A MICROPROCESSOR IMPLEMENTATION OF A HEARING BANDWIDTH TESTER

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1. INTRODUCTION.

There is increasing concern about the effects of industrial and environmental noise on our hearing. Unfortunately the current methods of measuring hearing loss do not give any significant measurement of hearing loss until it's too late. These work by measuring the absolute hearing threshold. However, recent research [1] has shown that a more sensitive and relevant measurement of incipient hearing loss, due to noise exposure, may be found by measuring the auditory bandwidths of our hearing system. At the present time only one of these measurement systems, based on the method of Evans and Pick, exists. The purpose of this project was to develop a simple to use and portable version which could be used as a "front-line" screening instrument to protect people from the insidious, but devastating, effects of noise induced deafness.

The paper will describe the result which was an implementation of the Comb Filtered Noise technique done entirely in software on the Motorola 68000 microprocessor. The paper will describe the techniques used in the implementation, particularly the methods used to realise the comb filtered noise, and report on its use. The all-microprocessor implementation means that it is a potentially cheap and viable instrument for screening.

2. EFFECTS OF NOISE ON THE AUDITORY FILTER SHAPE

Many experiments have been done on the effects of noise in the hearing system. Results have shown [1-2] that following noise exposure, there are two effects on the Psychophysical Tuning Curve (PTC), as shown in Figure 1.

- The threshold, (i.e. the tip) of the PTC is temporarily lowered.
- The bandwidth of the PTC is increased.

3. EARLY DETECTION OF HEARING LOSS

In order to detect the early signs of hearing damage it is important to find out which of these two effects shown in Figure 1 occur first.

Conventional hearing testers try to measure the threshold of the Psychophysical Tuning Curve, as a function of frequency, using pure tones . The results of this kind of test, known as pure tone audiograms, measure the Threshold Shifts that occur with hearing damage due to noise exposure.

However, a survey of the effects of noise exposure on frequency resolution [1-2] showed that psychophysical tuning curves became broader following noise exposure, even when pure tone audiograms showed very little or no Temporary Threshold Shifts (TTS). Furthermore, this broadening lasted much longer than the TTS. This suggests that testing the frequency

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resolution of the ear, that is, determining the bandwidth of PTCs, would be a more sensitive indicator of the damaging effects of noise exposure.

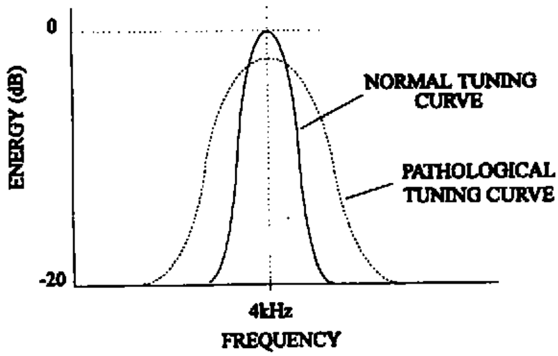

Figure 1 Diagram Showing the Effects of Noise Exposure on the Tuning Curve

A particularly good example of a bandwidth increase was obtained by Prof. Evans. A subject's bandwidth increased from about 800Hz to over 3000Hz after attending a rock concert! Most bandwidth increases are not as much as this, however, and results have shown that noise damage usually increases the 'normal' bandwidth of 700 Hz by about 15%.

It would seem therefore that a rapid and inexpensive method of measuring the ear's frequency resolution would provide a practical means of detecting incipient noise induced hearing loss. One such method is the comb filtered noise method.

4. THE COMB FILTERED NOISE METHOD

Comb-filtering can be achieved by mixing a time delayed signal to the original signal. When this is done, energies at harmonically spaced frequencies are enhanced and the energies at the intervening frequencies are reduced.

The general equation for the intensity spectrum of a Comb-Filtered Noise (CFN) signal is as follows:

$$I_N(f) = I(1 \pm \cos 2\pi f \tau)$$

I = Intensity spectrum of signal
t = Time delay between the two signals

The CFN signal is often quoted in terms of Relative Peak Density (RPD). This basically relates the time delay to a reference frequency, in this case the centre frequency of the tuning curve.

$$RPD = tF$$

where: t = time delay

F = Centre frequency of tuning curve.

