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Frequency Analysis of Stationary Signals recorded on Tape Loops

Frequency Analysis of Stationary Signals recorded on Tape Loops.

by R.B. Randall, B.Tech., B.A.

Introduction.

One of the problems associated with narrow band analysis of vibration (or acoustic) signals is the length of time required to obtain the complete spectrum, typically 10 to 30 minutes for three decades. Where this is to be done only occasionally, then the original signal could often be analysed in situ or at least recorded on a tape reel for the full 30 minutes or so.

It can be seen, however, that this would not be practicable where many signals have to be analysed, for example as part of a preventive maintenance scheme, and it would be preferable to record for a considerably shorter time and use a tape loop for the analysis. The length of signal recorded does not need to be longer than the maximum analyzer averaging time, since this is all that is seen by any individual filter. In some cases use of a tape loop is necessary because only a few seconds of the signal are available.

Problems arise, however, because of noise introduced by the tape splice and signal transition point, and although this problem has been solved for the analysis of transients (ref. 1,2) it does not appear to have been previously solved for analogue analysis of continuous signals.

Use of the tape signal gate Type 2972 with a continuous signal introduces almost as much disturbance as the original splice.

Another approach which has been used successfully is to employ the Gaussian Impulse Multiplier Type 5623 (ref. 3,4) as a splice noise eliminator

The Gaussian Impulse Multiplier Type 5623.

The Gaussian Impulse Multiplier Type 5623 (Fig. 1) was designed originally to allow accurate analysis of an "instantaneous spectrum" in conjunction with the Real-Time Analyzer Type 3347. Its function is to generate a gaussian shaped impulse with which the original signal is multiplied, the delay time after triggering being adjustable as required.

