Application Notes

Analysis of Transient and Non-Stationary Signals using the Real-Time Frequency Analyzers Types 2123 and 2133

by Roger Upton

1. Introduction

The Real-time Frequency Analyzer Type 2123/33 has two modes of operation highly suited to the analysis of transient and non-stationary signals, namely, input multispectrum and time mode. In input multispectrum mode, the analyzer is used to analyze and store the frequency domain evolution of a signal as a function of time or some other parameter. In time mode, on the other hand, an entire time signal is stored in the analyzer and later recalled for analysis in part or as a whole. This application note describes use of these two modes in the analysis of transient and non-stationary signals.

2. Use of Input Multispectrum in the Analysis of Non-stationary and Transient Signals

Multispectrum is a term used to described the ability of the 2123/33 to collect a complete array of spectral data. An input multispectrum is such an array collected at constant time intervals, allowing the 2123/33 to document a process as a function of amplitude against frequency against time. Two developments of input multispectrum are gated multispectrum and triggered multispectrum. Gated multispectrum allows the data collection to be synchronised with a repetitive event, such as a machine cycle, while triggered multispectrum allows data collection to be asynchronous and controlled by some third parameter. A further development is averaged multispectrum, where for repetitive events, multispectra collected for each event can be averaged together to average out, for example, random variations from event to event. All four types of multispectrum are equally applicable to the analysis of non-stationary and transient signals, and their use is described in the following section.

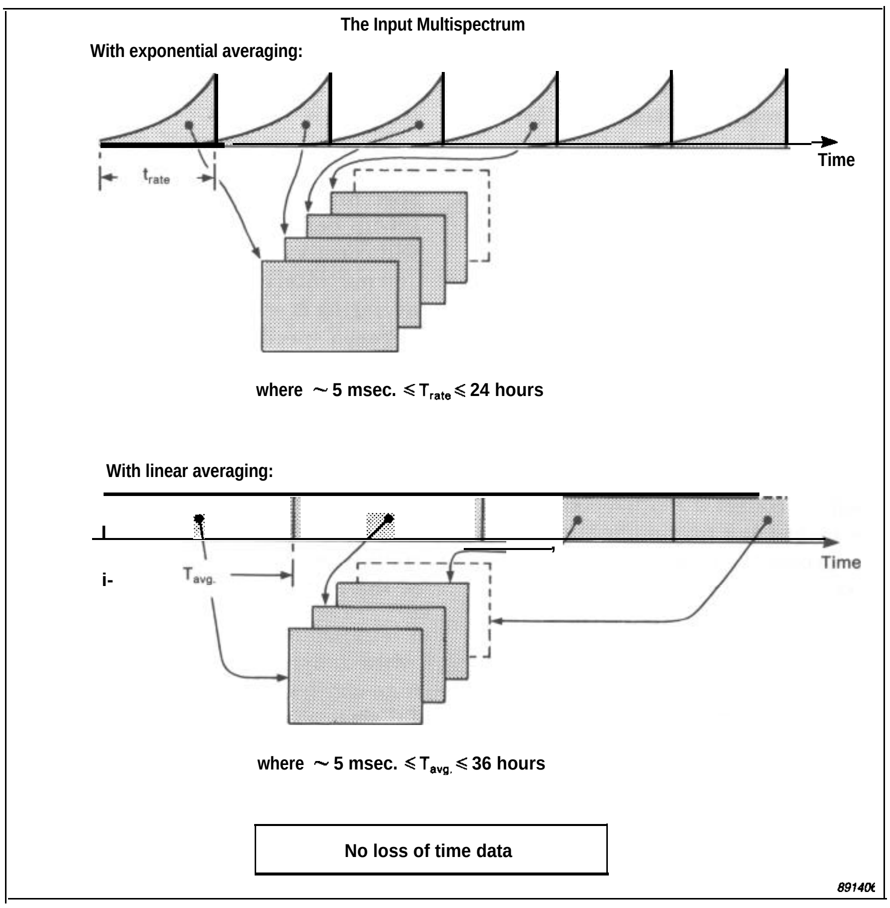

Fig. 1. Data collection in input multispectrum mode

2.1. Use of Input Multispectrum

Fig. 1 illustrates operation of the 2123/33 in input multispectrum mode. The precise operation of the analyzer depends on whether exponential or linear averaging is selected.

In exponential averaging, the input signal is continuously analyzed according to the exponential averaging time selected and spectra are stored at preset time intervals, the averaging time and the time interval between spectra being independent of each other. Each stored spectrum in the multispectrum therefore represents a "snapshot" of the ongoing analysis process at the time the spectrum was stored.

In linear averaging, the time interval between stored spectra is automatically set to be equal to the selected linear averaging time. The resulting multispectrum therefore comprises a series of contiguous linear averages. Note that these linear averages are exactly contiguous, in that there is no data loss between them.

