Characterization of Tape Recorder Flutter in an Airborne Environment

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Summary. While many methods are known for measurement of tape recorder flutter, most are intended for a laboratory environment, or at worst for situations where environment is under positive control. When the tape recorder is placed in a dynamic environment which is the source of the data to be recorded, tape flutter has a significant effect on the data accuracy. This paper describes some of the consequences of such flutter, and a method for separating the effects of flutter in the recording process from those encountered in playback; such information is required for the characterization of airborne tape recorders and for validation of data obtained.

Tape flutter (or wow, loosely defined as the low-frequency components of flutter) arises from the condition of nonzero acceleration of tape past the recording or playback head due to eccentricities in rotating components, tape elasticity, friction, and a variety of other causes. These effects are compounded considerably when the entire tape transport mechanism is in motion and experiencing vibration, as is the case in an airborne system. In most applications, an unmodulated frequency is recorded along with the data which, upon playback, is compared against a reference frequency and the difference between them used to control tape velocity. Such velocity error compensation can also be used to remove some flutter components, but such corrections are limited to fairly low frequencies, and attempting to broaden the bandwidth of the servo system will result in an underdamped system which will actually increase flutter above some frequency and will eventually lead to instability and oscillation in the correction loop.[1]

Flutter is of no concern unless it affects data. The effects that flutter can have are due both to its amplitude and frequency distribution, and to its repeatability or predictability. When the data recorded on tape is formatted as an FM carrier, the flutter signal will modulate those carriers, and in so doing degrade the desired signal. The effects of modulation of the carrier with the flutter signal become more severe as full-scale deviation of the carrier decreases. For example, a carrier whose full-scale deviation is ±40% would be deviated ±2.5% of full scale by a 1% flutter, while IRIG Channel 21A, 176 KHz ±2 KHz would be deviated ±8.8% of full scale by only 0.1% flutter. Frequency of the flutter signals, if of the

1 Law, E. L., "Frequency Response of Tape Transport Servo Systems," ITC proceedings, Volume XII, 1976.

same spectral content as the data signals, cannot be removed from the discriminator outputs by filtering. Additional complications arise in the airborne situation when the subcarriers are fed by transducers measuring vibration or sound levels, Subcarrier deviation for such signals is set such that the subcarrier will not overdeviate on the strongest signals, which may be present only for small amounts of time. Consequently, the majority of the signals are deviating each subcarrier only a small portion of full-scale deviation, and the flutter-induced signal is larger in proportion. Additionally, when the mechanical input to the system arrives that will cause the transducers to produce large signals, the same mechanical input is put to the tape transport, increasing the flutter signal at that point. As the tape recorder ages, moreover, the flutter becomes more pronounced.

If the possibility exists that data could be affected by tape flutter, it then becomes necessary to compare various tape recorders to determine which recorder is most suitable for any particular test series, and to observe a tape recorder's flutter performance as a function of age. To characterize the record process only, it is necessary to separate those flutter contributions of the playback process, or to play back the tape, for analysis on a machine whose flutter contribution is orders of magnitude lower than that of the tape recorder whose flutter we wish to measure.

Use of the velocity error servo control signal is not acceptable for this procedure, since the flutter of both the recorder and the playback machine will have equal effects on the signal even with the velocity servo disengaged. If the recorder has at least one playback head, however, it would be possible to detect the flutter in the air while the recording is being made, and placing the recovered flutter signal on a wide-deviation voltage-controlled oscillator for recovery and analysis in later playback on the ground.[2] Since the small deviations of the original signals cause wider deviations on the VCO, the effects of flutter in the playback process will be orders of magnitude lower in proportion, as desired.

The equipment for such a setup, in addition to a tape recorder, would be a discriminator made to respond to fairly low deviation signals (an example of which is a standard tape flutter meter), and a wide-deviation VCO to put the recovered error signal back onto the tape. The VCO signal, when recovered and decoded in playback, can then feed spectrum analysis equipment which then provides the desired recorder-only flutter data.

In the aircraft environment, however, the bulk, power supply requirements, and vibration sensitivity of the discriminator may preclude the practicality of such a test. However, if the recovered velocity error control signal (or any other fixed-frequency signal placed on tape for this purpose) is beat against a second unmodulated signal of nearly identical frequency, a difference signal can be produced which is still modulated by the flutter frequencies and

2 Law, E. L., "Analysis of the Power Spectral Density of Tape Recorder Flutter," Pacific Missile Test Center, Point Mugu, California, TP-76-7, 26 March 1976.

can be easily recorded. Since the translation operation changes the center frequency of the carrier but not its information deviation in Hertz, the deviation in terms of percent of carrier frequency is amplified. If, for example, the resultant frequency is one one-hundredth of the original, the deviation due to flutter is 100 times the original, easily masking the effects that might be produced in the playback machine. The velocity error servo in the playback system can be operated from the original high frequency signal, with the servo loop filters set to ignore all but the lowest frequencies present in the error signal.