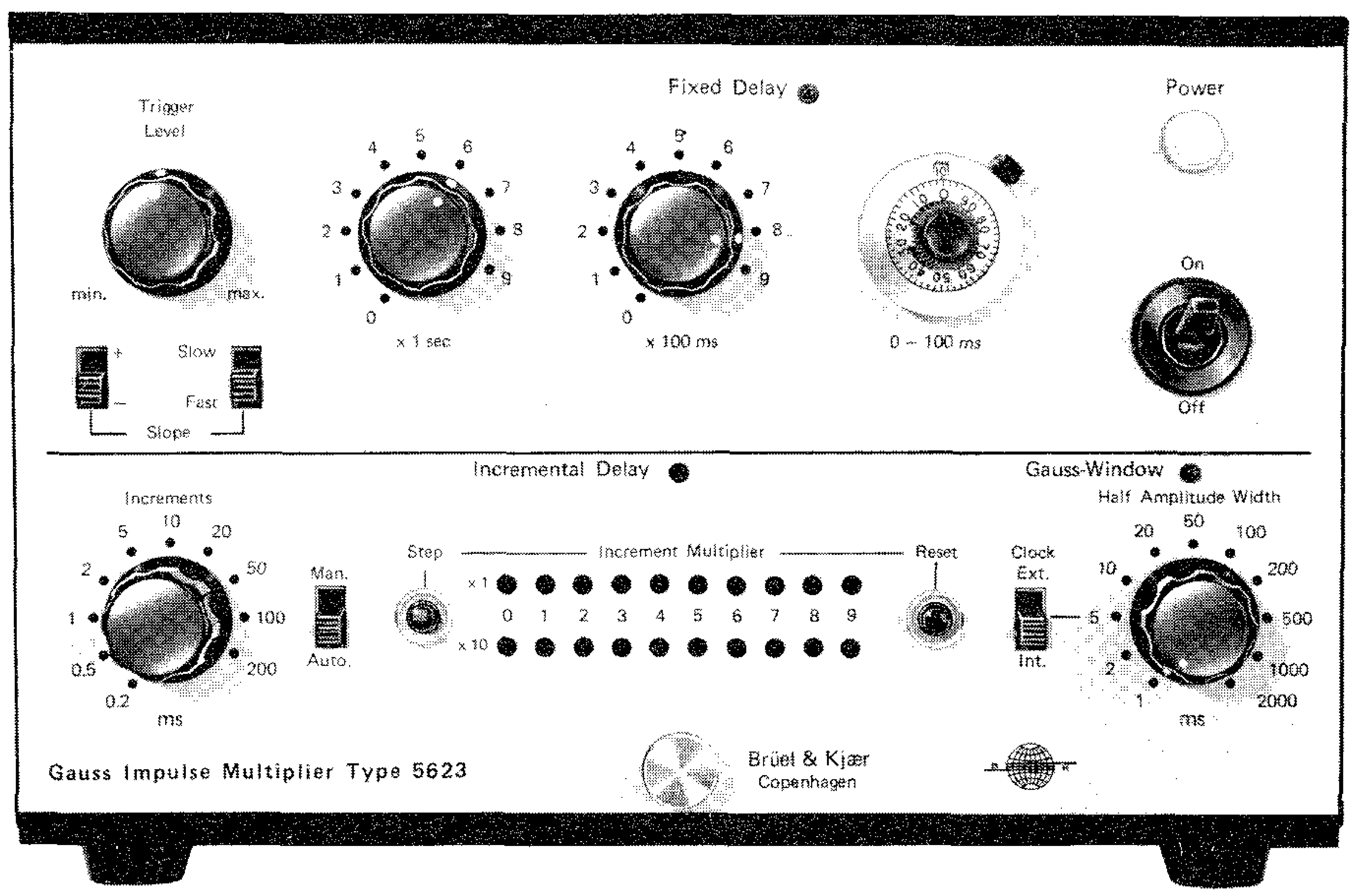

Fig. 1.

In the present context it is possible to use a marker signal on the voice track of the Tape Recorder Type 7001 as a trigger, with the delay time so adjusted that the gaussian impulse starts immediately after the splice has passed the read head. The tape loop length (or possibly external clock frequency) is adjusted so that the length of the gaussian impulse is just slightly less than the cycle time of the tape loop. (See Fig. 2).

The averaging time of the analyzer or level recorder must be sufficiently long that the cyclic fluctuations are averaged out.

A more detailed theoretical justification of the procedure is given in Appendix 1, but it can be explained in short as follows:

