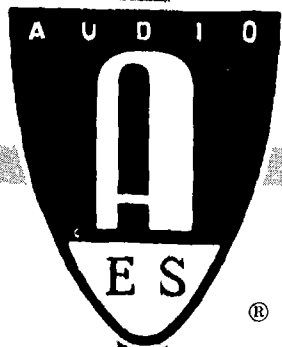


MODULATION NOISE IN TAPE RECORDINGS

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MODULATION NOISE IN TAPE RECORDINGS

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This paper reviews some of the causes of amplitude and frequency modulation noise and suggests a simple measurement technique.

Modulation noise is a familiar phenomenon in tape recording, yet only recently have any serious attempts been made to reduce it in audio recorders. At this time, there are no specifications or quantitative numbers applied to modulation noise as we do for background noise, flutter, distortion, etc. In fact, there is no standard method for measuring it. The writer will review the causes of modulation noise and how the ear hears it, describe some of the measurement techniques used and suggest a simple measurement that could produce a specification.

Modulation noise may be defined¹ as a noise which exists only in the presence of a signal and is a function of the recorded amplitude of the signal. The signal undergoes modulation in both amplitude and frequency. These two types of modulation produce sidebands of noise above and below the signal frequency.

The main causes for amplitude modulation noise are: a) Non-uniform oxide coating or magnetic characteristics of the tape, b) Surface roughness of the tape, or contamination, that would vary the head-to-oxide spacing. It should be noted here that a dropout is an amplitude modulation of the signal, and is therefore a form of modulation noise.

The main cause of frequency modulation noise is tape speed irregularities (flutter). The flutter frequencies that produce noise sidebands extend from the very lowest "wow" frequencies to beyond 10 kc. Flutter occurring between 2 kc and 5 kc is usually known as "scrape flutter".² It is caused by the frictional forces at the heads and guides exciting the length of tape between the reel idler and the capstan. Any form of rotating element will isolate this flutter. For example, if the entrance and exit guides at the head assembly rotate, the length of tape producing the scrape flutter will be the distance between the guides. As this distance shortens, the resonant frequency increases. The amplitude of the scrape flutter is usually at a maximum half way between the rotating elements. (A graph of a "scrape flutter" spectrum, and further literature references may be found in a paper by Narma and Fujii.³)

1. "Standards on Sound Recording and Reproducing: Methods of Measurement of Noise", Proc IRE, 41 508-512, April 1953.
2. P. Smaller, "The Noise in Magnetic Recording Which is a Function of the Tape Characteristics", Jour. Audio Eng. Soc. 7, 196-202, Oct. 1959.
3. R. Narma and W.M. Fujii, "Performance and Reliability Requirements for a Master Tape Recorder", Jour. Audio Eng. Soc. 12, 274-279, Oct. 1964.

Modulation noise can occur in either the recording or reproducing process. The majority of the AM noise is produced in the recording process.⁴ FM noise can occur in both, depending upon the location of the heads with respect to the rotating elements.

Anyone who has ever listened to sine waves reproduced on a tape recorder realizes they do not sound "right". The high frequency tones have a hissing noise behind them. What he is hearing is the signal plus the sidebands of modulation noise. When the modulation frequency is above several hundred cycles, the sidebands sound much like background noise. As the modulating frequency is reduced, this noise-like characteristic changes from a distinct noise to a coloration of the signal frequency. With modulations above approximately 50 cycles, the ear cannot distinguish AM from FM. All it hears are the sidebands produced by the modulating frequency. The modulating frequency itself is never audible. Below 50 cps a trained ear can begin to distinguish AM from FM. FM is heard as a change of pitch, or wow. AM is heard as a change in level, dropouts, or tremolo. An untrained ear can easily confuse the two. If a low frequency sine wave is recorded, AM noise is usually heard as pops and crackles added to the signal.

The discussion above applied to the recording of pure tones. Fortunately, we do not have to listen to sine waves. When program material is recorded, modulation noise is more difficult to detect because of the masking effect of the ear.⁵ Even though the sidebands near the carrier (those produced by low modulating frequencies) are higher in amplitude than those farther away, the masking effect of the ear usually makes them inaudible. A fuzziness of high frequency notes (particularly with violins), is often blamed on modulation noise. However, intermodulation distortion can produce similar effects, so modulation noise becomes rather difficult to pinpoint on program material.

Many methods have been used to measure modulation noise. The easiest way to detect AM is to view the reproduced waveform on an oscilloscope with the sweep set so many cycles are displayed (see Fig. 1). It is a little difficult to apply a number to this reading. In another method, the signal is fed to an AM detector (diode plus filter to remove the carrier and the sidebands). This in turn, can be metered or fed to a wave analyzer for spectrum analysis. Erickson⁶ and Price⁷ used an intermodulation distortion meter as the AM detector. These methods recover the modulating frequency, not the sidebands the ear hears. FM noise is usually measured by feeding the output to wideband discriminator similar to GR type 1142-A. This in turn is fed to a wave analyzer to obtain a frequency spectrum. Again, this recovers the modulating frequency, not the sidebands. The sidebands can be measured directly by feeding the output of the recorder to a wave analyzer. This, of course, does not distinguish FM from AM.