Typical RPDs used are: 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0.

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This signal is then presented to the ear. A certain amount of energy from the signal will then enter the tuning curve of the ear, shown shaded in Figure 2. The subject then varies the amplitude of a tone signal, which is superimposed on the CFN signal, until it is just audible. This gives a measure of the amount of noise energy within the bandwidth of the auditory filter.

A feature of the CFN signal is that the CFN spectrum can be inverted by subtracting, rather than adding, the time delayed signal from the original signal.

By measuring the tone thresholds at the inverted and non-inverted settings, and then subtracting these thresholds to get threshold differences for each CFN relative peak density, the bandwidth can be calculated. This is because as the RPD becomes commensurate with the bandwidth the threshold difference between the inverted and non inverted signals becomes small due to the presence of noise within the auditory filter bandwidth irrespective of whether the CFN is inverted or not.

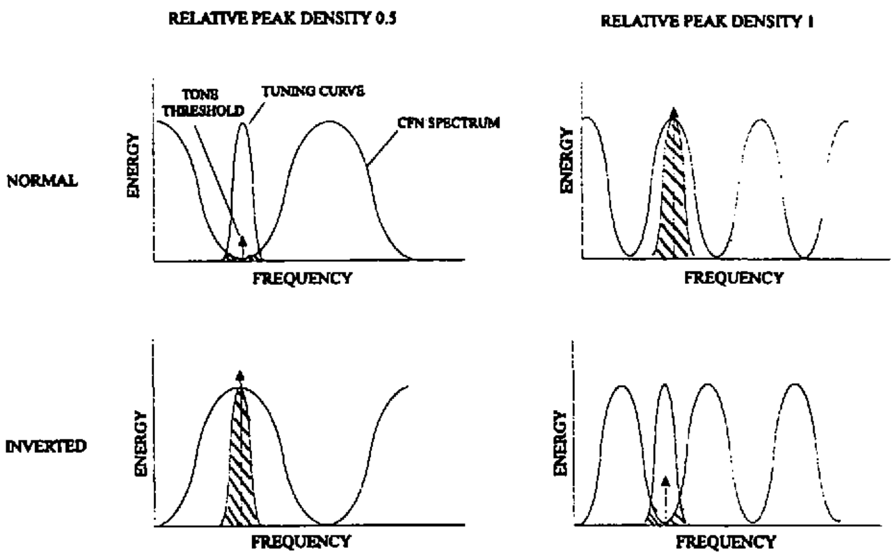

Figure 2 Diagram Showing CFN Methods

4.1 Calculating the Bandwidth Using CFN method

Having decided that the CFN method would be the most appropriate method to use, the methods that are used to determine the bandwidth needed to be investigated in more detail.

There are two main methods used to calculate the auditory bandwidths. These are: the Fourier Transform method and the Gaussian Iterative method.

The Gaussian Iterative Method assumes that the auditory filter is Gaussian in shape. The threshold differences that would be obtained using this tuning curve can be determined by calculating the amount of noise energy entering the tuning curve from the CFN signal, and assuming the threshold will be at a certain signal to noise ratio. These theoretical threshold

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differences are then compared to the results actually produced in the test. By varying the parameter, These calculated thresholds are then compared using a least squares iterative technique, to the actual results to see what value of bandwidth gives the closest fit.

The Fourier Transform Method makes no assumptions on the shape of the filter, but does assume that it is symmetrical. This method uses weighted cosines to relate the auditory filter shape to the threshold differences that were obtained in the test.

Both methods give reliable and accurate results [1]. Therefore we decided to implement the Fourier Transform method for the following reasons:

- No assumptions were made on the shape of the tuning curve (although it has to be symmetrical).
- This method seemed to be quicker and more efficient than the Gaussian method.
- We thought that this method would be more 'stable' if some of the threshold difference results were 'out of line'.

5. IMPLEMENTATION

The system was implemented entirely in software on an 8MHz MC68000 microprocessor. A block diagram of the system is shown in figure 3. Note that no DSP or specialised hardware was used. The required signals were generated entirely in software on the MC68000 and sent to a D/A converter. The microprocessor also handled the Bekesy tracking audiometry.

