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application notes

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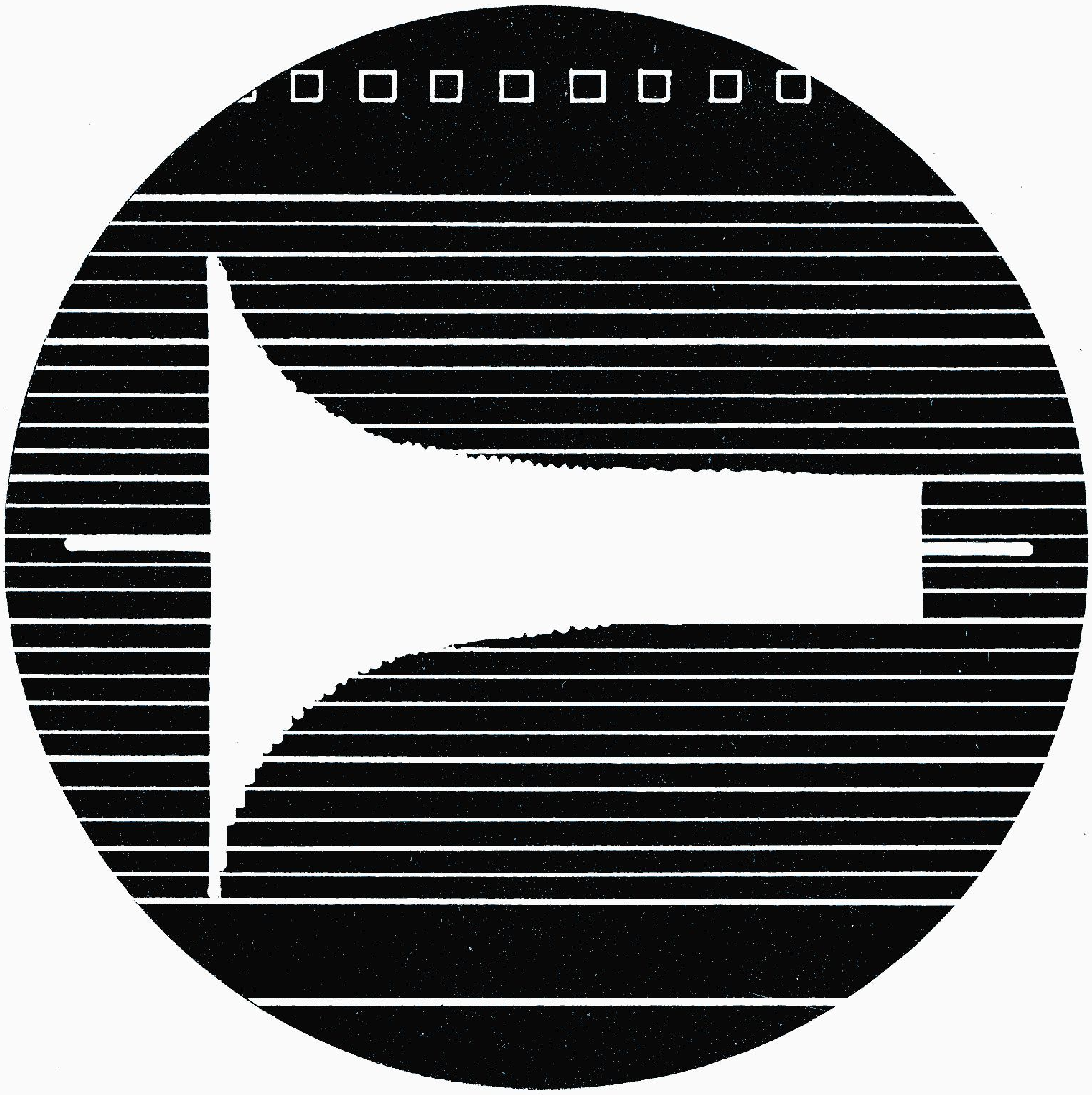

Use of a compressor loop in tone-burst measurements with the High-Pressure Microphone Calibrator Type 4221

by *Pierre Bernard,* Ing.ESE.

Introduction

The use of a compressor loop is common practice in measuring systems where the excitation signal is continuously applied. The High-Pressure Microphone Calibrator Type 4221 allows measurements to be made up to 1000 Hz (instead of 300 Hz without compressor) at levels up to 162 dB re. 20 μPa.

Tone-burst excitation allows higher sound pressure levels (max. 172 dB) to be reached. In order to eliminate problems due to the coupler resonance, compression techniques have been applied to tone-burst operation. This Application Note describes the set-up used and discusses the measurement results.

1. The High Pressure Microphone Calibrator Type 4221

The High Pressure Calibrator Type 4221 is delivered with two couplers: a high-pressure coupler and a low-frequency coupler. The latter cannot be used with tone-burst excitation and will not be considered. Fig.1 shows a cross-sectional drawing of the 4221 equipped with the high-pressure coupler. A piston driven by an electrodynamic exciter generates a high sound pressure in the coupler which can be fitted with one or two microphones. The high-pressure coupler can be used either without damping (closed) or with damping; in the latter case two hollow screws, each containing a disc of a sintered material, are partly released to introduce damping around the resonant frequency. However, due to non-linearity at high sound pressure levels, the coupler cannot be used with damping for tone-burst measurements.

