calculating preamplifier gain

from noise-figure measurements

Discussion of a new technique for calculating the gain of vhf/uhf preamplifiers from noise-figure measurements

Noise-measurement sessions have become a popular and regular feature of the various vhf/uhf conferences held around the country. In addition to giving the individual experimenter an opportunity to check out his vhf/uhf preamplifiers and converters on precision noise-measuring equipment, the published results allow an annual comparison against the previous year's performance, and provide an index of technical progress in amateur receiver design. In addition, the noise-figure measurements foster a competitive spirit which spurs many experimenters into upgrading their vhf receiver performance. Those amateurs who provide the measuring equipment are similarly inspired to improve the accuracy of their instrumentation and noise-measurement techniques.

The technique presented here, which allows indirect measurement of preamp gain, is an illustration of the latter effect. When I was asked by Wayne Overbeck, N6NB, Chairman of the 1977 West Coast VHF/UHF Conference, to conduct the receiver noise-figure measurements, I was at once flattered and shattered. Flattered because it was an honor afforded to few amateurs — but shattered by the prospects of carting an automatic noise-figure indicator, two noise heads, an i-f strip, five converters, two step attenuators, two power supplies, three signal generators, a power meter, and assorted pads, adapters, and cables 300 miles (480km) each way in the back seat of my small imported car. The most practical suggestion for coping with the latter problem came from one of my students: "Rent a trailer." Not being as practical as he, I had another thought, "Find a way to make the measurements with less test equipment."

importance of gain information

Fully half the test equipment listed above is used not for measuring noise figure at all, but rather for measuring the gain of the preamplifiers being tested. Gain information is necessary if true preamplifier noise performance is to be evaluated, because to measure the noise figure (NF) of a preamplifier, it must be connected to a converter. The converter will add some noise to the system, and to accurately characterize a preamp, this noise must be subtracted from the measured noise figure. Since the converter's effect on measured noise figure is a function of preamp gain, it is impossible to accurately measure a preamp's noise figure without knowing its gain.

The relationship between preamp gain, converter NF, preamp NF, and the noise figure of the cascade is summarized by Friis' well-known equation[1]

$$F_T = F_1 + \frac{(F_2 - 1)}{G1} \qquad (1)$$

where F_T = total Noise Factor
F_1 = preamp Noise Factor
F_2 = converter Noise Factor
G_1 = preamp gain

all of the above measurements are power ratios (*not* dB).

Since both noise figure and gain are generally expressed in dB, it is necessary to convert to ratios before applying the above formula, thus:

$$F\,(ratio) = Antilog\ \frac{NF\,(dB)}{10} \qquad (2)$$

why measure gain

Unless a preamp's gain has been measured, **eq. 1** results in two unknowns; to eliminate gain measurements (and avoid renting a trailer), it was evident that

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I had to find a way to solve for both unknowns. My math students reminded me that this could be accomplished only with two simultaneous equations. Clearly what was needed was yet *another* expression for preamp performance which contained no parameters other than those which could be measured on a noise-figure meter.

Inspiration struck when I considered solving Friis' equation for isolating the noise factor of a preamp of known gain, in front of a known converter, from the noise measurement of the cascade:

$$F_1 = F_T - \frac{(F_2 - 1)}{G} \qquad (3)$$

Imagine what the expression would be if the *same* preamp were measured in front of *another* converter of noise factor, F_3, yielding a new cascade noise factor, $F_{T'}$. Now

$$F_1 = F_{T'} - \frac{(F_3 - 1)}{G} \qquad (4)$$

Since F_T, $F_{T'}$, F_2, and F_3 can all be measured on a noise-figure indicator, **eqs. 3** and **4** represent two equations in two unknowns! This means we can now calculate gain solely as a function of noise-figure measurements; no gain measurements are required.

$$F_T - \frac{(F_2 - 1)}{G} = F_{T'} - \frac{(F_3 - 1)}{G}$$

$$F_T - F_{T'} = \frac{(F_2 - 1)}{G} - \frac{(F_3 - 1)}{G}$$

$$G = \frac{(F_2 - 1) - (F_3 - 1)}{F_T - F_{T'}}$$

$$G = \frac{F_2 - F_3}{F_T - F_{T'}} \qquad (5)$$

And knowing gain, we can solve for corrected preamp noise factor using either **eq. 3** or **eq. 4**.*

eliminating the second converter

From **eq. 5** it can be seen that preamp gain data can be derived from two different cascade NF measurements (F_T and $F_{T'}$) of the preamplifier in front of two converters of known and different noise factors (F_2 and F_3). Although we have eliminated the requirement for signal generators, step attenuators, power meters, and any other equipment associated with gain measurement, we now require two different instrumentation converters for each band at which preamps are to be measured. Hello again, *U-Haul*!

Actually, a single converter for each band can be used for both measurements, by preceeding it with a precision pad for the second measurement to degrade its noise figure by a known amount. NF_3 (in dB) would be *approximately* equal to NF_2 plus the loss of the pad, both in dB.* Of course, these numbers would be converted to ratios using **eq. 2**, before calculating gain from **eq. 5**.