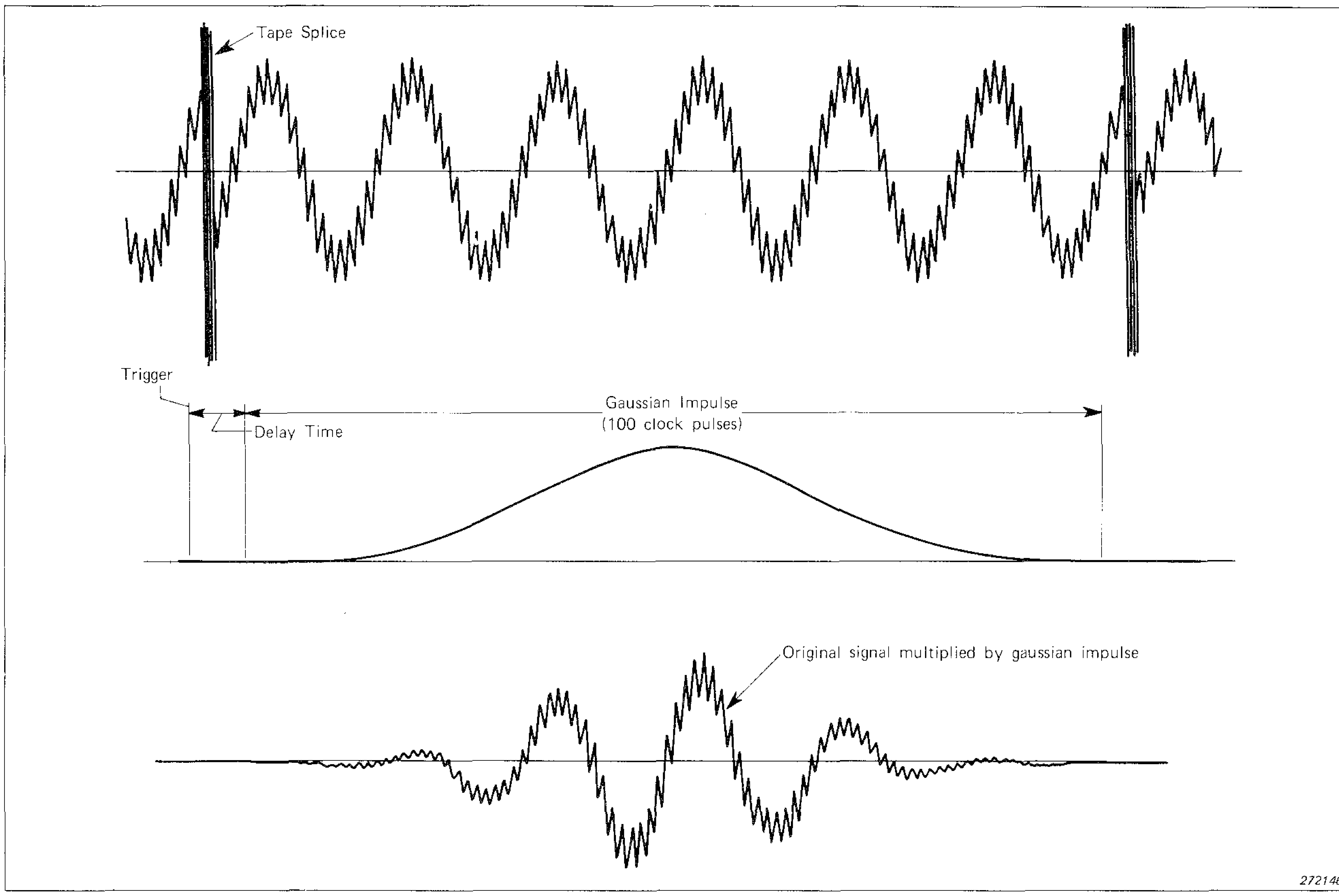

Fig. 2. Setting up Impulse Multiplier.

Multiplication in the time domain by the gaussian function is equivalent to a convolution in the frequency domain with the Fourier transform of the gaussian impulse which is also of gaussian shape (ref. 3). This convolution has little effect, however, since the gaussian function does not have side lobes (in contrast to the effect of most other window shapes) and since the width of the main lobe is normally small relative to the analyzer filter bandwidth.

The signal level must be calibrated by operating on a known calibration signal in the same way, but this is in any case standard practice for tape recorded signals.

Results.

The set-up used to verify the principle is shown in Fig. 3.

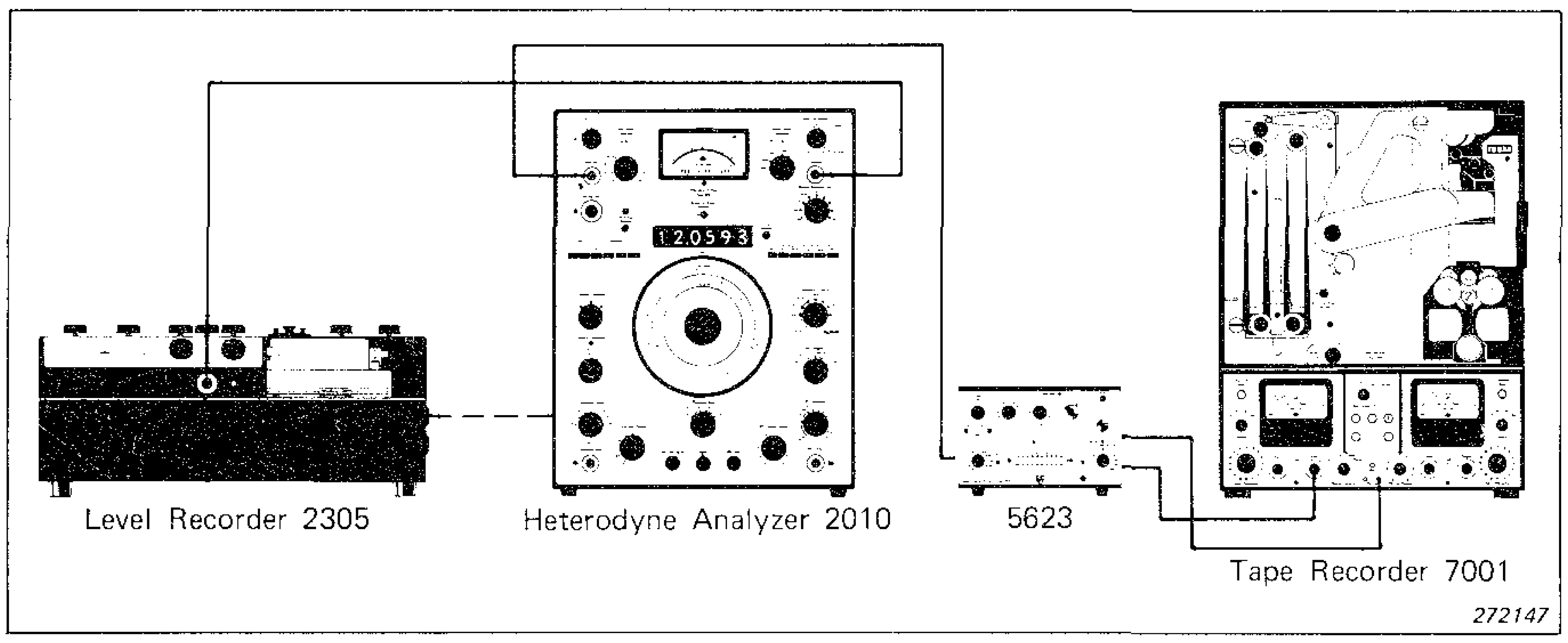

Fig. 3. Set-up for tape loop analysis.