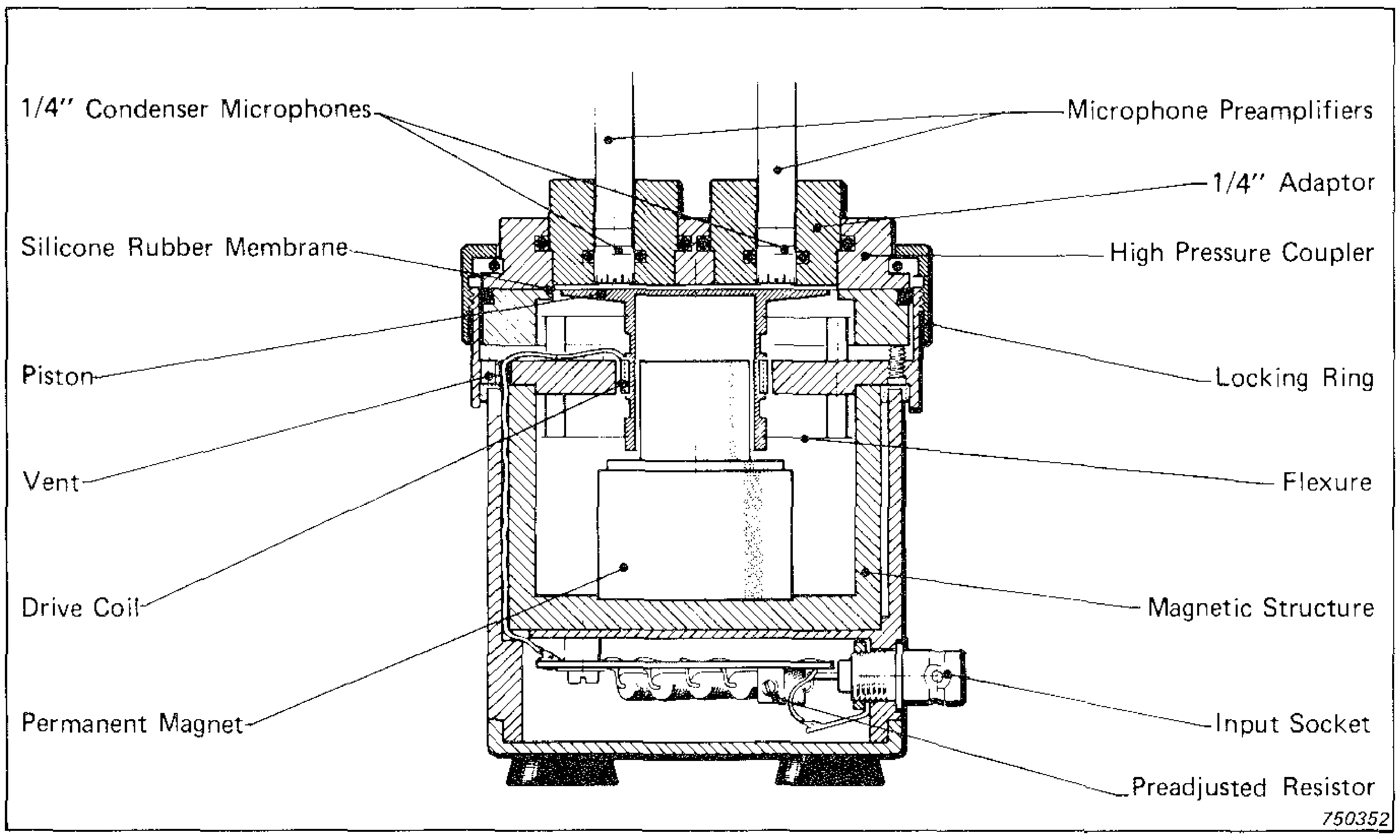

Fig.1. Sectional drawing of the 4221 with the high pressure coupler

The frequency response of the 4221 with closed coupler is shown in Fig.2. The resonant frequency is around 900 Hz. The Insert Voltage curve shows the voltage at the VOLTMETER socket of the 4221, which is porportional to the current through the driving coil. For measurements in the high-frequency range (without compressor) the difference between the two curves must be used as a correction factor to be applied to the nominal Pressure/Insert Voltage constant of