If a precision 10 dB pad is used to transform F_2 to F_3, the gain formula becomes:

$$G = \frac{9F_2}{F_{T'} - F_T} \qquad (6)$$

The measurement procedure is relatively straight forward:

1. Measure NF_2, noise figure of the converter

2. Measure NF_T, noise figure of the preamp-converter cascade

3. Insert a precision 10 dB pad between the preamp and converter

4. Measure $NF_{T'}$, noise figure of the preamp-pad-converter cascade

5. Convert the three NF measurements to power ratios using **eq. 2**

6. Calculate gain (ratio) from **eq. 6**

7. Calculate corrected preamp noise factor (ratio) from **eq. 3**

8. If desired, convert F_1 to dB:

$$NF_1\ (dB) = 10 \, Log_{10} \, F_1 (ratio)$$

accuracy limitations

Contrary to popular belief, the process of measuring uhf receiver noise figure is highly imprecise, even with such precision equipment as the Hewlett-Packard 340 Automatic Noise-Figure Indicator with argon-discharge noise head. In the near future, Bob Stein, W6NBI, has promised to present a discussion of noise figure indicators and their relative accuracy

*An HP-25 program for calculating noise figure and gain from these equations is available from the author upon receipt of a self-addressed, stamped envelope.

*In fact, the converter-pad combination exhibits a noise figure slightly greater than the sum of pad loss and converter noise figure. This is because there are really two sources of NF degradation when the pad is inserted: the power loss of the pad (its marked attenuation value), and thermal noise generated within the resistance of the pad as a function of its being a warm body (relative to absolute zero). If the attenuation of the pad is fairly high (I use 10 dB), the thermal noise contribution becomes negligible and can be omitted from calculations.

in *ham radio*. Without listing all the various error sources here, suffice it to say that measurements of the type traditionally taken at the regional vhf/uhf conferences are accurate to within only about ± 1 dB.

Why then, do we bother with this annual ritual? Primarily because the measurements made at these conferences are a good *relative* indication of the comparative performance of various designs and devices. You may be confident that the 1296-MHz preamplifier yielding the lowest noise figure at a *particular* competition is indeed the lowest noise-figure device, although, of course, the actual numbers are of limited significance.

I must caution participants in noise-figure competitions against drawing firm inferences from the comparison of data taken on different occasions, on different equipment, or at different times. The fact that all two-meter converters measured this year had lower noise figures than those measured last year is *not necessarily* an indication of technological progress. It's quite possible that differences from year to year are merely a function of divergent measurement errors.

Nonetheless, the "tweak and optimize" procedure generally followed at these noise-figure measurement competitions is entirely valid because the measurements are a good relative indication of receiver performance. I should point out that extensive tuning is not noted for greatly improving noise performance. If the equipment under test is operating reasonably well on the air a minor tweak of the input circuitry, as well as a possible adjustment to bias level, will usually suffice. In fact, I have seen converters tuned to within an inch of their lives, only to end up delivering a much lower NF at some frequency *out of the band* (usually the image frequency).

Along the same lines, note that if tuning the converter's local-oscillator chain results in an indicated NF improvement, it is only because the spurious components generated by optimizing the LO result in multiple mixing products. In short, tweak sparingly!

Since preamp gain information is to be extracted from noise figure measurements, the numbers derived for gain are subject to the same ambiguity which surrounds the measurement of noise figure. Further, considerable measurement error can result if the preamplifier gain should change between the measurement of F_T and $F_{T'}$. Since the input impedance of all converters is not necessarily 50 + j 0 ohms, it is likely that a preamp will see different load impedances with the 10 dB pad installed and removed; if the preamplifier's stability is marginal, the result may be a several dB gain variation. This will adversely effect both gain and NF measurement accuracy, but can be minimized by placing yet another loss pad (aside from the one used to establish F_T') in front of the converter for *both* measurements, to mask input mismatch.

If preamp gain and converter NF remain constant throughout the measurement sequence, this method appears capable of estimating preamp gain to an accuracy on the order of ± 1 dB per 10 dB of gain.

Santa Barbara field trial

I left my gain measuring gear at home and tried this technique at the West Coast VHF/UHF Conference in Santa Barbara in May, 1977. The results of measuring gain and noise figure of 57 different preamps in the 144, 220, 432, 1296, and 2304 MHz bands correlated closely both with theory and expectations. Several preamps registered unusually high gain, but errors were within the accuracy limits outlined previously. The only severe difficulty encountered was in measuring extremely high-gain (30 dB or so) multi-stage preamplifiers; these tended to overdrive the converters, sometimes introducing enough measurement error to yield values for $F_{T'}$ *lower* than F_T! Needless to say, under these conditions the computations fall apart.

Most of the participants in the NF competition were reasonably satisfied with the NF and gain measurements derived from this technique. There were, of course, a few who said, "Your measurements are all screwed up — I *know* my preamp's better than that," but I hear this at all NF competitions, regardless of the equipment or techniques which are used. The method will probably be retained at future West Coast Conferences, and is being recommended for use at the Eastern and Central States events as well.

disclaimer

I make no claim whatever that the technique presented here for noise-figure measurements is original. However, I have never personally seen the technique applied before, and have no knowledge of anyone else either advocating or using it. But the measurement is so simple, the concept so obvious, that I would fully expect someone, somewhere, has thought of it before. That doesn't matter. What counts is that we hams have yet another measurement tool at our disposal, one which hopefully will enable us to upgrade our vhf and uhf receivers and skills. Please don't consider these measurements sacred; this is, after all, *amateur* radio.

reference

1. H. T. Friis, "Noise Figures of Radio Receivers," *Proceedings of the IRE*, July, 1944, page 419.

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