The minimum time interval between spectra entering a multispectrum depends on a number of factors, such as frequency range, whether the data is in 1/1, 1/3, 1/12, or 1/24 octaves, whether one or two parameters are being measured, (the 2133 can measure two parameters simultaneously), and so on. The nominal minimum is 5 ms, this being for 1/3 octave audio frequency range single parameter measurements, although shorter time intervals are possible under special circumstances. The maximum time interval is 24 hours in exponential averaging and > 36 hours in linear averaging, although in linear averaging, the time taken to collect a multispectrum cannot exceed the maximum allowed linear averaging time, (36 hr: 24 min: 32s).

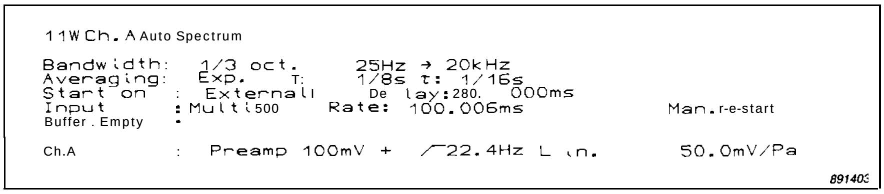

Fig. 2. A typical measurement set-up for collection of an input multispectrum

The maximum number of spectra in an input multispectrum also depends on a number of factors. For 1/3 octave audio frequency range single parameter measurements, this will be well in excess of 1000, although this capacity is reduced by about 1/3 when the time interval between spectra becomes small, (< 240 ms, nominal). Other factors, like the desire to leave memory space available in the 2123/33 for processing data might also mean that this capacity is reduced.

Fig. 2 shows a typical measurement set-up for collection of an input multispectrum. The "Input" fields of the set-up define that the multispectrum will consist of 500 spectra collected at 100 ms intervals, (since exponential averaging is selected, the time interval between spectra, or "Rate", can be set independently of the averaging time), while "Man. re-start" means that once the multispectrum has been collected, collection of another will first have to be enabled through the 2123/33 keyboard. The "Start on" fields, above the "Input" fields, define the triggering conditions required to start collection of the multispectrum. Here, an external trigger has been selected to give extremely precise triggering of the 2123/33.

Fig. 3 shows an example of use of input multispectrum to measure reverberation time, together with the corresponding measurement set-up. The 2123/33 is set to collect 100 spectra at 5 ms intervals, and since the excitation is to be an impulse, an internal trigger operating on the A-weighted RMS level is used to start data collection, a -50 ms trigger delay being set to enable capture of the leading edge of the impulse. The resulting multispectrum contains the reverberation decays as a function of frequency for the room under investigation. Fig. 3 shows just one of those decays, namely the 5 kHz 1/3 octave, displayed as a "slice" display, which is a plot of amplitude against position in the multispectrum for a single frequency. Each bar on the display represents a measured data point on the decay. The decays at other frequencies can be similarly displayed by selecting different frequency slices. Such slice displays can be calibrated in terms of amplitude against position in the mul-

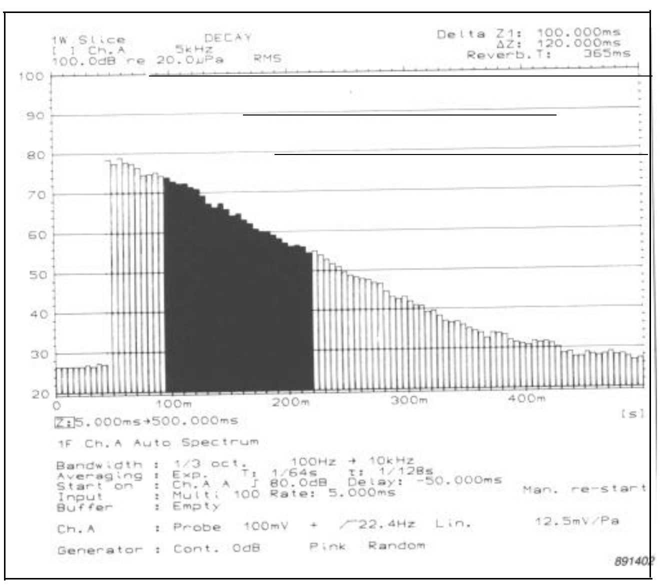

Fig. 3. An example of use of input multispectrum to measure reverberation time

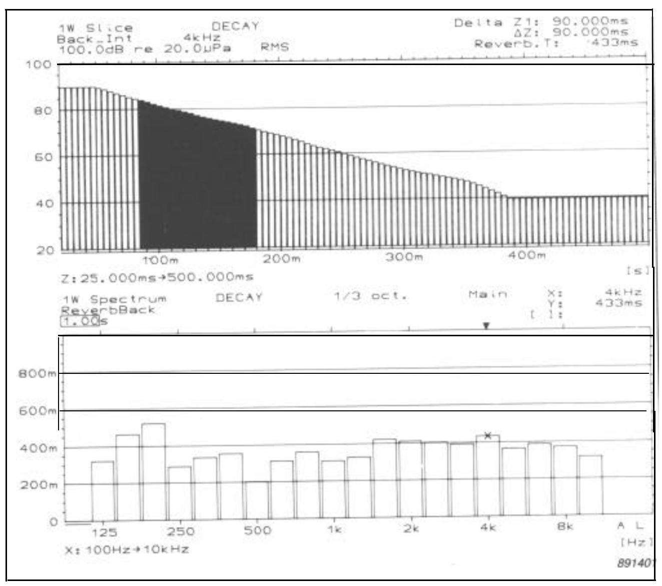

Fig. 4. Example of backwards integration, (upper display), and calculation of reverberation time as a function of frequency, (lower display), for the data captured in Fig. 3