The downconverted signal is relatively insensitive to velocity errors, which are not multiplied by the downconversion process. For example, if the playback machine is operating at 60 IPS but the original recording was made at 59 IPS, the resulting flutter carrier signal will be 60/59 the original on playback, rather than the much higher frequency that would result if the ratio of the two frequencies were multiplied by the downconversion process. Thus if a DC term due to velocity error is present on the carrier resulting from the downconversion process, the error will not cause a serious shifting of the carrier frequency which might drive the discriminator used for analysis of the signal to either bandedge. If the velocity error servo is used in the playback process, this term can be removed almost entirely.

Two systems, one operating on the flutter compensation signal only, and the other using the downconverted signal, were compared at NWC. The resulting flutter spectra would be due, depending on the system, to just the recorder or to the record-playback configuration. The test recorder and the playback machine were Ampex FR-100 units, which produce measureable flutter components in a static environment. Tape speed was 60 IPS, and the frequency used for the first oscillator was 315,625 Hz. The second oscillator, used for downconversion, was 318,906. 25 Hz; the difference frequency was therefore 3281.25 Hz, and the flutter amplification resulting from the conversion was thus 96.19. The frequencies used were selected from crystals on hand; exact values are not significant, but the resulting flutter amplification must be entered into the calculations.

The downconverted signal was fed to an EMR 4140 tunable discriminator set at 3280 Hz with ±15% deviation full-scale sensitivity, and the output lowpass filter set at 200 Hz. Although the discriminator is capable with these settings of an output passband of 500 Hz, the flutter components for which we were looking were in the lower frequency range. A plot of flutter as a percentage of tape velocity as a function of frequency is shown in Figure Two. This spectrum is due to flutter on the recording machine alone, since (assuming the two machines have similar flutter amplitudes) the flutter responses of the playback machine are suppressed by 39.66 dB by the downconversion process.

Recovery of the flutter components due to both machines is complicated by the fact that a velocity difference between the two machines makes the carrier more difficult to locate. The 315,625 Hz carrier was fed to an EMR 410 digitally-programmable discriminator, and set to deviation limits of ±10 KHz. These limits represent a maximum deviation of ±3.168%, while to produce a signal of equal magnitude to that recovered from the translator configuration would require a full-scale deviation of 0.16%, assuming that the playback machine produced no new flutter to measure. An outboard amplifier was required to bring the output of the discriminator up to the level required for the spectral plotter, which introduced some hum and noise. Additionally, since long-term velocity errors (wow) of the recorder and/or reproducer caused the signal to occasionally get close to the discriminator bandedge and consequently overload the amplifier, a one Hz highpass filter was required between the discriminator and amplifier. The resulting spectrum, shown in Figure Three, shows the flutter resulting from the recording-playback process. Inasmuch as the signal from this test is obviously not merely twice the recorder's contribution, but rather has attributes of its own, the source of flutter could not necessarily be predicted even between two similar machines.

Analysis of the data obtained shows energy of at least seven frequencies between ten and 200 Hz where the individual contribution to flutter is greater than 0.1% of the tape recorder's velocity. Each of these components would introduce an error greater than 12% of the peak-to-peak bandedge voltage of an IRIG Channel 21A subcarrier. Frequencies at which these flutter components are present are 14, 19, and 30 Hz, which might be removeable by velocity error compensation, but also at 39 Hz, and at five peaks between 100 and 200 Hz, which might be removable by electronic means but could not be corrected with the velocity servo. Clearly, without observation of this phenomenon, outputs taken from the subcarrier discriminators would be assumed to contain those signals actually due to the tape recorder flutter, giving erroneous results. These problems are only compounded by vibration of the recorder, and the results can seriously affect data, especially if the data is such that less than full-scale signals are encountered a large portion of the time.

A schematic diagram of the device used for the oscillator/downconverter is shown in Figure One. Crystals Y1 and Y2 are used for the high-frequency oscillator to be used on the tape recorder and for the downconverter local oscillator, in either order. Digital divide-by-sixteen counters with intermediate stages accessible are provided to allow the frequency to be brought within range of the tape recorder with a wide variety of crystals. The 74S140 drivers are used to drive the mixer and the tape recorder with a 50 to 75 ohm source.

<u>Conclusions</u>. The use of tape recorder characterization for flutter is indicated whenever flutter components might arise in magnitude or in frequency content such that data will contain those flutter components and thus be degraded. Such characterization is required to establish confidence limits in data gathered by any system, and for comparison of various types of recorders. The flutter problem is made more severe in a moving environment, especially when the movement induced is random or tied in some way with what is to be measured. Measureable signals exist that cannot be fully compensated for by present equipment, but this does not eliminate the requirement to know what those signals are.