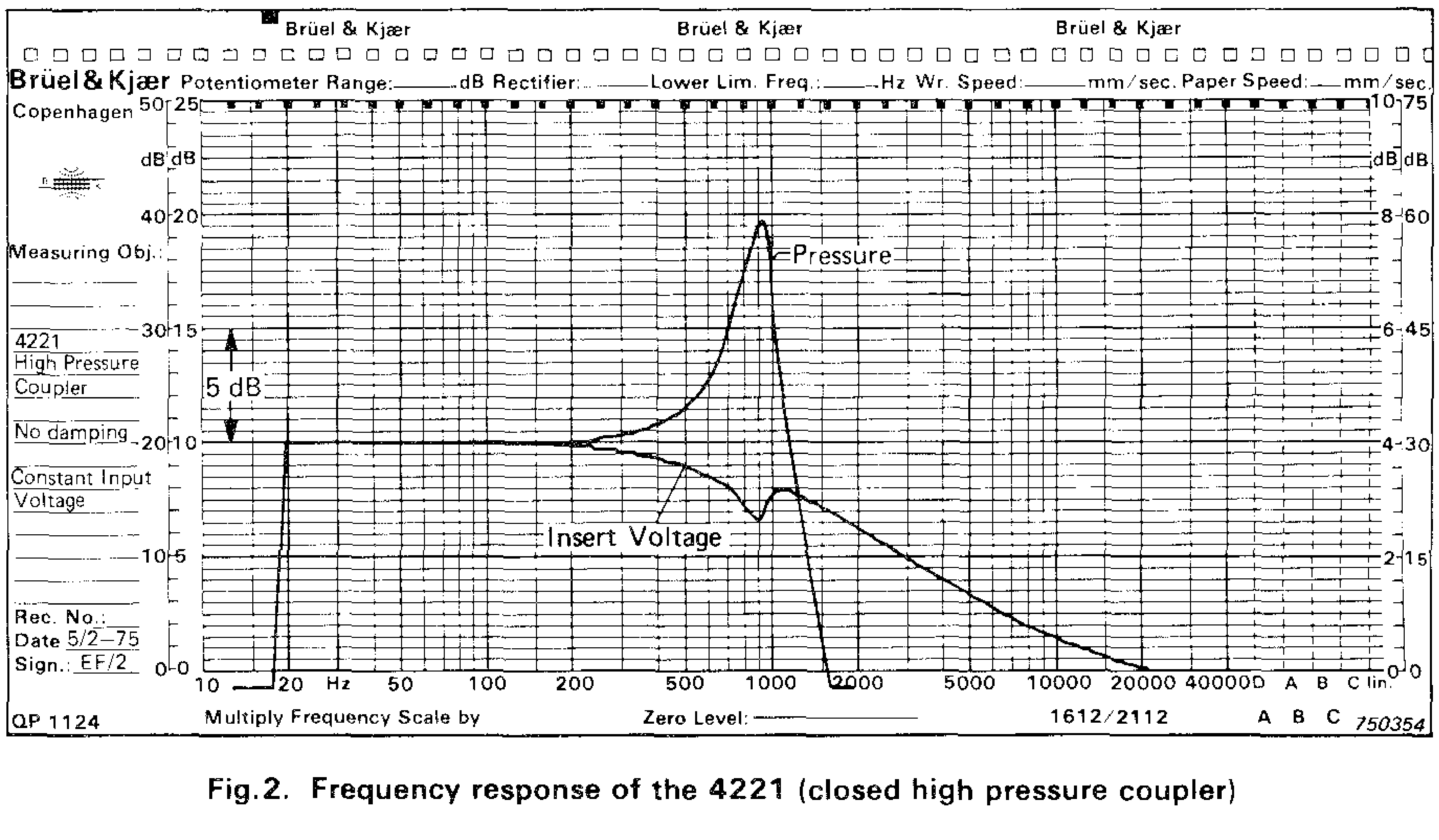

Fig.2. Frequency response of the 4221 (closed high pressure coupler)

20 Pa/mV. The 4221 is factory-adjusted to nominal specification at 95 Hz, and individual calibration data are provided.

In continuous operation, sound pressure levels up to 162 dB re. 20 µPa may be obtained and use of a compressor loop gives a flat frequency response up to 1 kHz. (Levels up to 164 dB may be obtained if operation above 162 dB is limited to 10 minutes.)

Tone-burst operation allows levels up to 172 dB to be reached. The ratio between the max. pulse-length and the repetition period is given in Fig.3 as a function of the sound pressure level to be obtained.

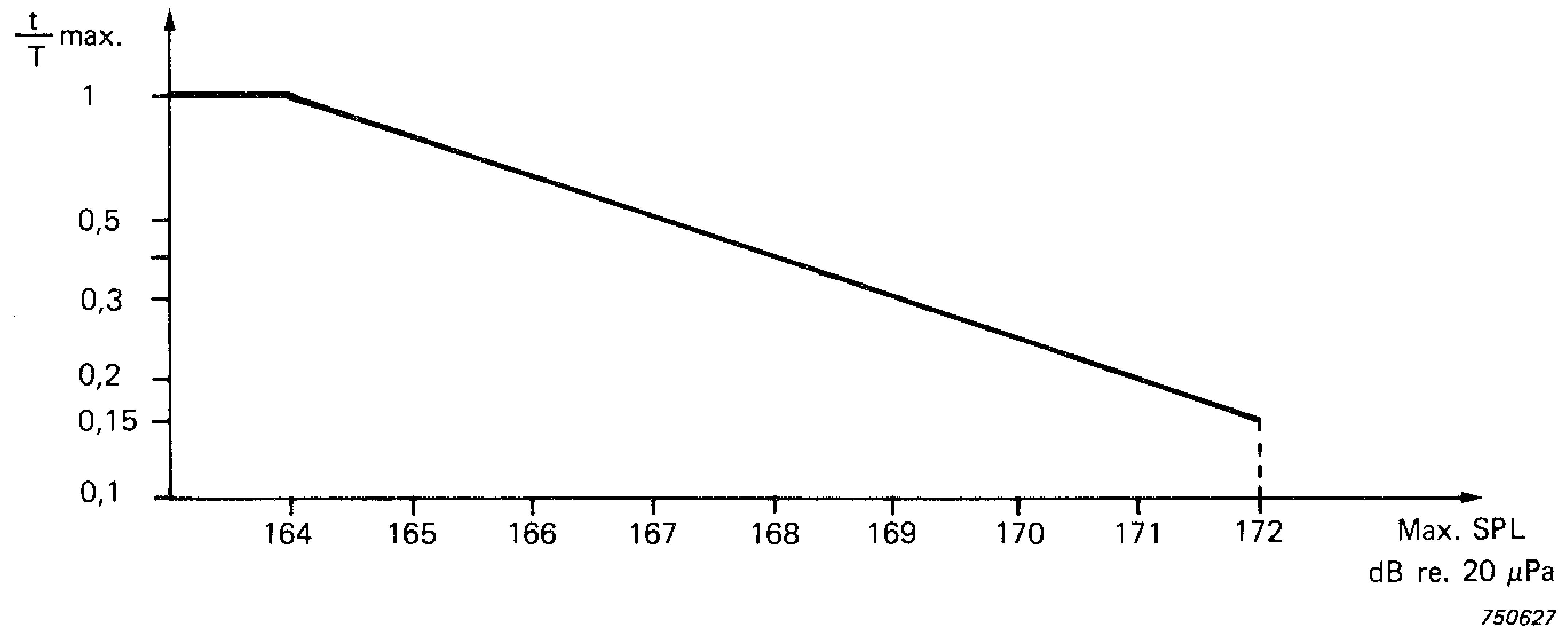

Fig.3. Pulse length to repetition period ratio

The Gating System Type 4440 is ideal for this application. Connected to a sine generator, it delivers tone bursts of adjustable length and repetition period. A zero-crossing detector controls the opening and closing of the transmitting gate to give minimum switching transients. The received signal may be fed to the 4440. Delay and width of the receiving gate are adjustable, allowing measurement on the steady-state signal only.

