A Comparison of Several Methods of Measuring Noise in Magnetic Recorders for Audio Applications*

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Summary.—**The various methods of measuring noise in audio magnetic recorders are discussed, and data are shown comparing the numbers observed for the different methods (IRE Standard Methods, and others) when applied to the same recorder. This data will enable one to compare other data taken by one method with data taken by another method.**

The present audio specifications based only on broad-band noise are shown to be inadequate, as the equipment noise in the range of low hearing sensitivity masks any improvements which may be made in tape noise, or with the Ampex Master Equalization. A measure of relative audible noise level should be added to the present broad-band measurement.

Introduction

SEVERAL methods are used to measure the noise level in magnetic recorders for audio applications. Some of these methods have the status of standards; other methods are used because they are more simply applied or more appropriate to the test equipment at hand. We will discuss the various methods, and their advantages and disadvantages, and compare the results of the different methods when used to measure the same magnetic recorder.

Definitions[1]

A noise measurement must be referred to something. We will take as reference the vu meter zero level, which is the "operating level" on the standard tape, and is nominally the 1 per cent distortion level of the tape.[2]

The "noise" may be a noise spectrum, unweighted high-frequency noise, broad-band noise, or weighted noise. These will be defined and discussed below. We also need to know what part of the system is generating the noise, and so we define the following: "system noise"—"the noise output which . . . is generated by the system or any of its components, *including the medium*"; "equipment noise"—"that . . . which is contributed by the . . . equipment during recording and reproduction, *excluding the medium* . . . "; and "medium noise"—"that noise which can be specifically ascribed to the medium."

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[1] The definitions in quotations are abridged from "Standards on sound recording and reproducing, methods of measurement of noise," Proc. IRE, vol. 41, pp. 508–512; April 1953. (Standard 53-IRE 19-S-1.)

[2] Various other choices for reference level are discussed in J. G. McKnight, "Signal-to-noise problems and a new equalization for magnetic recording of music," *J. AES*, vol. 7, pp. 5–12; January, 1959. See especially pp. 6–8 on "signal measurement."

This paper deals only with "zero-modulation medium noise"—"that noise which is developed in the . . . reproducing process when the medium is . . . in . . . the state of complete preparation for playback . . . except for omission of the recording signal: magnetic recording media . . . subjected to normal erase, and bias . . . fields characteristic of the . . . system with no recording signal applied." "Modulation noise"—" . . . which exists only in the presence of a signal and is a function of the instantaneous amplitude of the recorded signal"—will not be discussed here.

All data shown were taken with average reading meters, not true rms meters. This is permitted in the standards.

Noise Measuring Methods

All data below are for an Ampex Model 351 recorder, one-quarter inch full-track, 15-ips, NAB equalization, Irish 211 tape, biased to "peak" at 15-mil wavelength. Reference level is the "operating level" of the Ampex 4494 standard alignment tape (nominal 1 per cent distortion level).

Noise Spectrum Analysis

"The noise spectrum may be analyzed by . . . a very narrow bandpass filter of variable frequency. . . . The results, in terms of power, are divided by the equivalent bandwidth . . . of the filter at each test frequency."

This analysis may be either by a wave analyzer or by a one-half or one-third octave band filter. A wave analyzer is inherently a "constant bandwidth" device; therefore, the data need be corrected only by a constant correction (in db) = 10 log bandwidth (in cycles). Fig. 1 shows the data from a HP 302A wave analyzer, with the noise power as read (7-c bandwidth) and for noise power per cycle ($8\frac{1}{2}$-db correction added). Readings with a wave analyzer of narrow bandwidth (such as the HP 302A) are directly usable, but have the difficulty of involving an expensive unit; and the meter reading fluctuates greatly (due to the narrow bandwith) and must either be "eye-ball" averaged or have a large condenser shunted across the meter to average the reading.