The vibration signal analysed was taken from a small electric motor and recorded directly onto a ready-made tape loop. The loop length was approx. 3 m (10 ft) and tape speed 60 in/sec resulting in a loop cycle time of about 2 secs. The recording was stopped (by switching the tape recorder to "play-back" mode) as close as possible to the tape splice, in order that the transition point would have negligible effect. A short marker signal was recorded on the voice track starting about 15 cm (6") before the tape splice, and with the tape running at 6 ins/sec (for ease of positioning. Play-back was at 60 ins/sec).

Using an oscilloscope, the Gaussian Impulse Multiplier was set up in the manner shown in Fig. 2. An analysis was then recorded automatically with the Level Recorder in DC mode and using the variable bandwidth program of the 2010 (bandwidth varying between 3.16 and 1000 Hz). An averaging time of 10 secs was required to damp out the loop cycle fluctuations. The results are shown in Fig. 4, together with the results of an analysis obtained without using the Impulse Multiplier, and thus including the effects of the splice. The same averaging time (10 secs) and paper speed (0.1 mm/sec) were used for both recordings.

Another analysis was then run, without the Gaussian Impulse Multiplier, and with averaging time reduced to 0.3 secs. This allowed the analyzer to attain its correct value in between impulses from the tape splice, the short averaging time being possible because the signal consisted primarily of sinusoidal components starting at a relatively high frequency. The results are shown in Fig. 5.

