is also available with CCIR/ARM indication. Meters from the German companies of Sennheiser (Model UPM 550) and Rohde and Schwarz (UPGR) have facilities for adding filters; they can thus be used for CCIR/ARM measurements by plugging a circuit card into a designated position. The same approach is taken in the Amber Model 4400 A analyser.

6. Typical Performance Figures

Since reviewers are beginning to adopt the CCIR/ARM method, comparison can now be made from product to product; this is of course one of the objects of standardization. For interest, unweighted and CCIR/ARM noise levels are given for some typical audio systems in Table 2; these noise levels are all measured relative to fixed reference levels (defined at the bottom of the table). The total dynamic range of the particular medium may be derived by adding to the signal-to-noise figure a value (in dB) between the reference level and the maximum permissible level; this level will depend on the product, manufacturer, and commercial situation. Usually a level giving 2% distortion is chosen for professional products and 3% for consumer

7. Formal Standardization

It is usually in the natural order of things that standardization work lags behind the use of new techniques, if only for the reason that new ideas must be tried and attract a following even to be considered for international standardization. However, the CCIR/ARM technique is well on the way to becoming a de-facto standard used in many areas of professional and consumer audio, in both research and commercial applications. In due course we would expect to see formal recognition of this situation.

One step towards official acceptance has already been made. An SMPTE sub-committee on Audio Recording and Reproduction has approved a draft standard using the CCIR/ARM method for the measurement of noise on optical soundtracks (8). After ratification, this standard will emerge, and in due course will probably become an American National Standards Institute (ANSI) publication.

Product	Reference level	Unweighted S/N (dB) (20 Hz - 20 kHz)	CCIR/ARM S/N (dB)	Mid frequency headroom from reference to 3% distortion level (dB)	Dynamic range (dB)
Stereo FM tuner	(a)	-63	-69	5	74
Stereo FM tuner	(b)	-51	-52	5	57
Mono tuner	(b)	-67	-67	6	73
Professional open reel	(c)	-56	-57	10	67
Consumer open reel	(d)	-50	-51	10	61
Cassette recorder (ferrichrome tape)	(e)	-51	-54	5	59
Cassette recorder (chrome tape)	(e)	-51	-54	2	56
Cassette recorder (iron oxide tape)	(e)	-50	-51	5	56
Mono optical soundtracks	(f)	-49	-48	6	54
Stereo optical soundtracks	(g)	-45	-44	6	50

Reference levels:

- (a) ± 37.5 kHz audio deviation; 1 mV into 75 ohm antenna terminal (2 mV into 300 ohms); 75 usec de-emphasis.
- (b) As (a), but 30 uV into 75 ohms.
- (c) 185 nWb/m, $\frac{1}{2}$ track, 38 cm/s, NAB equalization.
- (d) 185 nWb/m, $\frac{1}{4}$ track, 9.5 cm/s, IEC equalization.
- (e) 200 nWb/m.
- (f) 50% modulation, 65 um bias line, single track width of 1.93 mm.
- (g) As (f), but each track width of 840 um.

TABLE 2 Typical signal-to-noise ratios and dynamic ranges of some audio systems (without noise reduction).

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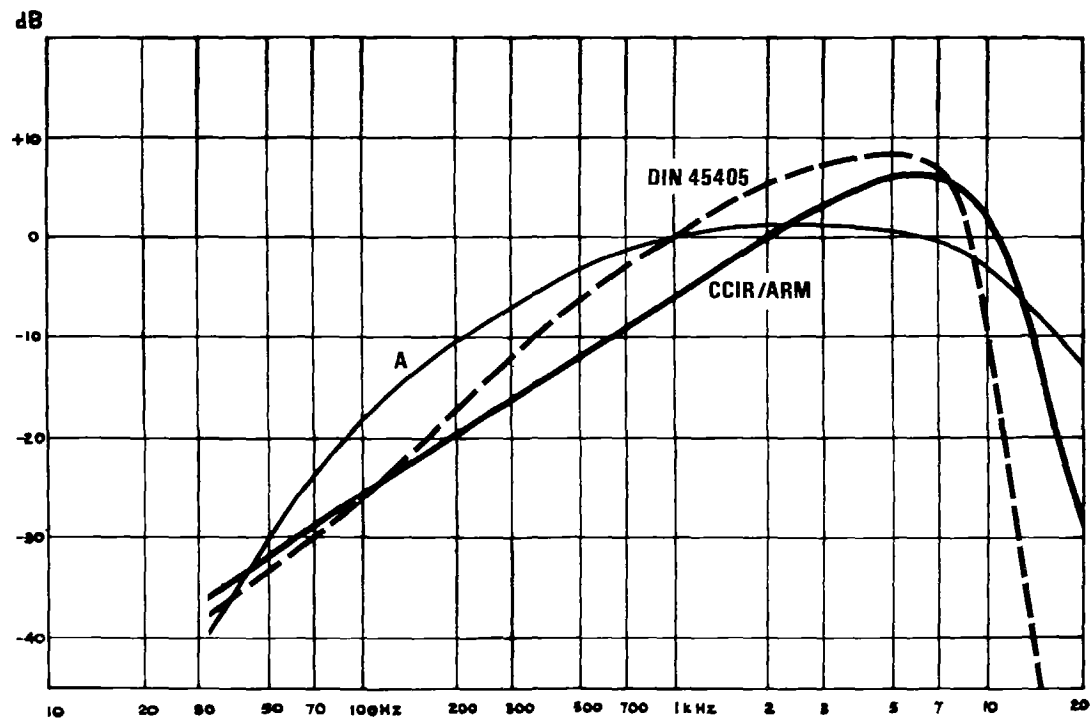