Fig. 2 shows the data from a Bruel and Kjaer Spectrometer, a constant percentage ($\frac{1}{3}$ octave) filter. Since these data are in power per one-third octave, they must be reduced to " power per cycle" form. The correction to be applied at each frequency (in db) is $10 \log \Delta f$, where Δf is

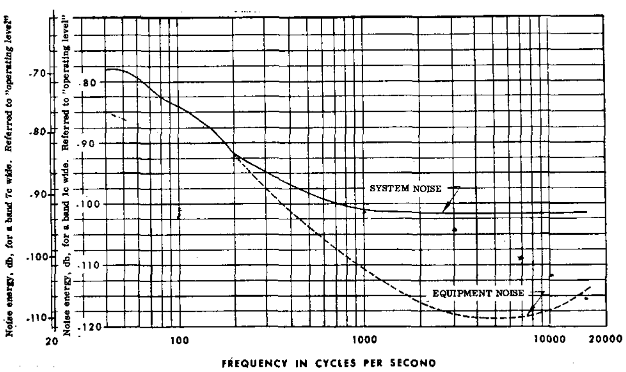

Fig. 1—Noise spectrum analysis. HP 302A wave analyzer, 7-c constand bandwidth. Ampex Model 351, one-quarter inch full-track, 15-ips, NAB equalization. Irish 211 tape, biased to "peak" at 15-mil recorded wavelength.

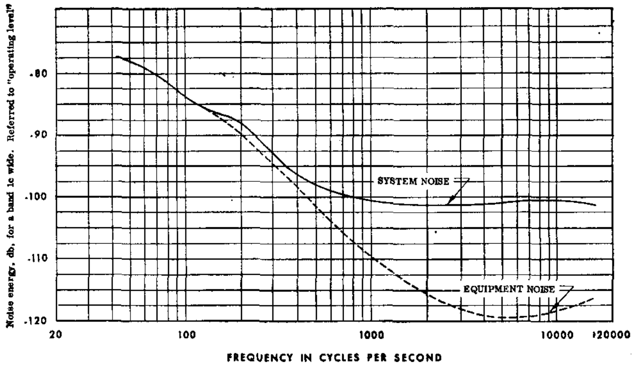

Fig. 3—Noise spectrum analysis. Bruel and Kjaer Spectrometer, one-third octave constant per cent bandwidth. Data converted to constant bandwidth (1c) form. Ampex Model 351, one-quarter inch full-track, 15-ips, NAB equalization. Irish 211 tape, biased to "peak" at 15-mil recorded wavelength.

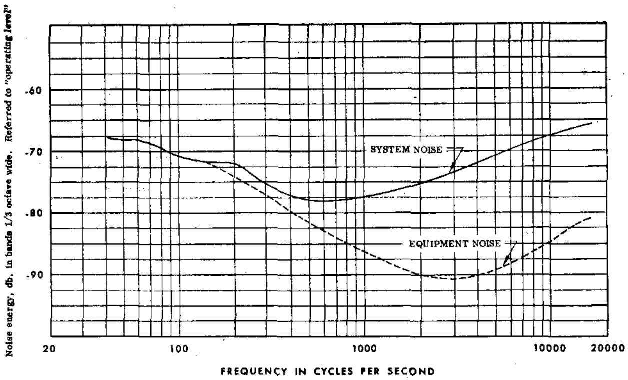

Fig. 2—Noise spectrum analysis. Bruel and Kjaer Spectrometer, one-third octave constant per cent bandwidth. Ampex Model 351, one-quarter inch full-track, 15-ips, NAB equalization. Irish 211 tape, biased to "peak" at 15-mil recorded wavelength.

the bandwidth, in cycles, of any band. Fig. 3 shows these data as corrected; this transforms the curve to the same curve as Fig. 1, from the wave analyzer, proving that the two methods are identical in result. The same advantages and disadvantages apply as for the wave analyzer, except that the correction is a function of frequency instead of a constant.

The noise spectrum analysis gives the most complete data on noise. It shows the actual amount of noise vs frequency; by measuring system noise and equipment noise, one can quickly determine whether the equipment noise is adequately below the medium noise. Single frequency components (such as hum) must be treated separately, and have not been discussed in this paper. To interpret *audible* noise level, one must compare the noise spectrum shape to the appropriate equal loudness curve for the ear.