With the 4221, the coupler resonance limits the useful frequency range to approx. 300 Hz. In order to extend the range up to approx. 1000 Hz, an attempt was made to apply compression techniques to tone-burst measurements. A favourable factor is the negligible time delay between the transmitted and received pulses, allowing the compressor to start working immediately as the pulse is transmitted.

2. Principle of the Method

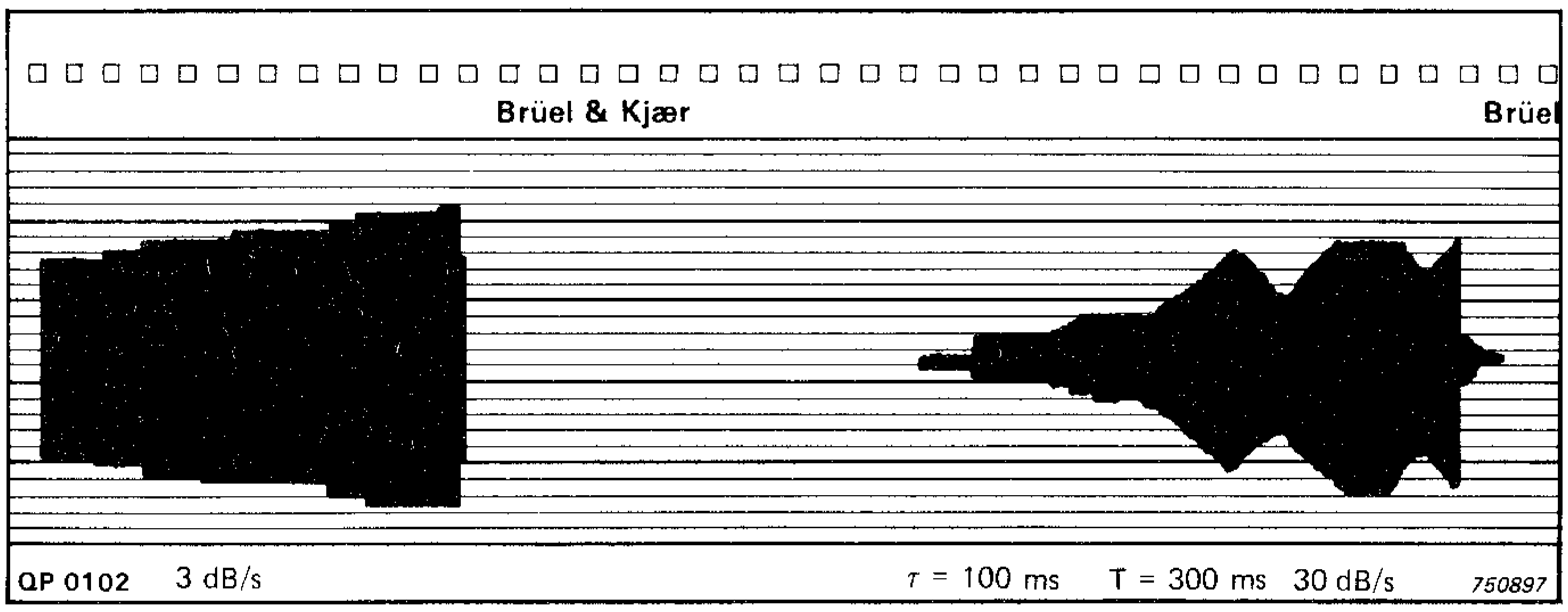

Fig.4. Generator output with direct control of the compressor from the receiving microphone (pulse length: 100 ms, repetition period 300 ms)

A major problem when considering the use of a compressor loop in tone-burst measurements is that the signal to be used to drive the compressor circuits is also a tone burst. If this signal is directly fed to the compressor input, the compressor will tend to increase the output gain of the generator in the absence of any received signal. This is illustrated in Fig.4, where the generator output voltage (input signal to the Gating System) is shown for various compressor speeds, the compressor being directly controlled by the tone burst received. If the tone bursts are shorter than half the repetition period, the compressor has insufficient time to bring the gain back to the steady-state level. The bursts should therefore be longer than half the period, which limits the measurement level to 167 dB (see Fig.3). In fact, the steady-state level should be even lower, since the actual sound pressure level at the beginning of the pulse is always higher than the steady-state level reached at the end of the pulse.

To allow working at higher sound pressure levels, the limitation on the pulse-length to period ratio can be suppressed by permanently feeding a signal to the compressor input. The principle is illustrated in Fig.5. A switching circuit connects the generator output to the compressor input in the absence of excitation pulse. When the Gating System delivers a tone burst, the GATE OUTPUT of the 4440 is used to turn the switching circuit so that the received signal is fed to the compressor. When the tone burst is over, the switching circuit is turned to its original configuration. Hence, in the absence of a tone burst, the compressor will stabilize at a known, selected level. Thus high compression speeds may be used. Furthermore, the generator output level can be adjusted so that the level at the beginning of the pulse is lower than the steady-state pulse level, ensuring protection against levels which could be too high.