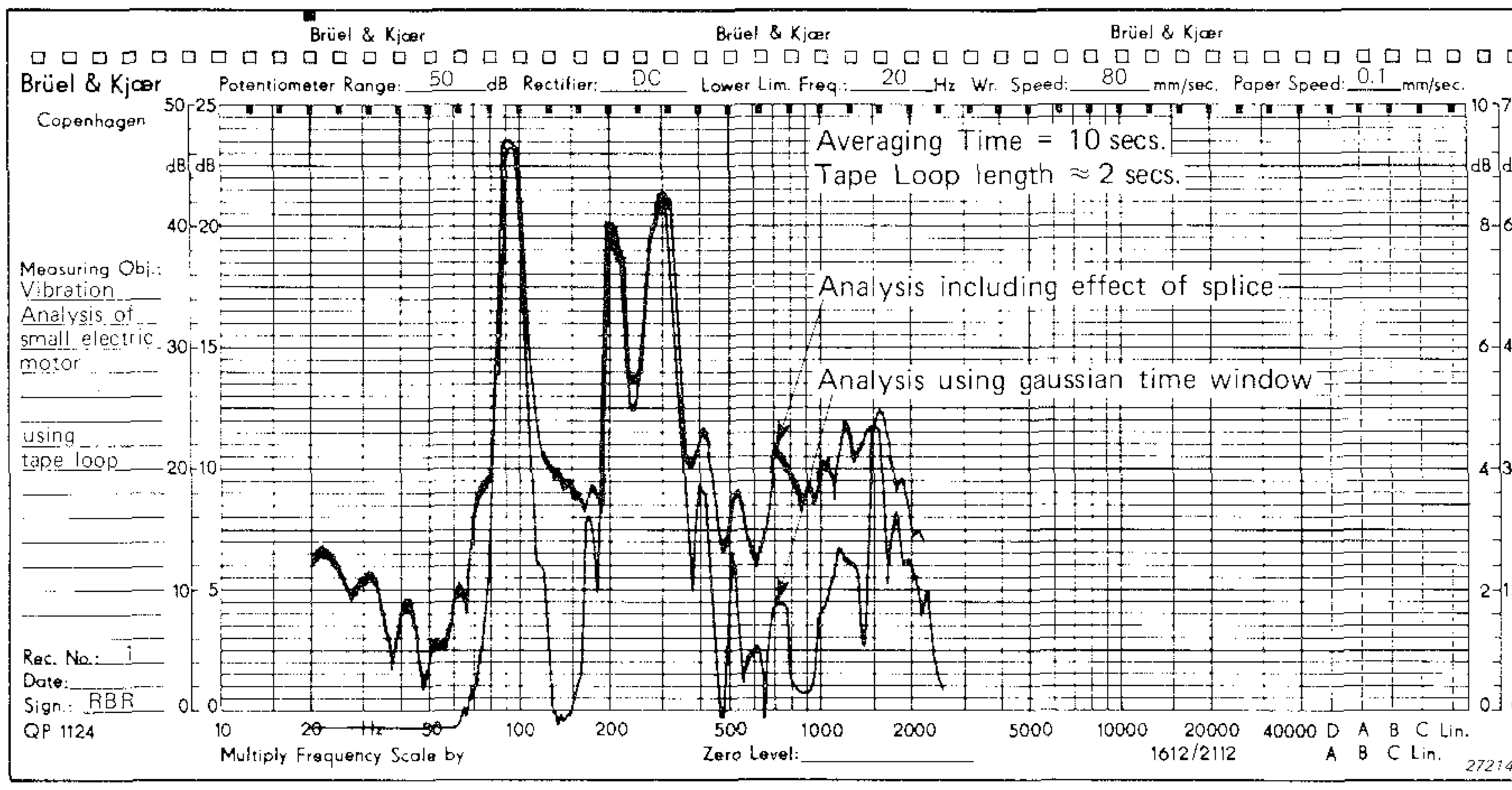

Fig. 4. Analysis with and without Impulse Multiplier.

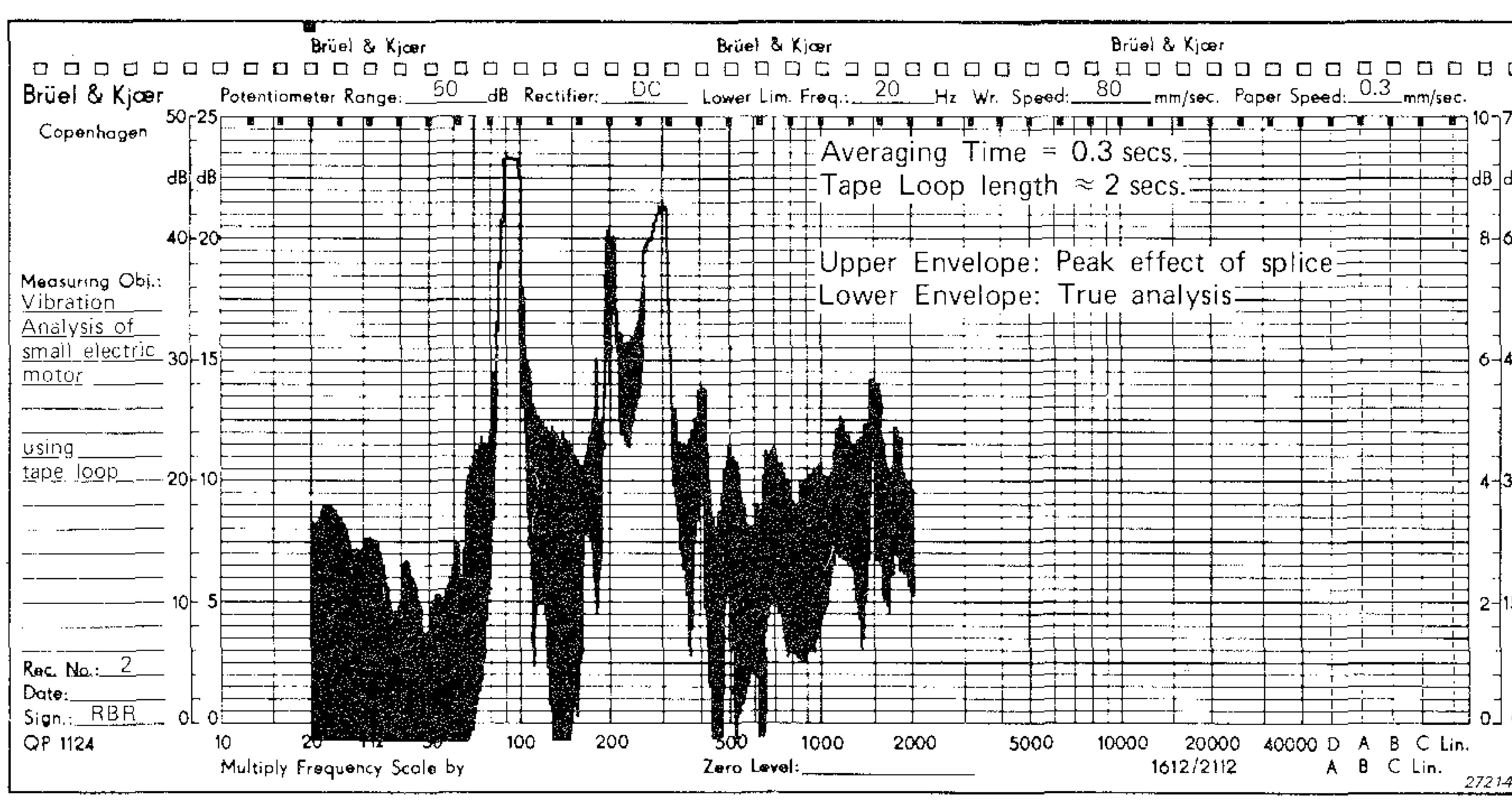

Fig. 5. Analysis with short averaging time.