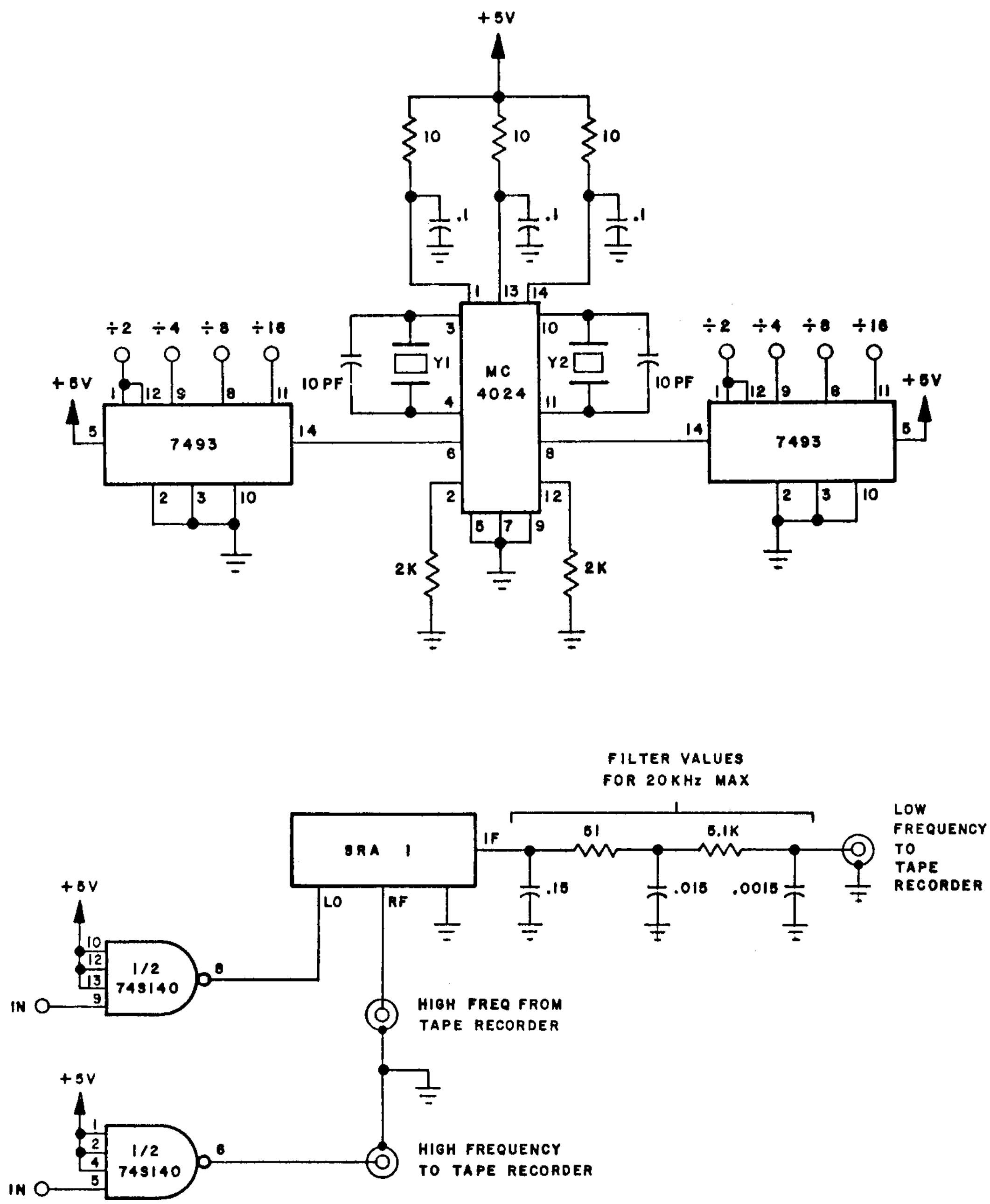

Figure One: Circuits Used in Flutter Signal Translator

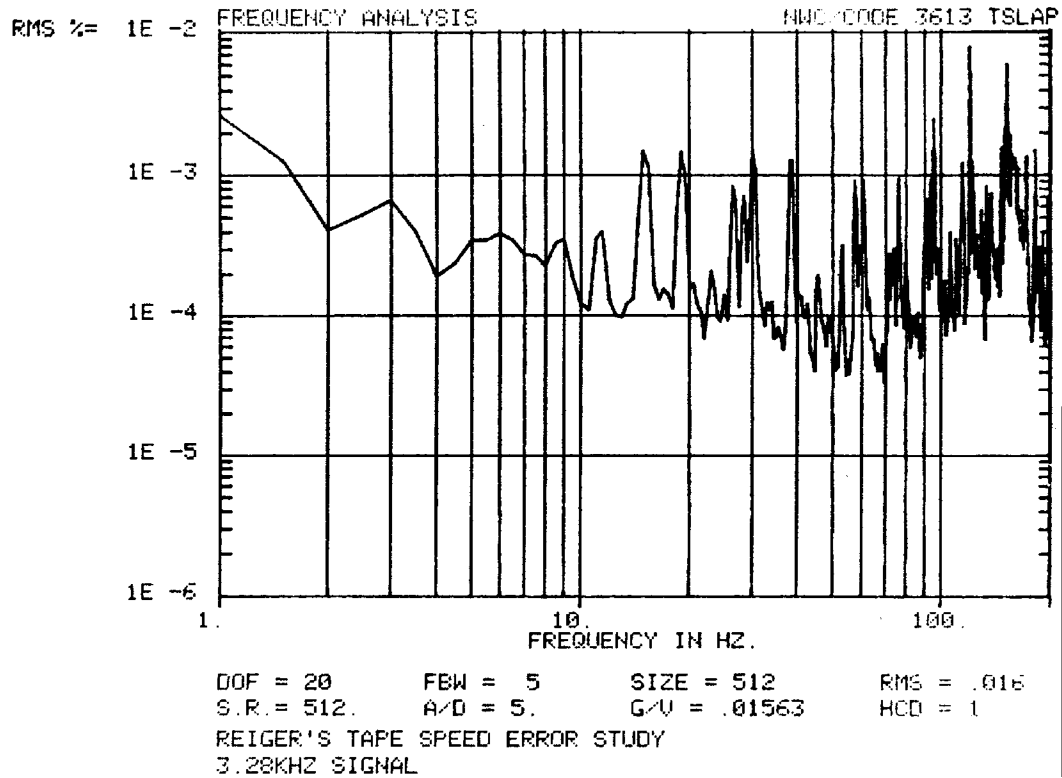