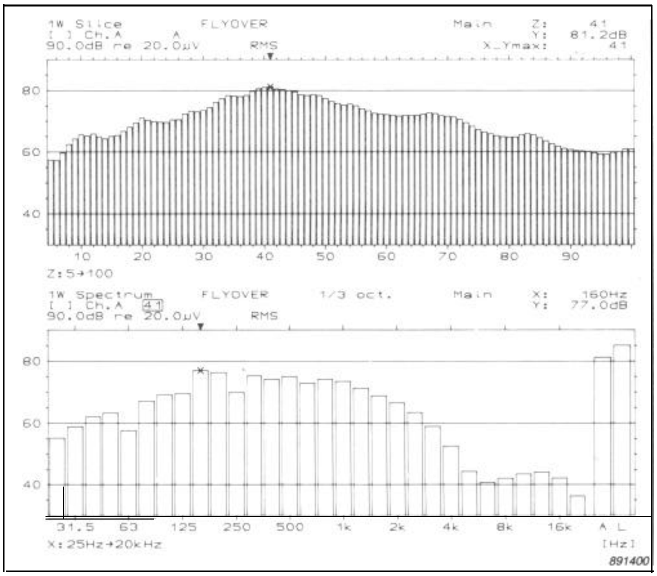

Fig. 5. Example of a multispectrum display for an aircraft flyover. An auxiliary cursor read-out has been used to identify theposition of the maximum A-weighted level, the corresponding spectrum being shown in the lower display

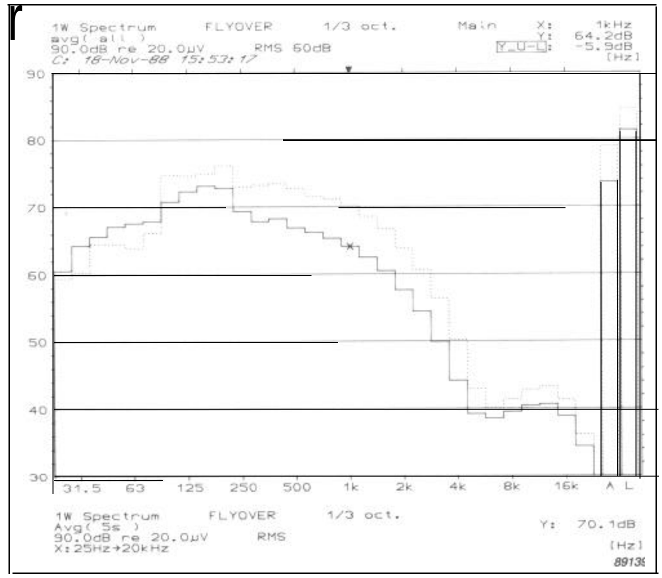

Fig. 6. Comparison of the average RMS spectrum for the entire fly-over of Fig. 5, (continuous line), with the average RMS spectrum for the 5 seconds around the peak A-weighted level, (dotted line)

tispectrum or amplitude against time, according to the wishes of the user.

In Fig. 3, a delta cursor has been used to calculate the reverberation time. Here, the calculation is made across the data points defined by the delta band. Fig. 4 shows two examples where the data has been further processed using the 2123/33, first with a backwards integration to smooth the data, and then to give the reverberation time as a function of frequency. The reverberation times calculated from the measured data are displayed as a bargraph, (the extra line under the graph at 100 Hz indicates that there was insufficient data there to make the calculation). A tabular display of the results is also possible.

Fig. 5 shows another example of use of input multispectrum, this time used in measurements on an aircraft flyover. In a dual display, the upper display shows the variation in the A-weighted RMS level as a function of position in the multispectrum. The auxiliary cursor field has then been used to identify the position giving the highest A-weighted level. The lower display has been set to show the spectrum at this position.

Fig. 6 gives another example of further processing of multispectrum data using the 2123/33, where the average RMS spectrum for the entire flyover is compared with the average RMS spectrum for the 5 seconds around the peak A-weighted RMS level.

2.2. Gated Multispectrum

Gated multispectrum is a development of input multispectrum. It allows the evolution of a parameter to be examined as a function of position in a repetitive cycle. A once-per-cycle trigger is needed by the 2123/33 to synchronise data collection. The 2123/33 then measures the cycle time and automatically selects a linear averaging time or, for exponential averaging, a time interval between spectra to suit the selected number of spectra in the multispectrum and the cycle time, (minimum linear averaging time or time between spectra, 5 ms nominal, maximum, 1 s).