By comparison between Figs. 4 and 5, it can be seen that the analysis obtained with the Gaussian Impulse Multiplier is almost identical with the bottom envelope of Fig. 5 which represents the true analysis. The top envelope of Fig. 5 has of course a similar shape to the upper curve of Fig. 4 and shows the effect of the splice (and signal transition point).

For comparison purposes, a further analysis was also performed on the signal direct from the source. This is reproduced as Fig. 6.

This analysis also compares quite well with that obtained using the Impulse Multiplier, and though some differences are apparent they are probably attributable to the normal variations between signal samples taken at different times.

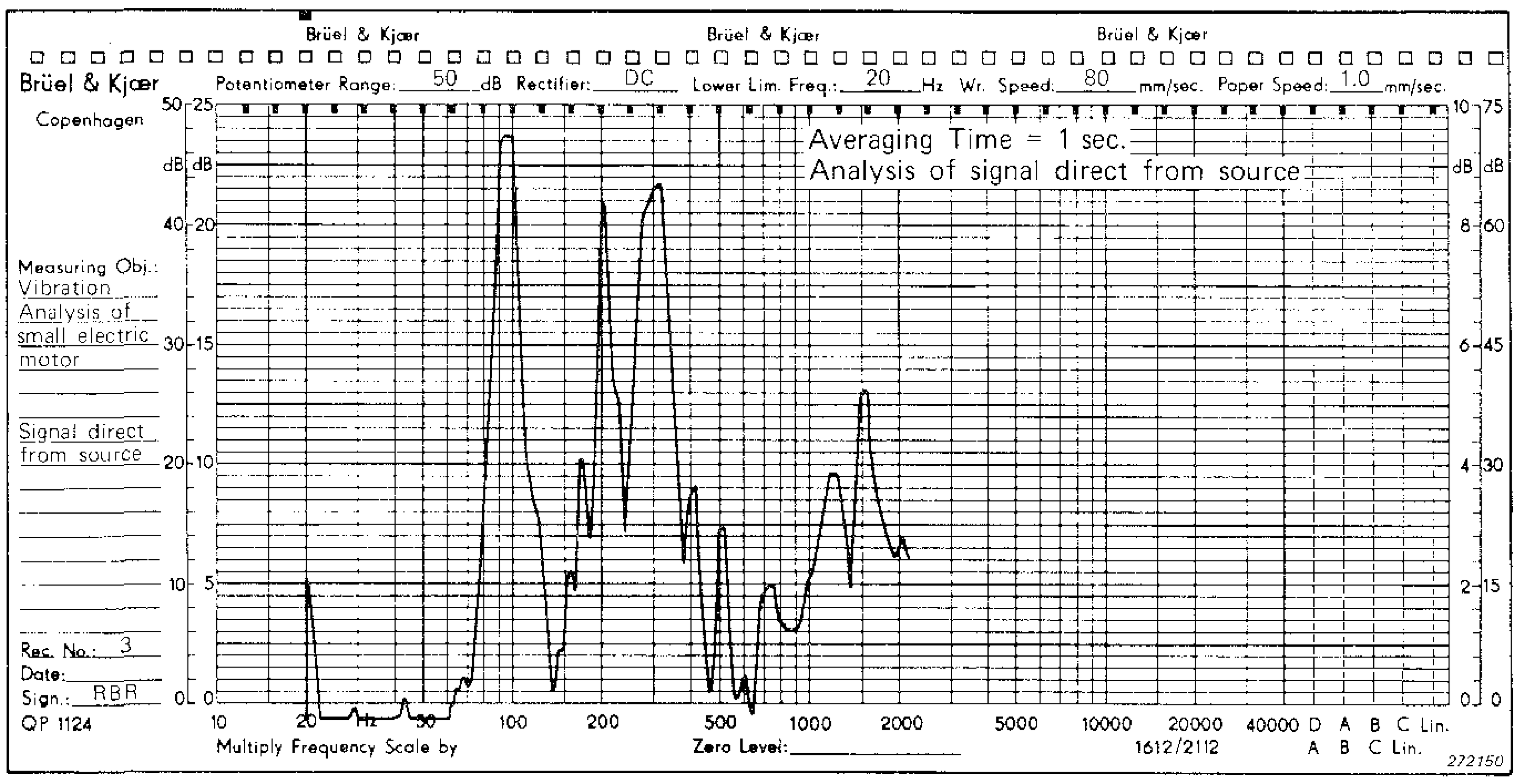

Fig. 6. Direct Analysis of Signal.