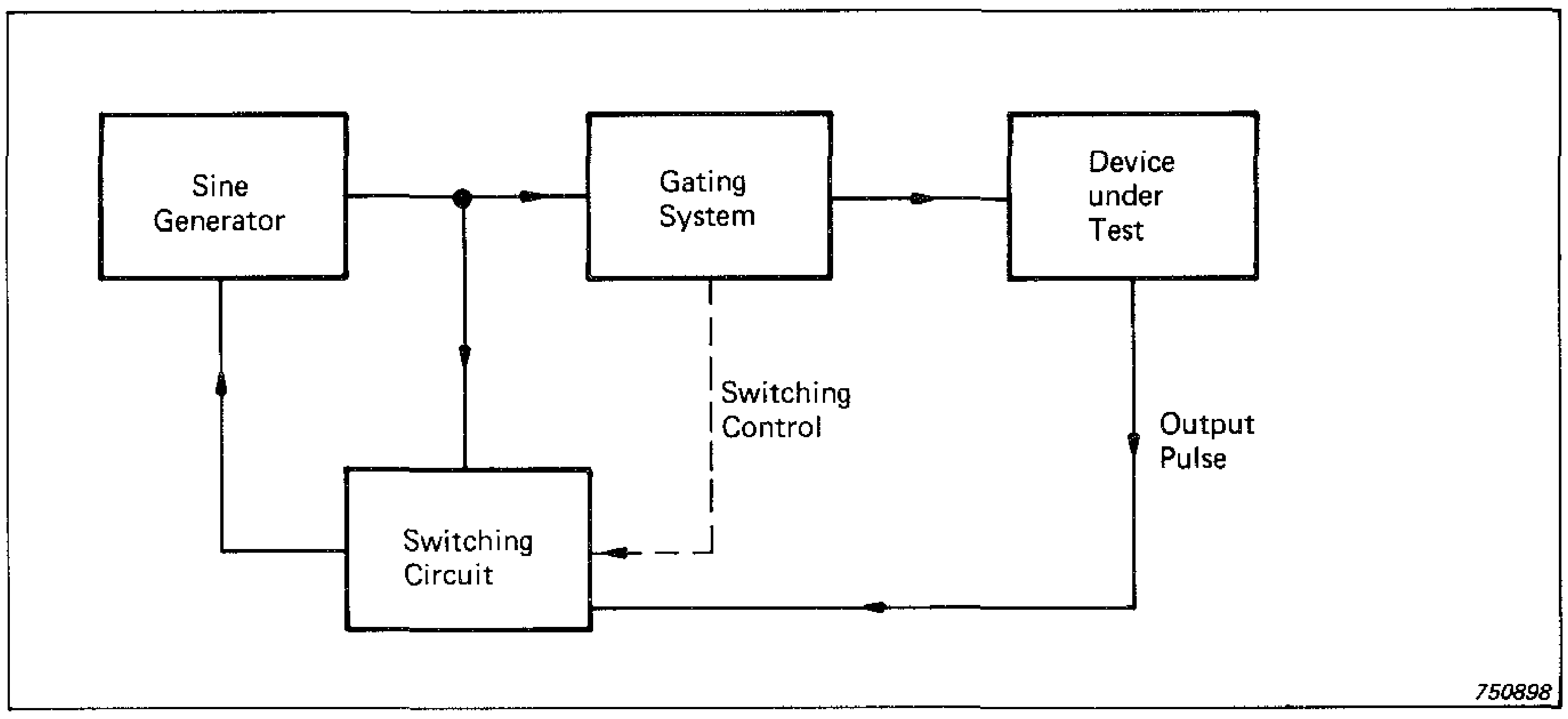

Fig.5. Principle of the method for tone-burst measurements using a compressor loop

3. Practical Set-up

A practical set-up is shown in Fig.6. The switching circuit used in the measurements was a Channel Selector Type 5619 driven by a specially-made control circuit.

The output signal from the Sine Random Generator Type 1027 is fed simultaneously to the GEN. INPUT of the Gating System and to one input of the Channel Selector. The PULSE OUTPUT of the 4440 is fed to the Power Amplifier Type 2706, which drives the 4221.

The CURRENT LIMIT switch of the 2706 is set to "5A RMS". The VOLTMETER output of the 4221 is connected to an Electronic Voltmeter Type 2425 for monitoring the excitation level. The microphone assembly is connected to a Measuring Amplifier Type 2607. The EXT. FILTER output of the 2607 is connected to one channel of the 5619 and to the EXT. FILTER input of the 2607. This ensures that the levels at the Channel Selector inputs are in the same range (the max. input voltage to the Gating System is 1 V RMS) while retaining a reasonable meter deflection on the 2607. The GATE OUTPUT of the 4440 controls the Channel Selector and triggers the Digital Event Recorder Type 7502. Finally, the output of the 5619 is connected to the COMPRESSOR INPUT of the 1027. A twin-channel oscilloscope, triggered by the GATE OUTPUT of the 4440, monitors the received tone burst and the generator output.