Operation of a gated multispectrum with linear averaging is illustrated in Fig. 7. Here, a multispectrum with 8 spectra has been selected, meaning that the 2123/33 divides the cycle into 8 equal segments, and gives a measurement for each of the 8 segments.

Gated multispectrum is selected on the 2123/33 by setting the "Rate" field of the "Input" fields to "Gate" (see Fig. 2). An external trigger is then required. Note that in this respect, the external trigger input of the 2123/33 can supply the power required to drive the Brüel & Kjær MM 0012 or MM 0024 photoelectric probes. Note also that a (positive) trigger delay can be set to offset data collection around the cycle.

2.3. Triggered Multispectrum

Triggered multispectrum allows asynchronous collection of data into an input multispectrum under external trigger control. Operation of triggered

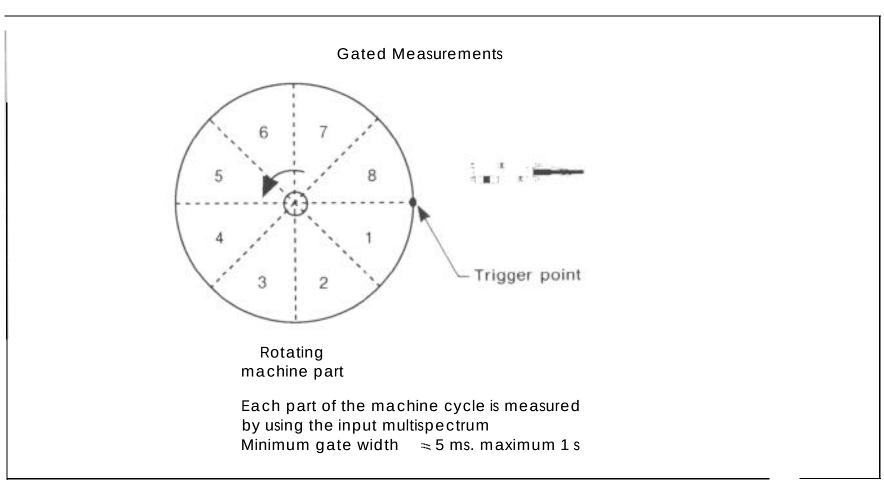

Fig. 7. Illustration of gated multispectrum with linear averaging

multispectrum is illustrated in Fig. 8. With exponential averaging, a spectrum is stored in the multispectrum with each external trigger, while with linear averaging, a new average is started and then stored with each trigger. The minimum time between triggers is 10 ms nominal.

Triggered multispectrum with exponential averaging allows data to be collected as a function of a third parameter, for example, distance down a test track in pass-by noise measurements or RPM in run-up/run-down tests. With linear averaging, it allows "fast" multiplexing, whereby the same trigger signal is used to switch a multiplexer and to start the linear average, meaning that essentially the only limitation in how fast the multiplexer can be switched is the natural limitation of the BT product. In such "fast" multiplexing, a delay can be introduced between the trigger signal and the start of linear averaging to allow any switching transients in the multiplexer to die away.

Another application of triggered multispectrum is in gated measurements where gate widths of < 5 ms nominal are required. The measuring gate can then be positioned within the cycle of the process under investigation by setting an appropriate trigger delay, and can be moved around the cycle by varying the delay. Note, however, that in contrast to the gated multispectrum measurements described in Section 2.2, it is now only possible to measure for one gate position at a time within the cycle.

Triggered multispectrum is selected on the 2123/33 by setting the "Rate" field of the "Input" fields to "Triggered" (see Fig. 2). Once again, an external trigger is required, and the same comments apply as in Section 2.2 with respect to powering the MM 0012 or MM 0024.

2.4. **Averaged Multispectrum**

Where the process being studied is repetitive, all of the different types of multispectra described in the previous sections can be averaged together to form averaged multispectra. Where, for instance, a series of input multispectra are being collected, each individual multispectrum will represent a frequency-amplitude-time landscape of one measured event. When several of these multispectra are then averaged together, an average landscape over all of the measured events will result, with the random variations from event to event being averaged out. An example of this is in reverberation time measurements using random noise as an excitation, where each set of decays will exhibit ripple due to the excitation. This ripple can be averaged out by measuring further sets of decays and forming an average multispectrum.