Concluding Remarks.

The use of the Gaussian Impulse Multiplier permits the accurate frequency analysis of continuous signals on a tape loop, provided they can be considered as stationary (average properties time invariant).

There are, however, three penalties:

1) The bandwidth of the analysis is increased over that dictated by the analyzer alone. (See Appendix 1).

2) To obtain a smooth curve, averaging must be over several gaussian cycles.

3) The effective record length is reduced somewhat by the shaping window.

The first is generally not a problem except perhaps with very narrow analyzer bandwidths which would normally be used only at low frequency. A numerical example will help to clarify this.

In the examples shown in this Note, the time between the half -amplitude points of the gaussian impulse was approx. 1/3 of the total loop i.e. 2/3 seconds. The halfwidth of the corresponding lobe in the frequency domain is approximately the inverse of this, or 3/2 Hz, thus resulting in a bandwidth of 3 Hz. This gives a considerable broadening at the lowest analyzer bandwidth of 3.16 Hz, but is negligible at the highest bandwidth of 1000 Hz. By using the maximum tape loop length of 5 seconds (at 60 ins/sec) the broadening could have been reduced to less than 1 1/2 Hz. If frequencies over 5 kHz are not of interest (which is likely if narrow bandwidth is desired) then the original recording could be made at 15 ins/sec, and on speeding up to 60 ins/sec for analysis, an effective bandwidth increase of less than 0.3 Hz could be achieved.

The second problem could be solved in some cases by using more than one gaussian impulse per tape loop. The marker signals could be accurately positioned evenly around the loop by running at low speed (1 1/2 or 6 ins/sec). The bandwidth is of course broadened accordingly, but this may be offset as described above.

In other cases it may be acceptable to allow the pen to fluctuate, using the upper envelope as the true spectrum (in the same way as for impulse analysis, ref. 2). This does, however, complicate comparison of successive records and is not desirable for a preventive maintenance scheme.

The third factor, viz. reduced effective record length, will primarily affect measurements on random signals, where it directly affects the BT product geverning accuracy of estimates. Using the method of comparison from ref. 5, the equivalent length of a gaussian impulse is 1.28 times the distance bewteen the half amplitude points, or 0.427 times the total cycle length in this case.

This would normally result in a corresponding reduction in analysis speed, since the effective bandwidth is not likely to be increased appreciably.

One final point worth mentioning is that the same system can be used in conjunction with the Digital Event Recorder Type 7502 instead of a tape recorder for playback during analysis. In this case, there is no splice noise as such, but the signal transition still gives rise to sidebands which can be eliminated using the gaussian window. One considerable advantage is that playback can be speeded up a minimum of 5 times, so that the inefficiencies resulting from use of the window can be more than compensated for. A minor disadvantage is that only two decades of frequency can be analysed at a time, though it is a simple matter to cover a wider range by recording again at a different digitising rate. The Digital Event Recorder is also considerably simpler to work with than a tape recorder with loop adaptor.

References.

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4. Brüel & Kjær System Development, "The Gauss Impulse Multiplier Type 5623. Publication Number 12-034.
5. J.T. Broch og C.G. Wahrman, "Effective Averaging Time of the Level Recorder Type 2305". Brüel & Kjær Technical Review No. 1, 1961.

Appendix 1.

The effect of the gaussian window will be demonstrated for a sinusoidal signal. Fig. 7 shows the way in which the signal and its spectrum are modified by a rectangular and a gaussian window and by the application of a sweeping ideal filter.