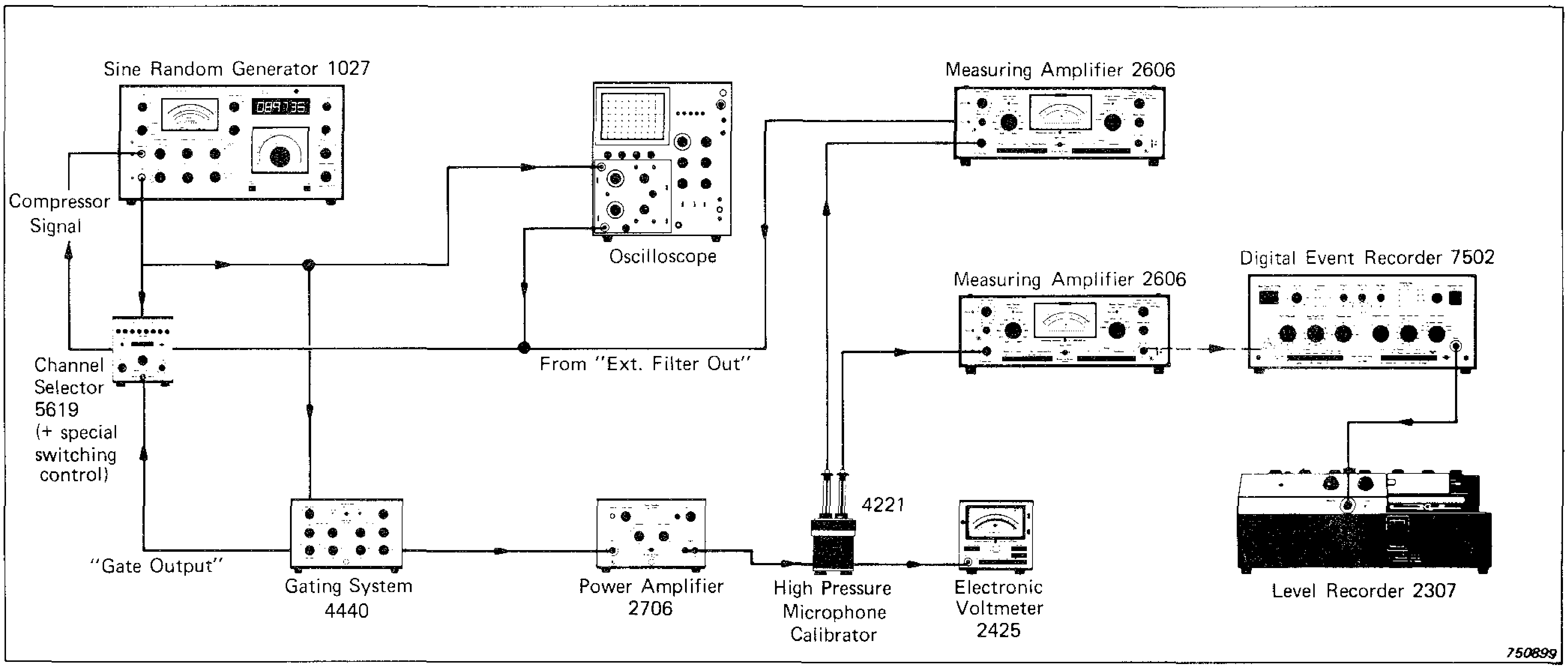

Fig.6. Set-up for tone-burst measurements using a compressor loop. The dotted connections show the additional equipment used for recording waveform

To adjust the measurement level, the Gating System is first set in its "Single Pulse" mode. The generator output is thus permanently connected to the compressor input. The output level of the generator is adjusted to a suitable value (between 0,5 and 1 V RMS) by means of the compressor-section controls. The pulse width and repetition rate are adjusted to the selected values and the attenuators of the 2607 are set, according to the expected input level, to give the proper voltage range at the EXT. FILTER output. With the GAIN CONTROL of the Power Amplifier turned to a minimum, the TRIGGER SELECTOR of the 4440 is set to "Intern Rate Gen." and the gain of the 2706 is adjusted to the required value. The steady-state pulse level can be adjusted using either the COMPRESSOR VOLTAGE potentiometer of the 1027 or the GAIN CONTROL (and INPUT ATTENUATOR) of the 2607, whereas the gain of the Power Amplifier sets the starting level at the beginning of the pulse. During adjustment it should be ensured that the OVERLOAD indicator of the 4440 does not light.

4. Measurements

4.1. Pulse Length and Compressor Speed

The maximum pulse length is 0,5 s due to thermal effect in the driving coil. The minimum pulse length depends on the compressor speed, since the pulse must be long enough to allow the compressor to reach the steady-state. Figs.7 and 8 show the output of the receiving microphone for various compressor speeds. In Fig.7, the steady-state level is lower than the starting level, while the opposite case is illustrated in Fig.8.

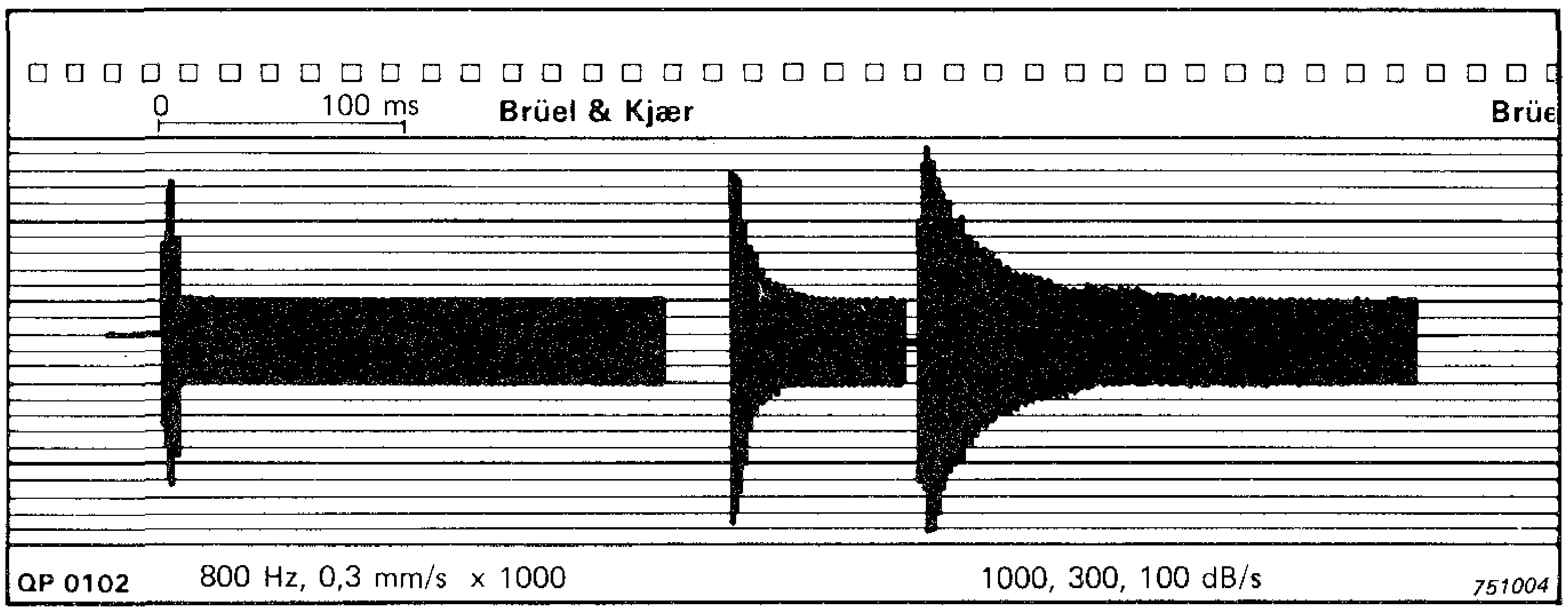

Fig.7. Received pulse waveform for various compressor speeds. Steady-state level lower than initial level

It can be seen that, when the steady-state level is higher than the starting level, the settling time is longer than in the opposite case. This is discussed in Appendix A.