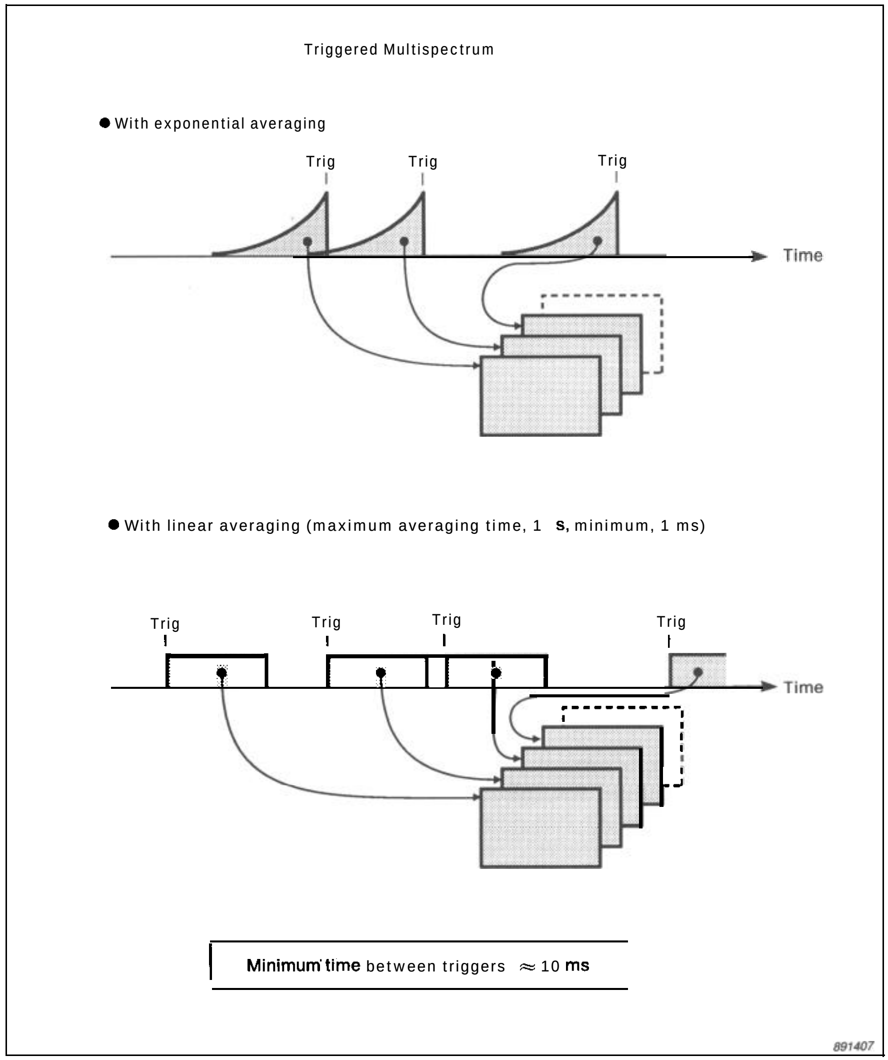

Fig. 8. Operation of the 2123/33 with triggered multispectrum

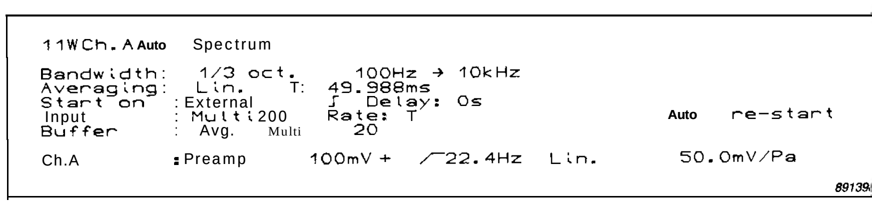

Fig. 9. A typical measurement set-up for collection of an averaged multispectrum

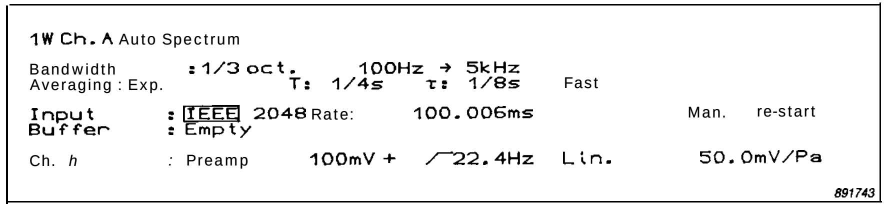

Fig. 10. Typical measurement set-up for spectrum history mode

A typical measurement set-up for collection of an averaged multispectrum is shown in Fig. 9. The number of multispectra to be averaged is set using the “Buffer” fields, and “Man. re-start” is reset to “Auto re-start” to enable a new input multispectrum to be collected with each new trigger.

In contrast to the measurement set-up of Fig. 2, the set-up of Fig. 9 has linear averaging selected. Note how, in the “Input” fields, “Rate” is now automatically set to the linear averaging time, *T*.

2.5. **Spectrum History Mode**

Where the internal memory of the 2123/33 is insufficient to store all of the spectra required for an input multispectrum, an alternative is to use spectrum history mode, where successive spectra can be output over the IEEE-bus for storage on an external medium. The minimum time interval between spectra in spectrum history mode is, for audio frequency range single parameter measurements, about 7 ms for octave data and about 15 ms for 1/3 octave data. A typical measurement set-up for spectrum history mode is shown in Fig. 10.

