Noise Index Measurements*

John G. (Jay) McKnight
Magnetic Reference Laboratory, Mountain View, CA
e-mail: mrltapes@flash.net

Paul Buff discussed "Console Noise Specifications" in *R-e/p* of 1977 December. Indeed, as he says, there is much confusion on this subject. Buff presents many good ideas, although I disagree with his "definitions", and with a few of his calculations. But the purpose of this paper is to offer some comments, ideas, and references that add to Buff's paper.

I've not spent any space on items I disagreed with, because I basically agree with Paul's conclusions, and because the parts I disagree with ("definitions" and some of the math) are really extraneous to the basic problem. In fact, they disappear completely if my recommendations are followed.

1 FORGET "POWER MATCHING"

Much of the confusion in audio systems in general, and in noise measurement in particular, comes from trying to describe signal and noise *power* characteristics, because (as Buff says) for best noise performance, the source must *not* be loaded, and therefore there is no input power whatsoever! Snow [1] and [2] has interesting discussions of this. The present IEEE Standard [3] goes to a great deal of effort to force *all* kinds of systems — equal source- and load-impedance systems, "bridging" (non-loading) systems, and all things in between — into a "power transfer" mold. The result is self-consistent, but has little else to recommend it — it is very difficult to understand, and Ifeel it is of little theoretical or practical value. (We tried in 1968 ... 1971 to update this standard, but it was not accepted. I think we should resurrect that draft) Smith and Wittman [4] also spend a lot of words on this problem. What they calculate about "EIN in dBm" and "EIN in dBV" is technically correct, but ultimately not very illuminating, except in a historical context of the IEEE Standard [3]. If anyone really wants to know where the "extra 6 dB" comes from, see IEEE [3], and Haefner [5].

Forget power transfer and power levels (dBm, Buff's dBme, etc.) completely — they are a useless and confusing fiction, especially in low-level input systems. Consider only signal and noise voltages and voltage levels.

2 IS THE SOURCE REALLY RESISTIVE?

If we are really serious about input noise measurements, we should ask "How good is our basic system model that assumes that the source impedance is a frequency independent resistance of the rated value?" Snow [1] discusses this a little. The only resistive source that I can think of is the carbon microphone! All the others — dynamic-, ribbon-, capacitor-, and the piezoelectric-microphones and phonograph pickups, and tape reproducing heads — are fundamentally reactive. Perhaps the pre-amplified capacitor microphone is resistive, but because of the pre-amplification, the console input amplifier gets a higher input signal level, so its noise is much less critical.

Werner [6] discusses the impedance of ribbon microphones, but he gives only the magnitude of the impedance, without the phase angle. Perhaps the microphone manufacturers have this information. In any case, measurement is not difficult — just time consuming.

If the sources turn out to be frequency-variable resistances (especially in the 8- to 16-kHz region), then does a measurement and specification of noise performance relative to a theoretical frequency-independent resistance have any value? I doubt it, but this deserves some thought.

But for now, I'll discuss measurements based on a frequency-independent resistance of the rated value, as though it had real meaning.

3 EQUIVALENT NOISE RESISTANCE

For design purposes, the designer wants to know the equivalent noise resistance of the input stage, in order to optimize its value if he has a fixed source resistance, or to optimize the source resistance if it is adjustable (such as with an input transformer).

This concept is detailed by Snow [1] and Argimbau [7] for vacuum tubes, and by Smith and Wittman [4] and their references, for transistors. Once the equivalent noise resistance R_{eq} and the source resistance R_s are known, the noise index is calculated directly [7] from:

$$\text{N.I.} = 10 \log_{10} [(R_s + R_{eq})/R_s].$$

4 MEASURING NOISE INDEX DIRECTLY

I agree completely with Buff's conclusion to measure the Noise Index (20 log noise voltage figure). Buff, and Smith and Wittman [4], mention only the method that Terman and Pettit [8] call the "Brute-Force Method" — measure the gain, the equivalent bandwidth, and the output noise, and calculate the Noise Index. Terman and Pettit also describe a "Noise Generator Method" which would seem to have many advantages in simplification of measurement and reduction of possible errors of measurement. It uses the principle that when two equal noise voltage levels are added, the sum of the levels is 3 dB greater than either level. Thus a known noise voltage is added to an unknown noise voltage; the known is adjusted to make the sum just 3 dB greater than the unknown alone. Then the unknown must be equal to the known. In practice, one would connect a noise voltage E_n with bandwidth B in series with the rated source resistance R_s to the amplifier input, as shown in Figure 1. Measure the output level in bandwidth B with the added noise E_n disconnected. Then connect the added noise voltage, and increase it until the output level in bandwidth B increases 3 dB. Measure the noise generator voltage E_n in bandwidth B, and calculate the Noise Index from:

$$\text{N.I.} = 20 \log_{10} (E_n/E_{ref}),$$

where $E_{ref} = \sqrt{(4\, k\, T\, R_s\, B)}$.

