SPSC2003: Phonetic Science: Acoustics of Speech and Hearing

AUDIO CASSETTE RECORDER LINEARITY

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Introduction

[Note: use your introduction to create a context for the experiment. Try to think about why the experiment may be useful to do, justify the way in which the experiment is constructed and set out what you hope to find]

Audio recorders are widely used within speech and hearing science for making a permanent record of speech signals so that speech can be analysed off-line, distributed or archived. However every audio recorder is imperfect in the sense that the output signal from the recorder is inevitably a modified version of the input signal. For any application it is necessary to ensure that the type and size of such modifications do not invalidate any subsequent analysis of the signal. This is particularly important when the recorded signal is to be analysed using instrumental methods, where noise and distortion caused by the recorder may affect the numerical results of, for example, fundamental frequency or formant frequency measures.

Audio cassette recorders are analogue devices which transform a low-level electrical signal into a pattern of magnetization on a thin plastic tape which has been coated with small magnetic particles (typically ferric oxide, or chromium dioxide). Before recording, the magnetization of the individual particles are randomly oriented such that the overall magnetization of any region averages to zero. After recording, the magnetization of any area is an analogue of the input signal, with positive input voltages signified by the particles being mostly oriented in one direction, while negative voltages signified by the particles being mostly oriented in the other. During playback, the magnetization pattern on the tape induces a small current in the playback head which is amplified to reproduce the input signal.

This basic recording mechanism has a number of deficiencies. These include (i) very small signals are not large enough to change the orientation of the magnetic particles, and so are not recorded at all, (ii) particles which are not affected by the recording process continue to have random orientations which add random electrical noise to the recovered signal, and (iii) the tape has a maximum signal amplitude that can be represented – once all particles are oriented in the same direction. The first issue can be improved by the introduction of a bias signal during recording. The action of the bias signal is outside the scope of this report, but more information can be found in [1]. The perceptual effect of added tape noise (tape 'hiss') can be ameliorated to some extent through signal pre-emphasis and de-emphasis – this is the basis for the Dolby™ method of noise reduction [2]. However the existence of a maximum recordable signal amplitude must be the concern of the users of any audio recorder. If recording levels are set too high then the largest amplitude excursions of the input signal are not captured (this is sometimes referred to as "peak clipping") with the consequence that the reproduced signal is a distorted version of the input. However if recording levels are set too low, then the low-level components of the input signal may be masked by tape noise, leaving the overall recorded signal with a poor signal-to-noise ratio.

This experiment investigated the linearity of a typical audio cassette recorder, here the Marantz CD-XXX. A range of tones were recorded and the amplitude of the recorded signal was compared to the amplitude of the input signal. The results allow the assessment of the range of amplitude values within which the recorder functions well, and the extent to which linearity is lost for very low-level and very high-level signals. *[Note: for lab experiments, the Method is provided on the handout, so there is no need to copy this into your report. Instead, simply summarise the means by which the experimental results were obtained as the last paragraph of your introduction.]*

To obtain the measures of linearity, the audio cassette recorder was fed input sinusoidal signals at 1kHz from a sine-wave generator. The input voltage was varied from 0.15mV to 1V, and recordings were made on a Type I (ferric) audio cassette. The RMS amplitudes of the input signal and the replayed output signal were measured with an AC millivoltmeter.

Results and Discussion

[Note: for lab reports it is most convenient to merge your presentation of experimental data with your analysis of its interpretation, rather than leaving all discussion to the conclusion section].

For assessment of linearity, the input tone was varied in amplitude across 35 roughly logarithmic steps, and the amplitude of both the input tone and the recorded tone was measured with an accuracy of about 1%. The measured input and output voltages are shown in Table 1, columns (a) and (c). To make comparison across such a wide range of voltages more easy to see, the values have also been converted to decibels with respect to a reference of 1mV using the formula

$$dB = 20.\log_{10}\left(\frac{Voltage}{1mV}\right)$$

with the decibel values in columns (b) and (d).

A graph of the output amplitude as a function of input amplitude in decibels is shown in Figure 1. At low levels the output of the recorder appears to be at a small voltage independent of the input voltage, this is presumably due to the added tape noise. This noise appears to be at about 2mV RMS, or about –50dB below the maximum recordable voltage. Thus the best possible Signal-to-Noise Ratio of the recorder is only 50dB, and even this may not be achieved for signals recorded at levels significantly lower than the maximum.

At high levels, Figure 1 clearly shows how the output voltage reaches a maximum of about 1volt (60dB re 1mV) for inputs above 600mV regardless of their size. This means that any input signal with amplitude variations larger than 600mV will be clipped and distorted by the recording system.

Overall, this recording system seems to be fairly linear over a 40dB range between input voltages of 1mV and 100mV, but with increasing amounts of amplitude compression above 100mV.

[Note: for your final paragraph, just add a few summary remarks, perhaps thinking about the consequences of your experimental finding for clinical practice or research].

Audio cassette recorders are analogue systems often designed to achieve a low selling price rather than the highest audio signal quality standards. This particular experiment on the linearity of one such recorder shows that good recordings may be made, but only within a relatively small dynamic range. Low-level signals are corrupted by added noise, while high level signals may suffer amplitude compression. For applications where a higher level of signal quality is required, it may be preferable to look elsewhere, for example at digital audio recording systems.

Bibliography

[Note: if you present facts in your report that are not supported by the experiment and not in the common knowledge of the target readers of your report, you should always indicate where you obtained the information.]

[1] HyperPhysics, sound and hearing: Biasing in Tape Recording.
http://hyperphysics.phy-astr.gsu.edu/hbase/audio/bias.html

[2] Dolby Laboratories:
http://www.dolby.com/assets/pdf/tech_library/212_Dolby_B,_C_and_S_Noise_Reduction_Systems.pdf

Table 1. Raw measurements of input and output amplitudes for 1kHz tone

(a) Input (mV)	(b) Input (dB re 1mV)	(c) Output (mV)	(d) Output (dB re 1mV)
0.15	-16.5	1.90	5.6
0.20	-14.0	2.00	6.0
0.40	-8.0	2.20	6.8
0.60	-4.4	2.70	8.6
0.80	-1.9	3.40	10.6
1.00	0.0	4.20	12.5
2.00	6.0	7.80	17.8
3.00	9.5	11.00	20.8
4.00	12.0	15.00	23.5
5.00	14.0	18.50	25.3
6.00	15.6	22.00	26.8
7.00	16.9	26.00	28.3
8.00	18.1	30.00	29.5
9.00	19.1	33.00	30.4
10.00	20.0	37.00	31.4
20.00	26.0	77.00	37.7
30.00	29.5	115.00	41.2
40.00	32.0	155.00	43.8
50.00	34.0	190.00	45.6
60.00	35.6	230.00	47.2
70.00	36.9	270.00	48.6
80.00	38.1	300.00	49.5
90.00	39.1	330.00	50.4
100.00	40.0	360.00	51.1
200.00	46.0	620.00	55.8
300.00	49.5	780.00	57.8
400.00	52.0	890.00	59.0
500.00	54.0	970.00	59.7
600.00	55.6	1000.00	60.0
700.00	56.9	1000.00	60.0
800.00	58.1	1000.00	60.0
900.00	59.1	1000.00	60.0
1000.00	60.0	1000.00	60.0

Figure 1. Graph of output amplitude against input amplitude for 1kHz tone