3. Use of Time Mode in the Analysis of Transient and Non-stationary signals

An alternative method of analyzing transient and non-stationary signals on the 2123/33 is to use time mode. This is where the analyzer is set up to capture and store time signals of up to

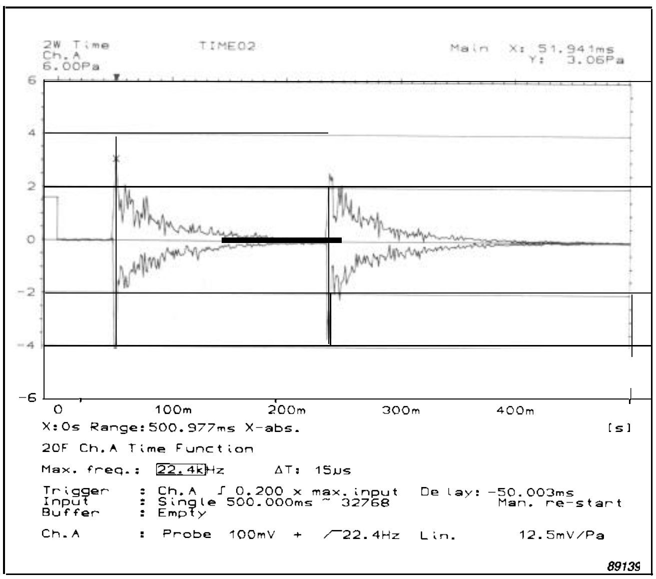

Fig. 11. Example of a time signal captured using the 2123133, together with the corresponding measurement set-up

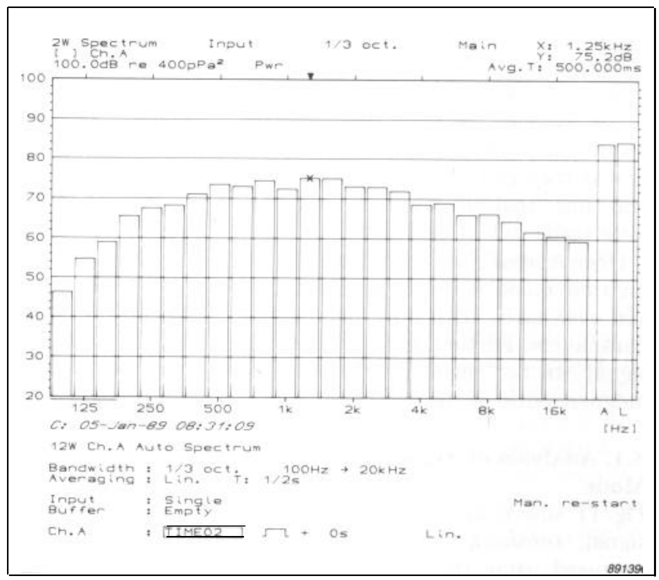

Fig. 12. A 1/3 octave analysis of the entire time signal captured in Fig. 11, together with the corresponding measurement set-up

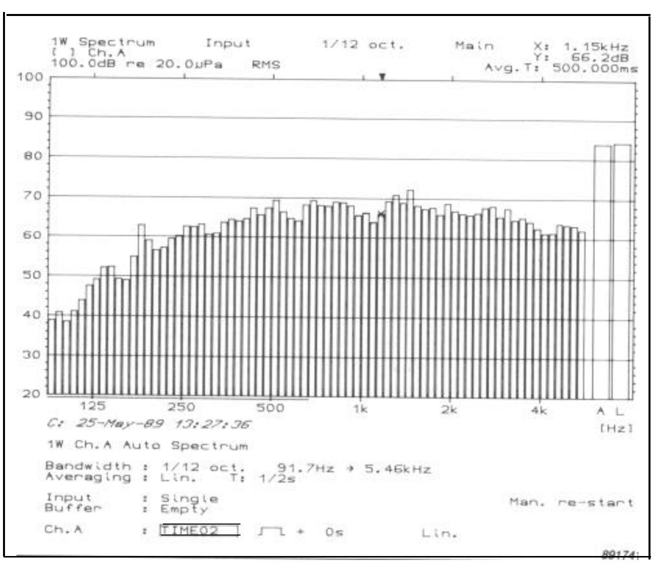

Fig. 12. A 1/3 octave analysis *of the entire time signal captured in Fig. 11, together with the corresponding measurement set-up*

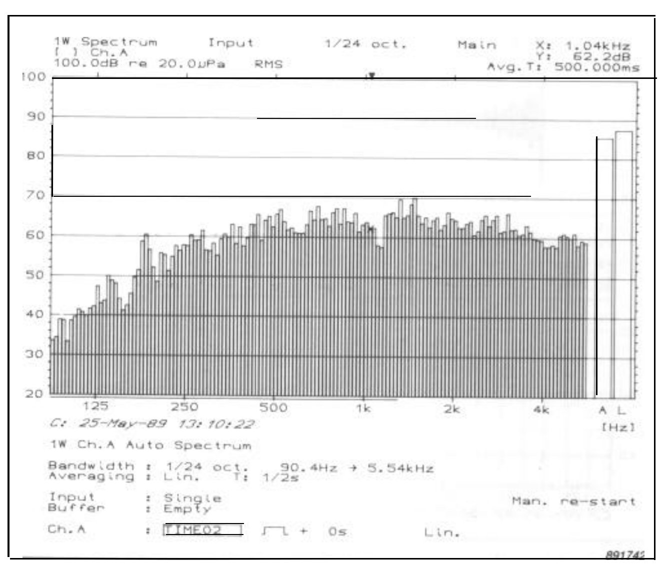

Fig. 14. A 1/24 octave analysis *of the entire time signal captured in Fig. II, together with the corresponding measurement set-up*