This method still requires one bandpass filter to set the given

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bandwidth B of the voltmeter, both when measuring the output noise level and adjusting the added noise level, and when measuring the "known" added noise voltage E_n. But there are several other simplifications over the "brute-force" method:

- There is no need to measure the gain, and get embroiled in that mess.
- The rms value of the noise generator voltage must be measured, but there is no need to correct for the response of an average-reading *output* meter, since it affects both the "with" and the "without" added noise reading equally.
- And, finally, any source loading losses are automatically included.

In a practical measuring system, rather than *calculating* the Noise Index from the noise voltage ratio, one could easily design an attenutator between the noise generator and the input circuit to take care of all of the miscellaneous mathematics, so that an average-reading voltage level meter could *directly* indicate the Noise Index. The values given in Figure 2, for instance, are calculated for use with an average-reading meter which reads levels referred to 0.775 V; with R_s = 150 ohms, B = 20 kHz, T=300 K(27 °C). The level reading on the meter will be the Noise Index in dB, directly. How's that for simplicity? No goofs, and no fudge.

I must admit having not run these measurements myself, but it certainly sounds like an idea that the industry should consider. If it really works out in practice, it should be written up for publication, and be made into an industry-wide standard method. If this or some other methods work out in practice, and are acceptable to audio engineers, then I am sure that the Audio Engineering Society's Standards Committee would be anxious to help with the procedures of standardization.

REFERENCES:

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[7] L B. Argimbau and R. B. Adler, *Vacuum-Tube Circuits and Transistors,* New York, John Wiley & Sons, 1956. See Chapter XV, Noise.

[8] F. E. Terman and J. M. Pettit, *Electronic Measurements,* New York, McGraw-Hill, 1952. See Chapter 8, Amplifier Measurements; Sec. 8-12 Noise in Amplifiers; Sec. 8-13 Noise Figure in Amplifiers; and Sec. 8-14, Measurement of Noise Figure of Amplifiers.

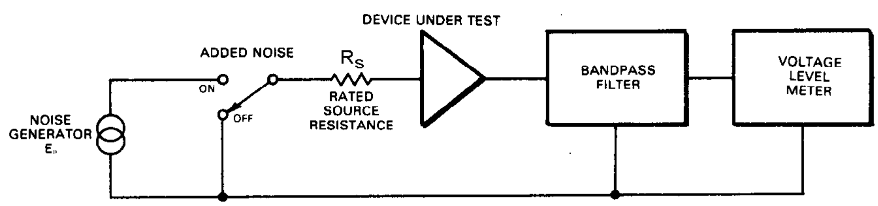

Figure 1: Basic circuit for measuring noise index by the "Noise generator method."

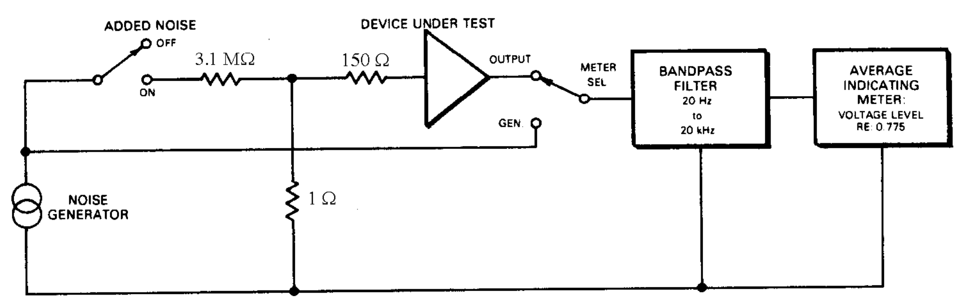

Figure 2: Practical setup for a direct-indicating measurement of the noise index by the "noise generator method." These particular values hold only for a source resistance of 150 Ω, bandwidth of 20 kHz, and an average-indicating meter of voltage level re 0.775 V. (A balanced circuit could be used if needed.)

Measurement Procedure:

1. Meter Selector to "Output"; Added Noise to "Off". Read Output Noise Level on Voltage Level Meter.
2. Meter Selector on "Output", Added Noise to "On". Adjust Noise Generator so that Output Noise Level increases 3 dB.
3. Meter Selector to "Gen. ". Level in dB read on Voltage Level Meter is directly Noise Index of this system.