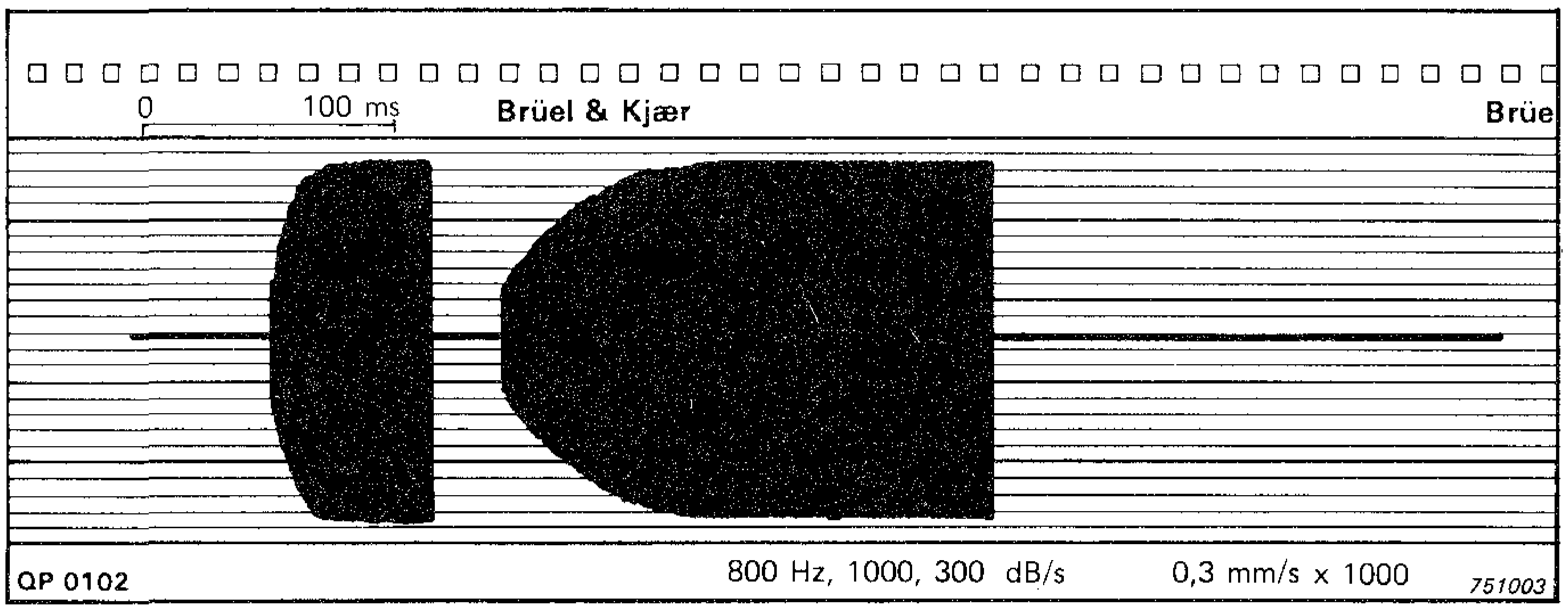

Fig.8. Received pulse waveform for various, compressor speeds. Steady-state level higher than initial level

However, in both cases, a compressor speed of 1000 dB/s is to be preferred since this allows the shortest settling time. Table 1 gives settling times at 1000 dB/s as a function of the difference between initial and steady-state levels. For the derivation of the settling time, see Appendix A.

Δ dB	− 20		− 10		− 6		− 3		+ 3		+ 6		+ 10		+ 20	
$\epsilon = 100\frac{\lvert V - V_B \rvert}{V_B}$	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1
Settling Time (ms)	24,7	29,5	18,5	23,3	15,2	20	11,3	16,1	10	15	12,2	17	14,2	19	19,2	24

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Table 1. Settling times at 1000 dB/s compressor speed as a function of level difference and relative error

Also in Fig.7, it can be seen that the max. peak value is lower at higher compressor speeds.

As compression is to be used at relatively high frequencies (above say, 200 Hz), distortion due to high compression speeds can be neglected. With the Type 1027 third-harmonic distortion is more than 30 dB below the fundamental at 200 Hz.

Thus, in the system described, a compressor speed of 1000 dB/s will be used. The tone-burst length must always be selected to be greater than the settling time (found from Table 1), but it can be varied within rather wide limits (up to 0,5 s).