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4. D. F. Eldridge, "DC and Modulation Noise in Magnetic Tape", Proc. Intermag. Conference IEEE, T-149, (April 1963).
 5. H. Fletcher, Speech and Hearing in Communications, D. Van Nostrand Co., Inc., New York, NY, 153-175, (1953).
 6. W. H. Erickson, "Magnetic Tape Testing on a Comparison Basis", Dept. of Defense Symposium on Magnetic Recording, Dept. of the Navy, BU Ships, Code 362, Washington 25, D.C. Paper No. 13, pp. 1-13.
 7. R. L. Price, "Modulation Noise in Magnetic Tape Recordings", IRE Trans. on Audio, AV-6, 29-40, (Mar - Apr 1958).

All of the above techniques are more suitable in a laboratory than in the field. The writer felt the need of a simple one-number measurement that would tell if a recorder was performing adequately. An SKL model 302 band-pass filter and an HP 330B harmonic distortion meter were available, so the recorder output was fed to the filter set for 200 cps to 4.5kc pass-band. We chose a 6-kc signal frequency and fed the filter to the distortion meter (see appendix for details of test method). It was used to null the 6-kc carrier and give us a one-number reading that represented total side-band energy in a 200 to 4 kc band, expressed in db below the carrier frequency. The writer later built an m-derived filter that replaced the filter and distortion meter (see Fig. 2).

Is this an adequate measurement of modulation noise? Of course not. It has all the disadvantages of any one-number measurement. It does not detect sidebands created by modulating frequencies below 1500 cps. It gives no clue as to the source of the noise. Why was a 6-kc carrier chosen? It seemed like an adequate compromise so measurements could be made down to $3 \frac{3}{4}$ ips. The method fails completely if the response is not reasonably flat between 200 and 6 kc. Why a 200 cps to 4.5 kc passband? The 200 cps is used to eliminate low-frequency response variations, hum and $1/f$ noise. The 4.5 kc was determined by the sharpness of a 6-kc notch filter.

On closer inspection, maybe the measurement is not quite so inadequate. We already have a measurement of low frequency FM noise, namely the traditional flutter and wow measurement. Low frequency AM noise is easily visible on the oscilloscope. This additional measurement does put a number on what the ear hears in a 200 cps to 4.5 kc band when a 6-kc signal is recorded. It may be the missing link in our measurement of modulation noise phenomenon.

The writer used this measurement technique in an attempt to determine how modulation noise varied with track width and tape speed. Table I shows the results obtained with three track widths, with and without scrape flutter. If scrape flutter is present the signal-to-modulation-noise ratio remains essentially constant with variations in track width. Since scrape flutter is a coherent modulation occurring equally across the whole width of the tape, doubling the track width will double the signal, but also double the modulation noise due to the scrape flutter. Therefore the signal-to-noise ratio remains constant. When the scrape flutter is removed, the remaining modulation noise seems to be mostly AM, which is a non-coherent phenomenon occurring randomly across the tape width. In this case, as can be seen from Table I, doubling the track width results in a net gain of 3 db in signal-to-noise ratio, since the signal increases 6 db but the random modulation noise only increases 3 db.

Table II shows the results obtained when tape speed was varied with and without scrape flutter. Unfortunately, no conclusions can be drawn from this data, as in the case of track width variation. Some of the variables involved are:

- a) modulation noise characteristics of the tape,
- b) tape-head transfer characteristic (response curve obtained with constant current to the recording head, including both tape and reproduce chain response losses),
- c) amount of pre-emphasis and post-emphasis employed, and
- d) whether the modulation occurs in recording or reproducing.

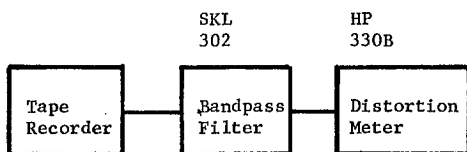
All that can be safely said is that with a given tape on a particular recorder the modulation noise will be worse at the slower speeds. Price¹ showed that at a given speed the AM sidebands will increase as the signal frequency increases, but the amount of increase would vary drastically depending on the tape, averaging about 2 db per octave. This was proved to be a wavelength phenomenon - that is, recording the same frequency at two speeds will show an increase in noise at the slower speed. The writer recorded a signal of 12 kc at 15 ips and 6 kc at $7\frac{1}{2}$ ips using constant recording current vs. frequency, and a flux responsive reproducer. When both recordings were played back at $7\frac{1}{2}$ ips the modulation noise was identical. Smaller² showed that the FM sidebands increased roughly 6 db per octave as the signal frequency increased. However, this increase is not strictly a wavelength phenomenon since higher speeds produce an increase in tape-head friction, thus increasing the modulating amplitude. However, the net result at audio tape speeds will be an improvement as speed increases.

It can be clearly seen that there is more to be learned about modulation noise. Improved measurement techniques are needed - techniques that can be correlated with subjective listening tests. The writer hopes that this paper will generate increased interest in isolating the causes and behavior of modulation noise in magnetic recording and thereby serve to smooth the sound of the "fuzzy" violin string.