In order to do this extensive use was made of table lookup techniques. To reduce the amount of memory required a method of producing the different tone levels using a combination of shifts, adds, and table lookups was used. This allowed real-time operation using only 6 tables for the tone. We also pre-calculated the CFN signal in the gaps between tests, as these remained constant for a given RPD threshold test. The initial random numbers for CFN signal were generated using the subtractive technique [3]. These were then added to, or subtracted from, a delayed version to give a CFN signal with the required RPD. This signal was then loaded into a large cyclic table which was read out and added to the scaled tone signal to provide the stimulus signal. The resulting measured output signal spectra for normal and inverted CFN signals are shown in Figure 4.

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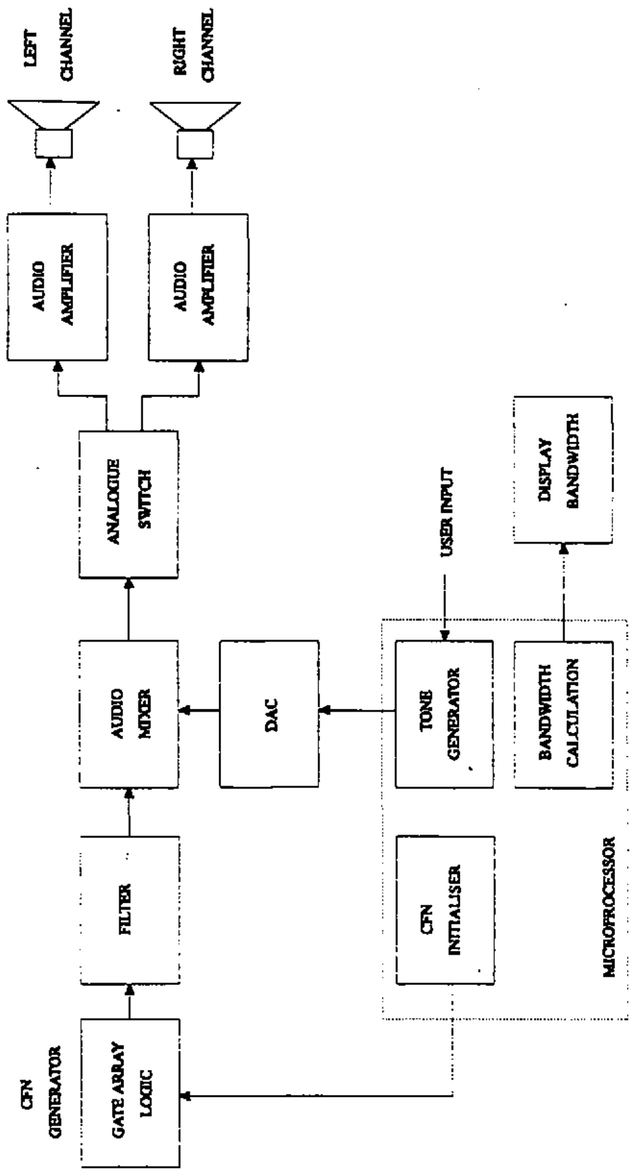

Figure 3 Diagram Showing the Software Based System

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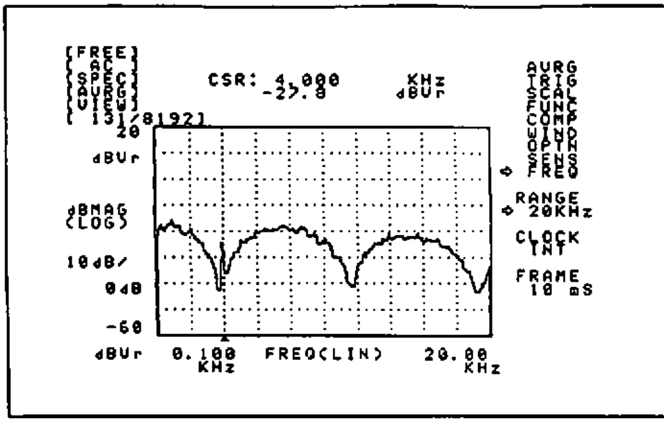