Broadband Noise Measurements

For broadband noise measurement, a sensitive voltmeter is connected across the equipment output terminals. The only precaution is to be sure to avoid reading any bias frequency which may be present in the "record" mode. Bias may be eliminated either by playing back separately after record (instead of during record) or by using a filter to eliminate the bias (but not to attenuate the pass band). This method gives a system noise of $-53\frac{1}{2}$ db and an equipment noise of -56 db.

This measurement requires the least equipment and provides the least useful data. It is adequate for simple quality control purposes, as the measuring equipment is relatively inexpensive and a single number limit may be set on allowable noise. However, this scheme is inadequate for evaluation of the medium (tape) noise, since (as can be seen in the spectrum analysis of Fig. 1) the medium noise is completely masked by equipment noise below 300 c. Also, any increase in the system noise in the 3-kc region (where the ear is most sensitive) would be masked by the low-frequency noise.

The reading will, of course, depend upon the bandwidth of the "broad band." Equipment specifications should include the band to be used. Fig. 4, (a) and (b) shows the effect of inserting a high- or low-pass filter between the equipment output and the meter. These also point out the fact that the equipment noise largely controls the reading at low frequencies.

Unweighted High-Frequency Noise Measurements

"A 250 c high-pass filter . . . is connected between the . . . equipment and the . . . measuring device. All measurements . . . may be repeated to obtain the signal-to-noise ratio corresponding to the portion of the spectrum which is essentially free of the low-frequency vacuum tube 'flicker' noise of the playback preamplifier input stage and hum of the power-line frequency and its major harmonics." The readings for a bandpass of 250 c to 16,500 c [as could also have been read from Fig. 4(b)] are system noise of -57 db and equipment noise of -68 db.

This method has the simplicity of the broad-band method, with the advantage of showing up differences in medium noise or equipment noise in the 3-kc region but the disadvantage of not indicating possible low-frequency hum and noise.

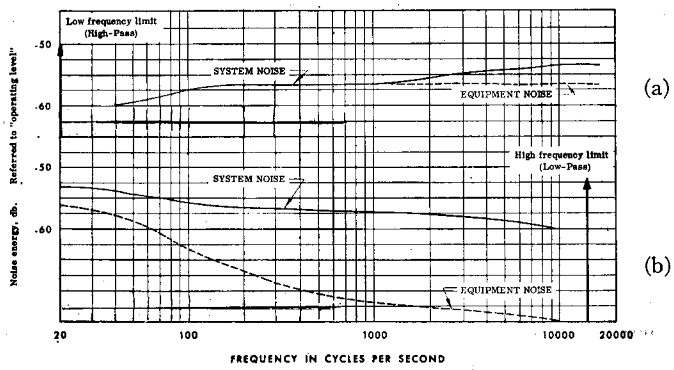

Fig. 4—Cumulative noise. "Broad-band" noise restricted by high- or low-pass filter. SKL Model 302 filter (18-db octave). HP 400L voltmeter. Ampex Model 351, one-quarter inch full-track, 15-ips, NAB equalization. Irish 211 tape, biased to "peak" at 15-mil recorded wavelength. (a) Variable low pass—noise below frequency. (b) Variable high pass—noise above frequency.

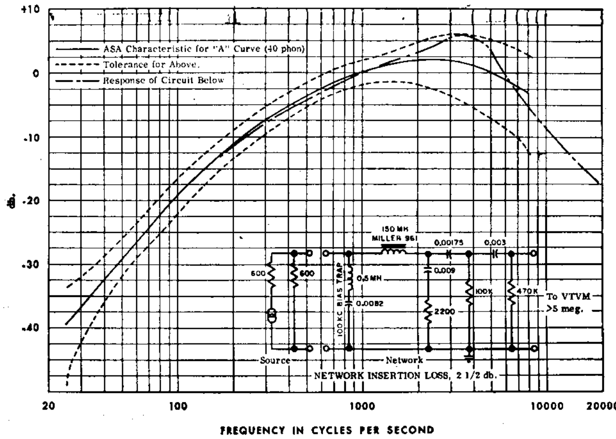

Fig. 5—Response-frequency characteristics and circuit of network for objective noise measurement.