Figure Two: Tape Flutter Plot--Recorder Only

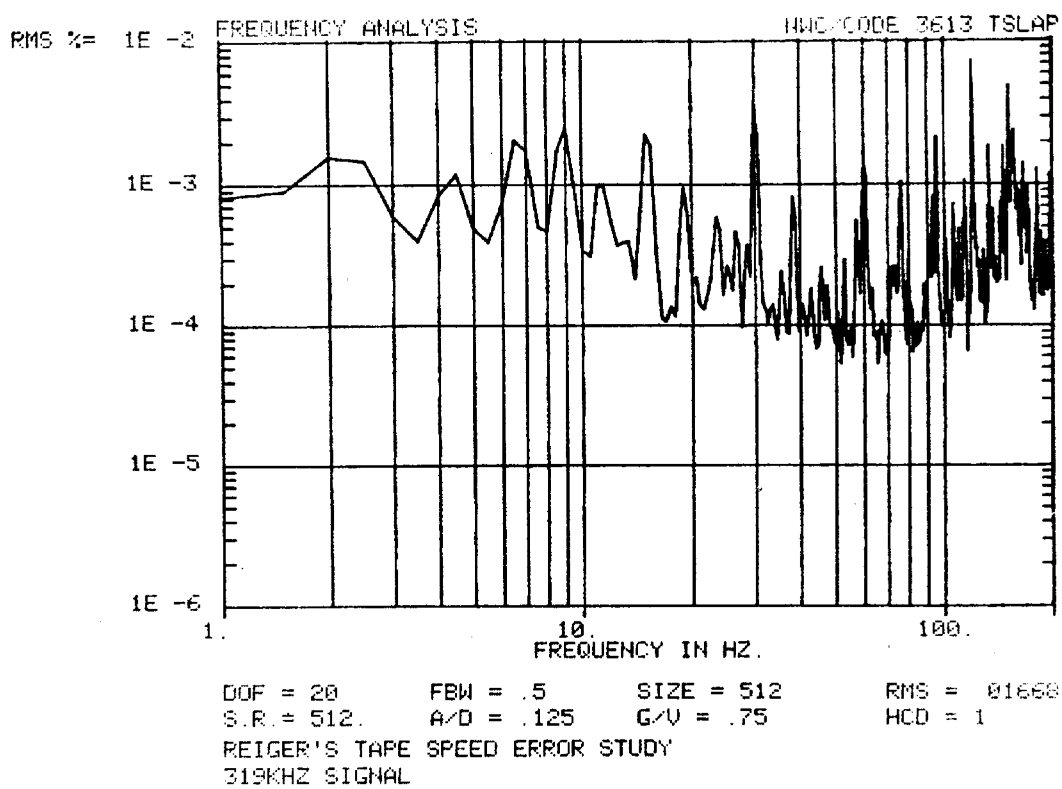

Figure Three: Tape Flutter Plot--Recorder and Playback Machines Combined