100 k samples duration. Such signals can be viewed on the 2123/33 display and stored on disc, allowing the analyzer to be used as a transient recorder. In addition to this, signals stored on disc can be recalled into the 2123/33 for subsequent spectral analysis.

The maximum duration of a signal which can be captured using time mode depends on the selected frequency range during capture. As a guideline, with a frequency range of 11,2 kHz selected, 100 k samples of time domain data corresponds to 3s single channel, (2123 and 2133), or 1,5 s/channel dual channel, (2133 only). This duration will decrease or increase proportionally with a selected higher or lower frequency range, respectively. Stored signals can be analyzed across their full frequency range in octaves or 1/3 octaves, or up to one quarter of their frequency range in 1/12 or 1/24 octaves. In such analyses, the results are always "quasi" real-time, that is they give the same results as a real-time analysis, even though they were made out of real-time.

Once a signal has been captured using time mode, it can be analyzed over and over again, with differing analysis parameters. Further, parts of the time signal can be "gated out" for analysis independently of the rest of the signal.

3.1. Analysis of Signals using Time Mode

Fig. 11 shows an example of a time signal, consisting of two transients, captured using the 2133/33, together with the corresponding measurement setup. The signal was captured using an internal trigger with a -50 ms delay, the 2133 having first been set to store 500 ms of signal. Having captured the signal in the 2123/33 internal memory, the next stage is to store the signal on disc. Figs. 12 through 16 illustrate some of the possibilities available for analysis of the signal when it is recalled from the disc.

Figs. 12 through 14 shows analyses of the entire signal in Fig. 11 in 1/3 1/12 and 1/24 octaves, respectively, together with the corresponding measurement set-ups. Note how the measurement set-ups are identical to those for real-time operation of the 2123/33, except that the "Ch. A" fields at the bottom of the measurement set-ups are set to recall data from the disc-file in question, in this case TIMEOB. The analyses of the entire time signal were obtained by selecting linear averaging with an averaging time equal to the signal duration, and pressing the "Measurement Start" key on the 2123/33 keyboard.

Figs. 15 and 16 show two further examples of signal analysis using time mode, namely, partial analysis of the time signal and formation of a multispectrum from the time signal, respectively. In Fig. 15, a window has been applied to the time signal to window out part of it for analysis independently of the rest. The figure shows the original time function, where the delta cursor has been used to highlight the part of the signal windowed out for analysis, and the resulting analysis. The measurement set-up used to obtain this is shown in Fig. 17. Looking at the lowest line of the measurement set-up, the input is once again the file TIMEOB. The next field to the right shows a symbol indicating that a rectangular window is to be used, (a rectangular window with adjustable cosine tapers can also be selected). The second field to the right of this allows the time corresponding to the start of the window to be entered, while the width of the window is entered as the linear averaging time.

Fig. 18 shows the measurement set-up used to obtain the multispectrum of Fig. 16. Such a set-up is identical to what is described in Section 2, except that the input source becomes TIMEOB. An advantage, though, is that in time mode, windows of < 5 ms (nominal) can be obtained. The analysis of Fig. 16 was obtained by using linear averaging with 20 ms averaging time, and an input multispectrum consisting of 25 spectra.

3.2. Signal Enhancement in Time Mode

Signal enhancement, otherwise known as time domain averaging, can be employed on the 2123/33 when capturing time signals. In this type of data acquisition successive time records from a repetitive process are averaged together under the control of a once-per-cycle trigger. One of the results of this process is that background noise which is asynchronous with the trigger is averaged out.

An enhanced time signal is stored and analyzed in the same way as any other signal using time mode. However, since the enhancement process re-

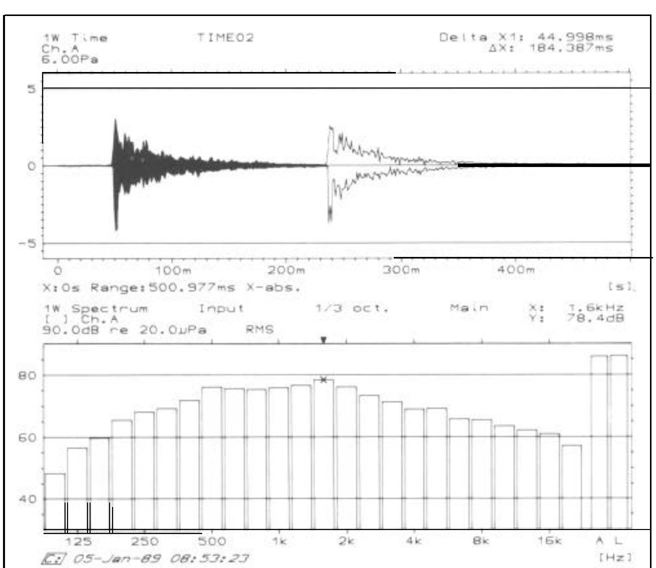

Fig. 15. An analysis of part of the time signal from Fig. 10. The part windowed out for analysis is highlighted using the delta cursor