A nonstandard variation of this method has been to use 1-kc to 5-kc unweighted high-frequency noise measurement. This gives a system noise of −64 db and an equipment noise of −75 db. The medium noise is seen to be 7 db less than for the 250-c to 16,500-c bandpass (−57 db vs −64 db); equipment noise is also reduced by 7 db (−68 db vs −75 db). This might be desirable when making measurements on the medium itself, where the high-frequency noise is of primary importance and the possibility exists of having a medium whose noise spectrum may approach that of the equipment in the 3-kc region.

Weighted Noise Measurement

"Appropriate contour curves may be used as a basis for establishing a weighted response . . . if it is desired to relate the data to the hearing characteristic." A response similar to the ASA "A" weighting curve is appropriate.[3] The Bruel and Kjaer Spectrometer contains an "A" weighting curve; or a very simple circuit can be used, as shown in Fig. 5. The B and K "A" network gives system noise of −62 db, equipment noise of −71½ db.

The network in Fig. 5 is more similar to the ear curves than the response established by the ASA (this network is still within ASA tolerances) and gives system noise of −58½ db and equipment noise of −72½ db. This network is seen to have a response roughly similar to the filters used for unweighted high-frequency noise measurement, and gives similar results.

The weighting network has the same advantages (readings are proportional to audible noise and equipment is simple and inexpensive) and disadvantages (hum and low-frequency noise are not indicated unless very large) as the unweighted high-frequency noise measurement, with the additional advantage of being much less expensive than a band-pass filter.

[3] *Ibid.*, pp. 8–9, on "noise measurement."

Comparison Table

Table I is compiled from the data discussed above and is presented so that data taken in the different forms may be compared. All data are for an Ampex Model 351 recorder, one-quarter inch full-track, 15-ips, NAB equalization, Irish 211 tape, biased to "peak." Reference level for all measurements is the "operating level" of the Ampex 4494 standard alignment tape (nominal 1 per cent distortion level).

TABLE I

Type of Measurement	System Noise, Decibels Below Operating Level	Equipment Noise, Decibels Below Operating Level
Noise spectrum data at 3 kc:		
Uncorrected data		
HP 302A (7-c bandwidth)	93	110
B&K Spectrometer (⅓ octave)	73	93
Corrected data, energy/cycle (HP or B&K)	101½	118½
Broadband: (no response limiting filter used)	53½	56
Unweighted high frequency:		
250 c–16 kc	57	68
1 kc–5 kc	64	75
Weighted: B&K "A" weighting	62	71½
Network, Fig. 5	58½	72½

Conclusion

A noise spectrum analysis gives complete data necessary for evaluation of the system, equipment, and medium noise, but the measuring equipment (a wave analyzer, or one-half or one-third octave filter) is expensive, data-taking is somewhat time consuming, simple data corrections are necessary, and interpretation of the data requires some skill.

The broad-band noise measurement is very simple, but the data tell little except that there is probably no gross defect of the system.

Unweighted high-frequency noise measurement, and weighted noise measurement both give a good indication of the relative "noisiness" as judged by the ear, but may not indicate low-frequency hum or noise unless they are extreme. It is suggested that, for audio magnetic recording equipment, specifications and quality control methods be based on broad-band noise measurements (as presently used) to indicate low-frequency hum and noise, plus either unweighted high-frequency noise or weighted noise measurement to indicate the relative audible noise level.

The addition of this "relative audible noise level" measurement is also desirable because of our development of new, lower noise systems (the Ampex Master Equalization) which show no improvement in broadband noise, due to the low frequency equipment noise.

For measuring the noise of the medium, the unweighted high frequency, or "A" weighted readings or one-third octave at 3 kc are equally valid. Use of the unweighted high-frequency noise (either bandpass) is the simplest standard method using standard lab equipment. Use of the "A" weighting network in Fig. 5 is the very simplest standard method, if one is willing to construct the network.

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