Figure 4a Spectrum the Tone Mixed with a Non Inverted CFN Signal

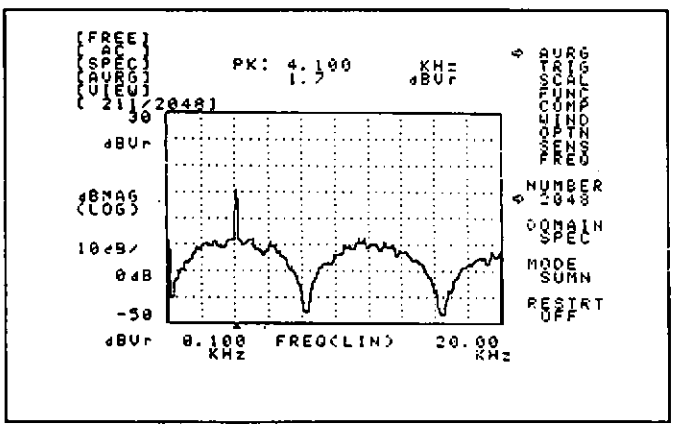

Figure 4b Spectrum the Tone Mixed with an Inverted CFN Signal

6. RESULTS

A group of 10 people, in the age range 20-24, with normal hearing were tested. Theoretically, these subjects should all have about the same bandwidth. All subjects were given a verbal explanation of the test procedure and a description of the signals they would be hearing.

Threshold Differences were obtained for the right ears of all test subjects, although time allowed for only a few of the subject's left ears to be tested. In order to get a good comparison of the subject's bandwidths, only the right ear results are shown.

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The bandwidth results are listed, for each of the test subjects, in Table 1. Normal hearing people in the same age group, in this case 20-24, should have very similar bandwidths. The results show a mean bandwidth of 759Hz, with a standard deviation of 42Hz.

These results compared well with the test results obtained from similarly aged subjects using the Keele CFN system. However the higher intensity CFN signal we used caused our bandwidths to be slightly larger than the Keele system where a 70dB SPL CFN level had been used.

Subject	Bandwidth (Hz)	Bandwidth Difference from Mean (Hz)
AP	692	67
AP2	697	62
KG1	782	23
KG2	741	18
IC1	780	21
IC2	814	55
JE	795	36
TB	757	2
TR1	760	1
TR2	772	13
Mean:	759	
Standard Deviation:	42 Hz	

Table 1 Results from the Tests done on Normal Hearing Subjects

7. FURTHER WORK

Some of the test subjects complained that the test seemed to be too long, although others had no complaints. Market research also showed that GPs did not object to tests being about half an hour long. However, if the system were to be marketed to screen employees of large companies, the test time may need to be reduced.

The length of the test can be reduced by finding which CFN Relative Peak Densities (RPDs) are the most sensitive indicators of potential damage. The most sensitive RPDs are those around the 'turning point' of the threshold difference against RPD.

By finding out where this turning point occurs, a measurement of the bandwidth can be done more quickly. In fact, the test need not start at RPD 0.5, instead it could start at RPD 2, and then use estimates of the 0.5, 1 and 1.5 RPD threshold differences.

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We decided to use the Fourier Transform method to determine the bandwidth. However, Professor Evans has found that, in general, the Iterative Gaussian method is slightly more accurate.

Comparing the results obtained from both methods, we observed that the Gaussian results were about 10% higher, on average, using the same threshold differences. However, it is difficult to ascertain which is the 'correct' bandwidth. More research will need to be done in this area.

8. CONCLUSIONS

An implementation of a hearing bandwidth tester, implemented entirely on a standard microprocessor, has been developed. Although it uses no DSP hardware, judicious programming has resulted in a fully functional system which would be inexpensive to produce. It is hoped that such a system may for a useful "front line" weapon in the battle against noise induced hearing loss.

9. ACKNOWLEDGEMENT

The authors would like to acknowledge the generous help, advice and information given by Professor E F Evans.

10. REFERENCES

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