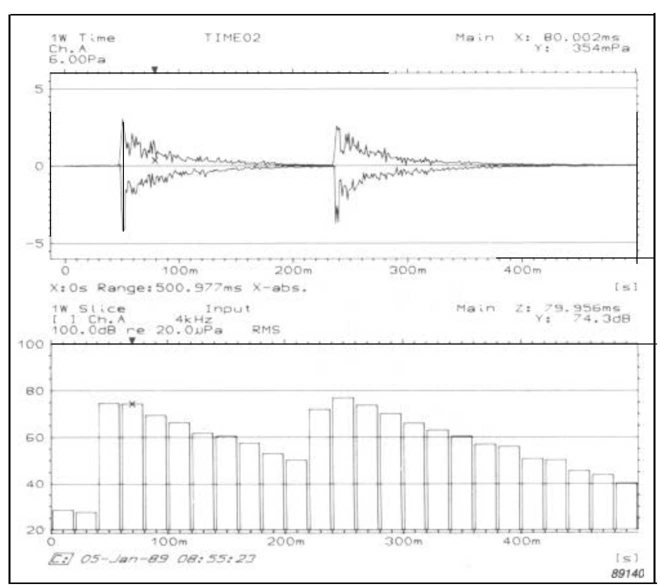

Fig. 16. An input multispectrum generated from the entire time signal captured in Fig. 10. A slice display of the 4 kHz 1/3 octave is shown

```
1W Ch. A Auto Spectrum
Bandwidth :          1/3 oct.       100Hz → 20kHz
Averaging : Lin.              T:   184.387ms
Input          :  Single                                   Man.   re-start
Buffer         :  Empty
Ch. A          :  TIME02  ⎍  +  44.998ms  Lin.
```

Fig. 17. The measurement set-up used to obtain the analysis shown in Fig. 15

```
1W Ch.A Auto Spectrum
Bandwidth :          1/3 oct.       100Hz → 20kHz
Averaging :          Lin.     T:   19.989ms
Input          : Multi      25 Rate: T                     Man.   r-e-start
Buffer         : Empty
Ch. A          :  TIME02  ⎍ +        0s          Lin.
                                                                  89174
```

Fig. 18. The measurement set-up used to obtain the analysis shown in Fig. 16

```
1W Ch. A Time Function
Max. freq.:  22.4kHz        AT:   15µs
Input          :  Single 199.997ms  ~ 13107                Man.   re-start
Buffer         :  Enhanced   Lin.   50
Ch. A          :  Acc.     60pC    +   ⁄‾22.4Hz Lin.           1.00pC/m/s²
                                                                  89174
```

Fig. 19. Typical measurement set-up for enhanced time measurement

```
1W Ch.A Time Function
Max. freq.:  22.4kHz        AT:   15µs
Input          :  IEEE  10.000000s  ~ 655360              Man.   r-e-start
Buffer         :  Empty
Ch.A           :  Preamp 100mV +    ⁄‾22.4Hz L in.            50.0mV/Pa
                                                                  8917
```

Fig. 20. Typical measurement set-up for time history mode

quires use of some of the *2123/33s* memory capacity, the maximum duration of an enhanced time signal is *33* ksamples. A typical measurement set-up for enhanced time is shown in **Fig. 19.**

3.3. Reversed Time Analysis

For signals with very short decay times, reversed time analysis can be used. In this type of analysis, the time signal is entered into the digital filter bank backwards. Since the filter bank has a much faster rise time than decay time, such reversed time analysis means that the analyzer can correctly analyse shorter decays than with normal, forward analysis. This mode can be used, for instance, to measure reverberation times down to well under 100 ms.

3.4. Time History Mode

Where the internal memory capacity of the 2123/33 is insufficient to capture the entire signal of interest, time history mode can be used instead. In this, the 2123/33 is used purely as an ADC, with the digitised time domain samples being streamed out over the IEEE-bus for storage on an external medium. Time domain data can be output over the IEEE-bus in real-time to 22,4 kHz in single channel, (2123 and 2133), or 11,2 kHz dual channel, (2133 only). A typical measurement set-up for time history mode is shown in Fig. 20.

4. Conclusion

It has been demonstrated that both input multispectrum and time mode can be used in the analysis of non-stationary and transient signals. Of the two methods, time mode probably presents the greatest flexibility, although it is only applicable to relatively short signals. Input multispectrum, on the other hand, is more generally applicable, and can be used on signals having durations of from tens of milliseconds to many hours.

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