The author wishes to thank J. G. McKnight for his assistance in the preparation of this paper.

APPENDIX

MODULATION NOISE TEST PROCEDURE



1. Set filter for 200 cps high pass and 4.5 kc low pass.
2. Record 1 kc and adjust distortion meter in set level position for a convenient reference reading.
3. Record 6 kc same level and null distortion meter in distortion position.
4. Read noise in db below reference level.

NOTE: Recorder response should be flat 200 to 6 kc.

TABLE I. MODULATION NOISE vs. TRACK WIDTH AT 7 1/2 IPS

<u>Track Width</u> <u>Mils</u>	Modulation Noise db Below Carrier	
	<u>With Scrape</u> <u>Flutter</u>	<u>Without Scrape</u> <u>Flutter</u>
43	40	46
75	41 1/2	48
150	41 1/2	51

Data obtained using 3M111A tape on Ampex Model 354 and F-44 tape recorders.

TABLE II. MODULATION NOISE vs. SPEED AT 75 MIL TRACK

<u>Tape Speed</u> <u>IPS</u>	<u>Modulation Noise db Below Carrier</u>	
	<u>With Scrape</u> <u>Flutter</u>	<u>Without Scrape</u> <u>Flutter</u>
3 3/4	38	44 1/2
7 1/2	41 1/2	48
15	48	51

Data obtained using 3M111A tape on Ampex Model 354 and F-44 tape recorders.



NOTE: SMALLEST DIVISION IS 1 DB

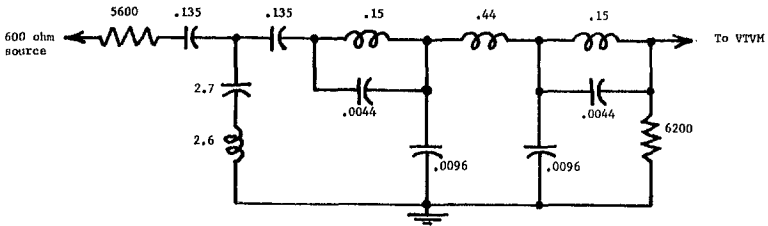
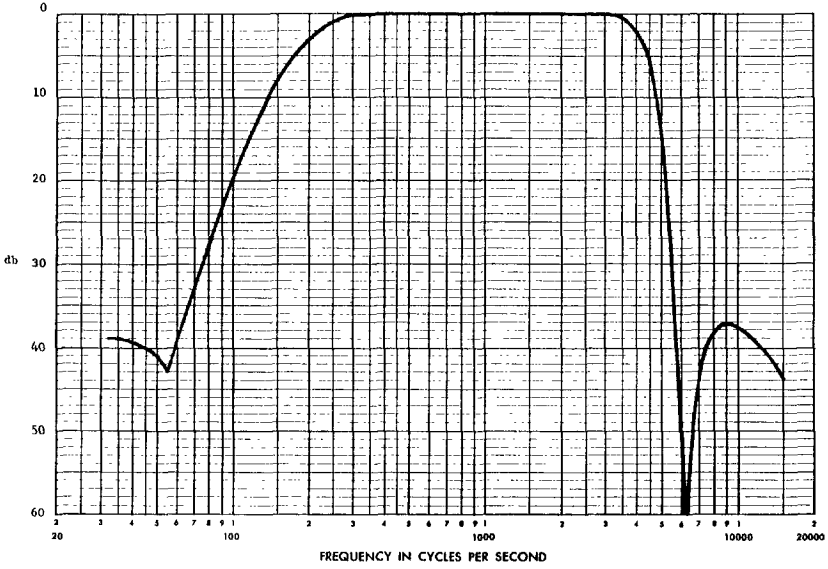


FIG. 2 SCHEMATIC AND ATTENUATION OF m - DERIVED FILTER. CAPACITORS IN MICRO-FARADS, INDUCTORS IN HENRYS; RESISTORS IN OHMS.

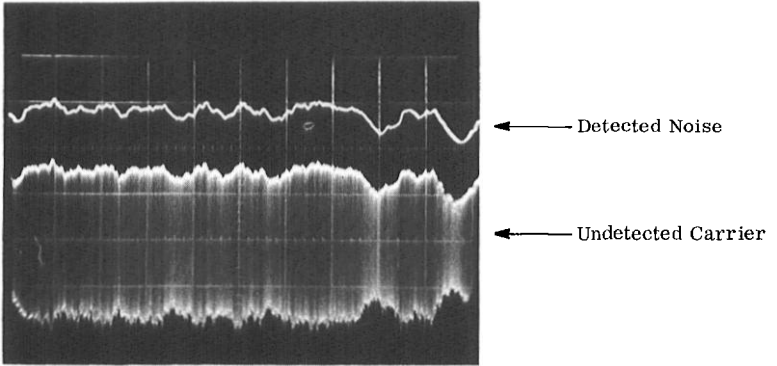


Fig. 1 AM Noise