ABSTRACT

The Fast Fourier Transform (FFT) technique has long been used for spectral analysis but it has not been fully exploited for data compression purposes. This paper presents the concept for compressing telemetry data using the FFT in such a manner that the time domain waveform can be recovered. The sampled time-domain data is transformed into the frequency-domain data and only the significant components are selected and transmitted. Actual flight data is used to simulate the data compression performance. Some comparisons are made between this FFT approach and other possibilities.

INTRODUCTION

We examine the possible application of the Fast Fourier Transform (FFT)/Inverse Fast Fourier Transform (IFFT) techniques to telemetry situations where data compression is an objective. It is shown using actual flight data as examples that transmission bandwidths can be reduced by as much as 5 to 1 and still retain good time fidelity. For signals likely to be encountered in flight test telemetry, it compares favorably with other data compression techniques [1],[2]. This is accomplished by performing a complex FFT and keeping only the most significant spectral lines.

Filtering in the time domain can be accomplished using the FFT/IFFT pair where certain spectral lines are removed while in the frequency domain. When this process is made adaptive in the sense of keeping the significant spectral lines rather than a fixed subset, data compression can usually be effected. The penalty for this technique is that the overhead necessary to identify the significant lines must be included in determining net bandwidth saving. It has the important advantage that usually no significant information will be lost. It is necessary to be selective in the lines retained because no data compression results if all the spectral lines from a time to frequency transformation are retained. A situation that might be of considerable interest is where the signal comes from a vibration sensor. Here, a resonance or set of resonances above a background of random
signals would be preserved using this technique. The merit of the technique in this situation is that the resonance can be located over a wide frequency span without being lost. A limiting case occurs when the lines become sensibly equal in amplitude (i.e. white noise) making selective retention of dubious value. In this event a special selection process might be employed which preserves total signal amplitude.

**THE TECHNIQUES**

The Fourier Transform pair allows signal to be described equivalently in both the time and frequency domains. By taking a sampled time domain signal and applying the discrete version of the Fourier Transform, we can display the frequency components of the signal. The frequency resolution of the result depends on the number and time resolution of samples going into the process. It is necessary that both real and imaginary components of the result be retained if the time waveform is to be recovered using the inverse transform. The net result is that the total number of samples required in the two domains is the same. No data compression results from this direct operation. One way of reducing the amount of data is to combine lines into fractional octave intervals. However, this is only useful if energy per band is the parameter of interest. Data reconstruction in the time domain is no longer possible after this has been done. Typically a large fraction of the lines in a real signal are small in amplitude which can be ignored at only a small cost in overall data fidelity. Figure 1 shows a typical signal segment in which the original and reconstructed version are compared after nearly 75% of the lines were deleted before the inverse transform was performed. As fewer lines are retained, the error of the reconstructed waveform increases. This is shown in Figures 2 and 3. It becomes the responsibility of the system design to make the appropriate compromise weighing accuracy versus available bandwidth. If information about possible high frequency components is most important, then the thresholds can be tailored to deemphasize the low frequency components. It is evident from the example signal segments that the largest potential errors occur at the discontinuities of the data sets. This is the result of windowing and can be improved by slightly overlapping the FFT data sets. An overlap of 10% is sufficient for the range of data set sizes considered here. Before an estimate can be made of the potential savings in transmission data rates, the approach to line identification overhead needs to be examined. A worst case can be determined by simply binarily coding each potential line location and attaching it to the complex number data value for each retained line. For example, in a 256 point FFT, there are a maximum of 128 lines. A seven bit code uniquely identifies each one. Against a complex pair of 8 bit data words this represents a 44% overhead. For a 512 point FFT 256 lines result requiring an 8bit code or 3 words for every 2 words of 8 bit data.

More efficient techniques are possible. For example, a linear map of line locations can be created.(i.e. a ‘1’ if the line is to be retained and a ‘0’ if deleted) When organized into 8bit
words this comes to 16 words for the 256 point FFT. If more than 16 lines are retained, this method is superior to the one above. At 32 lines, for example the penalty is only 25%. Table 1 has been prepared where this approach as well as the binary coded location approach are shown. Only the bits necessary for proper line identification are counted with no attempt made to beat the results into a particular word size. The data values themselves are assumed to be 8 bit. For 1/4 of the lines retained the net bit rate is 34% of the original time representation and for 1/8 of the lines retained, it becomes 20.8%. Without overhead these numbers would be 27.7% and 13.9% respectively. Under this approach the savings is independent of the number of points assumed in the FFT. A 10% overlap was assumed.

COMPARISON WITH OTHER TECHNIQUES

It is useful to compare the result in data fidelity and timeliness using the subject approach with other possibilities. The basis for compressions will be that the available transmission bit rate is fixed and is inadequate for a particular signal using conventional sampling guidelines. One situation is typified by the signal shown in Figure 4. Here resonances or oscillations exist on an otherwise well behaved signal. It has already been shown how a 256 point FFT, where 1/8 of the samples are retained for the inverse transform does a respectable job of portraying what is going on in the time domain. With overhead added, the net data rate for that case is 20.8% of about 1/5 of the original. By lowpass filtering the signal such that a bit rate of 20% of the original is safe from an aliasing point of view, the presence of the resonances would never have been known. This is shown in Figure 5. Simply sampling the signal at 1/5 the rate would result in aliasing errors. Figure 6 compares the original with the reproduced signal after such inadequate sampling. This is sometimes the only choice available to the telemetry systems engineer where the bandwidth just isn’t there.

The transmission bit rates for Figures 4, 5 and 6 are all the same. The selective spectral line retention technique provides a much more accurate picture of the real situation.

The delays involved here are dominated by the time spanning the FFT data sets and might range from 10msec to 250msec depending on FFT size and sampling rates. For a 256 point FFT and sampling a 2KHz vibration signal it would be no more than 50msec. This is much less than might be experienced in schemes using a flexible buffer memory such as described in reference 2. Signals associated with a catastrophic event might be lost if the latency of the data is too long.

CONCLUSION

The increasingly available number of DSP type products capable of performing FFT’s in real time makes this a viable technique in telemetry situations. The bandwidth necessary to
telemeter a typical signal is only a fraction of that needed using pure PCM techniques. 
Alternately a severalfold increase in the number of signal sources that can be serviced over 
an available data link is evidently possible.

REFERENCES

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Las Vegas, NV, pp. 429-440.

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TABLE 1 DATA COMPRESSION EFFICIENCIES
FIGURE 1  ORIGINAL AND RECONSTRUCTED WAVEFORMS
RECONSTRUCTION USED 32 COMPLEX FOURIER
COEFFICIENTS
FIGURE 2 RECONSTRUCTION USED 16 COMPLEX FOURIER COEFFICIENTS
FIGURE 3 RECONSTRUCTION USED 10 COMPLEX FOURIER COEFFICIENTS
FIGURE 4(A) TIME DOMAIN SIGNAL IS RECONSTRUCTED WITH 16 FOURIER COEFFICIENTS
FIGURE 4(B) MAGNITUDE SPECTRUM. SOLID LINES REPRESENT RETAINED FOURIER COEFFICIENTS AND DOTS REPRESENT DELETED DATA.
FIGURE 5 FILTERING HAS REMOVED EVIDENCE OF OSCILLATIONS
FIGURE 6 RECONSTRUCTION AFTER INADEQUATE SAMPLING OF SIGNAL IN FIG. 4