Figure 1 Noise weighting characteristics

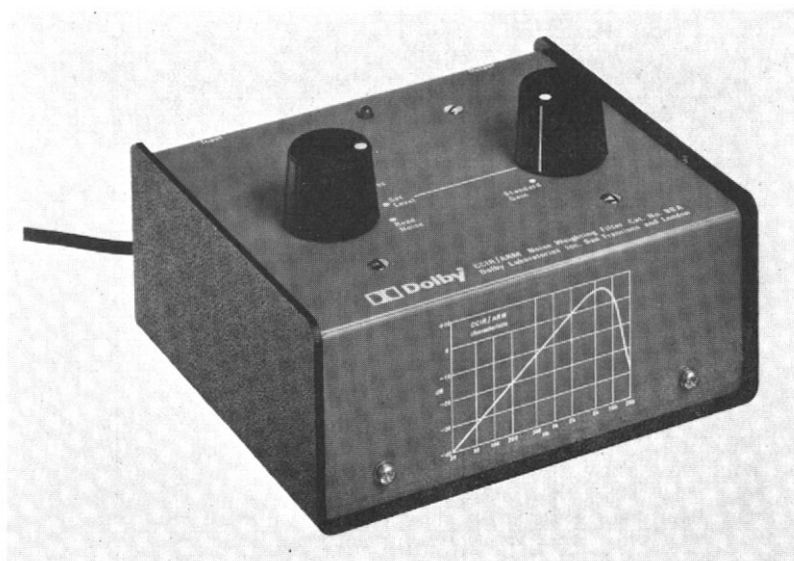


Figure 2 Noise weighting filter, Cat. No. 98A

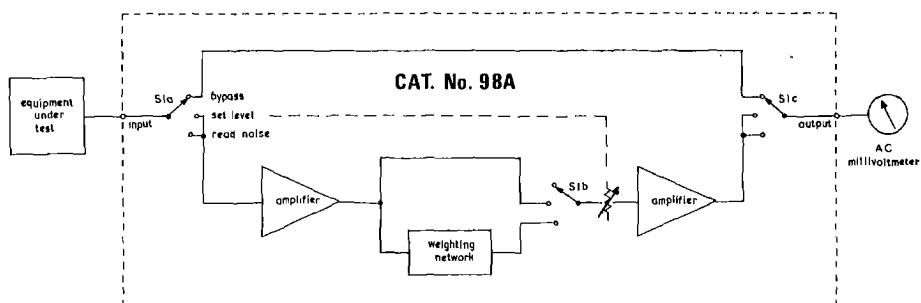


Figure 3 Block diagram of noise weighting filter

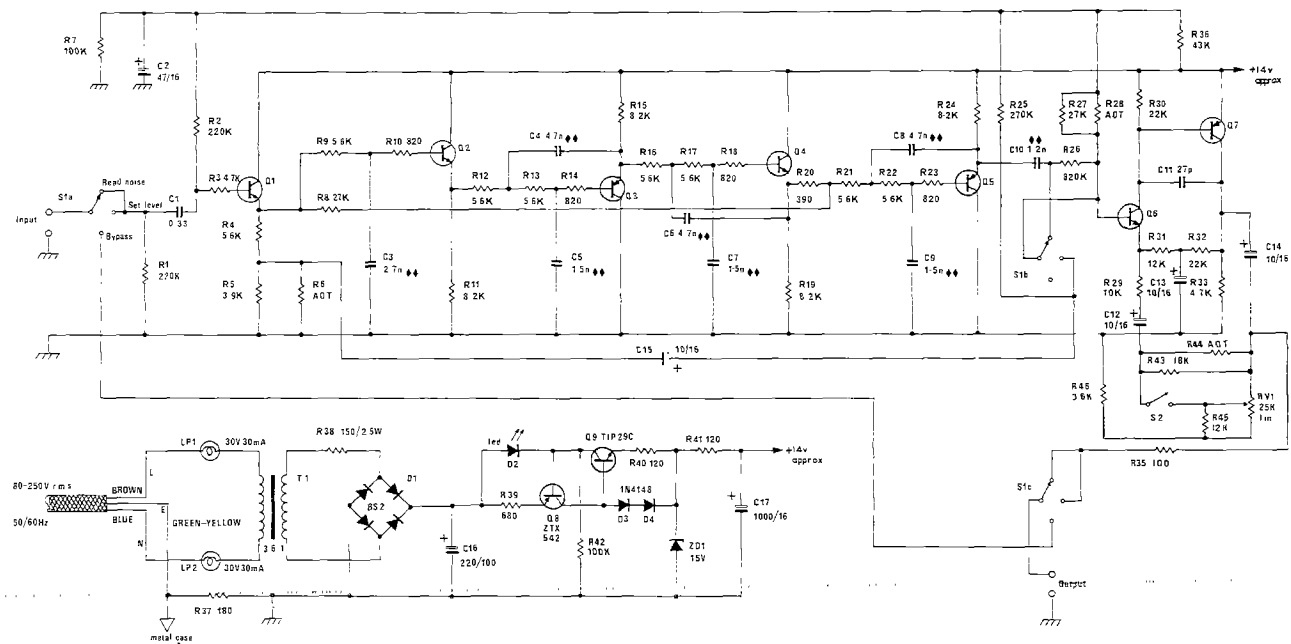


Figure 4 Circuit diagram of noise weighting filter