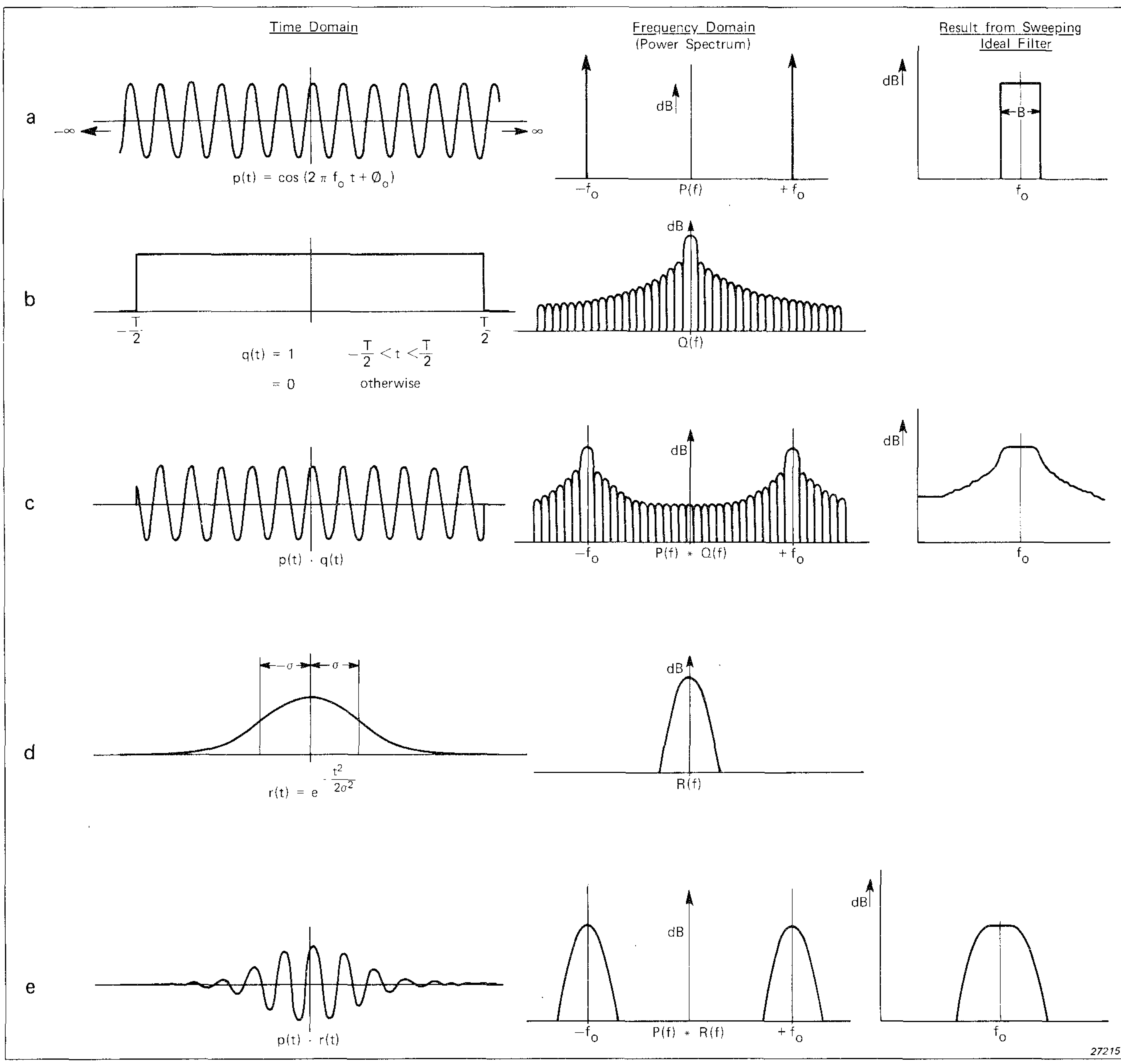

Fig. 7. Comparison of Gaussian and Rectangular Windows.

Fig. 7a shows a cosine signal p(t) of infinite extent and its (2-sided) power spectrum in the frequency domain P(f) which in fact is a pair of spectral lines (delta functions) situated at $\pm f_0$ the frequency of the cosine signal. The (one-sided) spectrum obtained by passing on ideal filter of bandwidth B across this true spectrum is also shown. Note that the two spectra have been drawn to logarithmic amplitude scales but linear frequency scales.

Fig. 7b shows the power spectrum of a rectangular window q(t), illustrating the extent of the side lobes obtained in the power spectrum Q(f).

Fig. 7c shows the effect of multiplying the original infinite signal p(t) by the rectangular window q(t). This results in the convolution $P(f) \ast Q(f)$ in the frequency domain. The further convolution obtained by sweeping the ideal filter across the true spectrum is also shown. It can be seen that the side lobes result in a considerable reduction of resolution.

Figs.7d and 7e show the analogous results obtained with a gaussian window. Note that on a logarithmic amplitude scale, the gaussian spectrum has the form of an inverted parabola with no side lobes. The effect on the output of the ideal filter is to give a slight broadening near the top, but a considerably improved shape factor compared with the rectangular window.

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