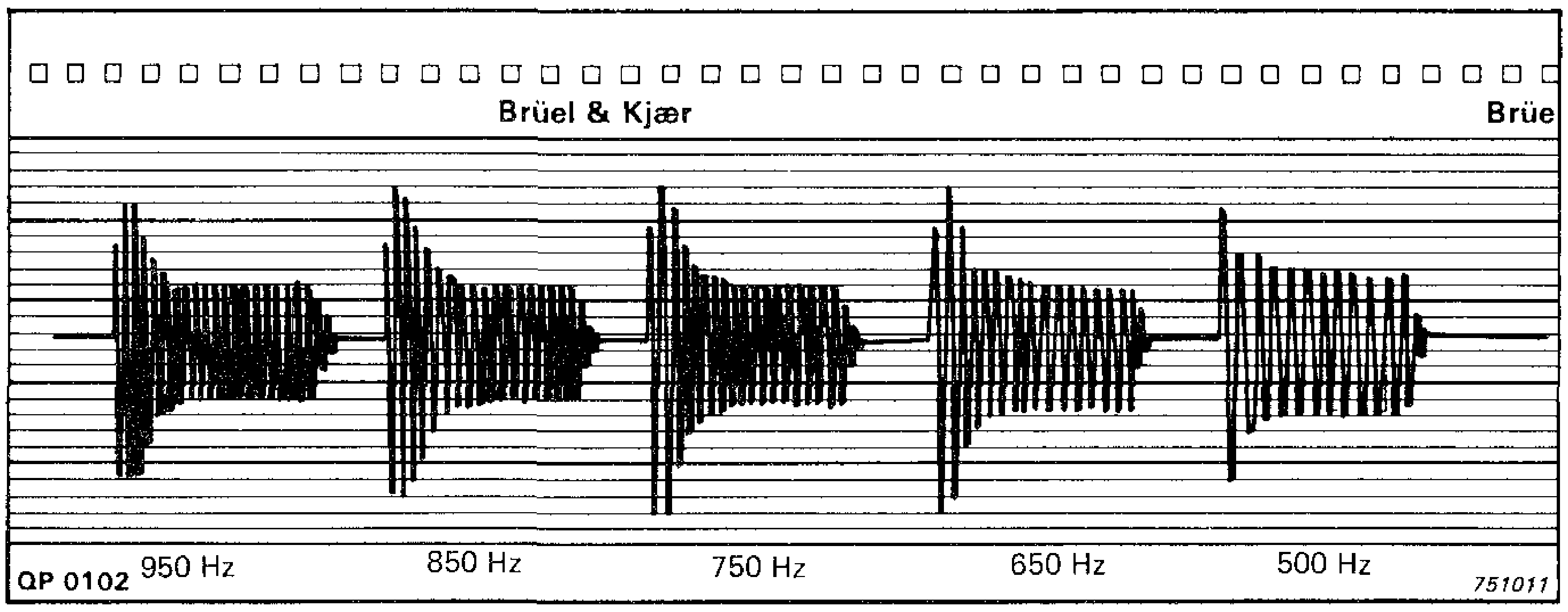

Fig.9. Received pulse waveform at various frequencies. Steady-state level lower than initial level

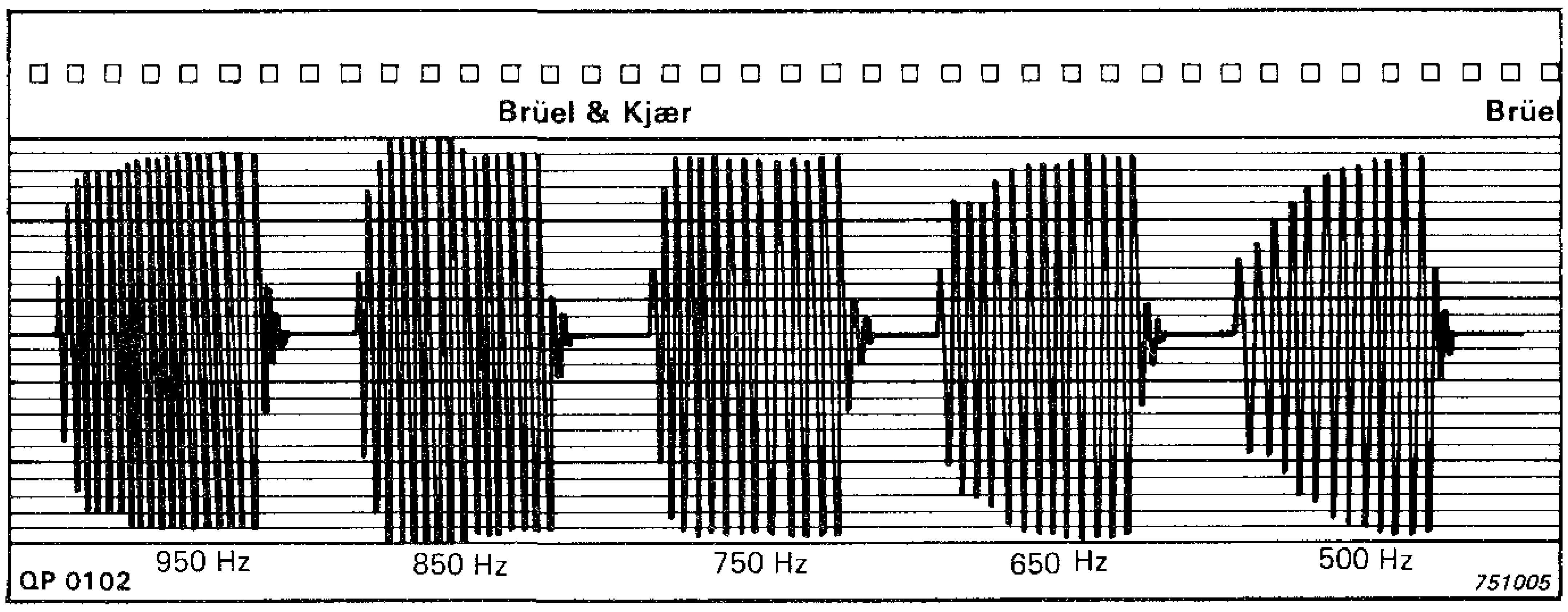

Fig.10. Received pulse waveform at various frequencies. Steady-state level higher than initial level

4.2. Steady-State Levels

The choice of the steady-state levels decides whether the initial pulse level will be higher or lower than the steady-state level. The difference in settling times is not critical at 1000 dB/s compressor speed. However, if the initial level is chosen to be lower than the steady-state level, it should be checked that the Gating System is not overloaded when the pulse is applied.

If the pulse steady-state level must not be exceeded over the whole frequency range of interest, pulse adjustment should be carried out around the resonant frequency (or frequency giving the highest response).

Both cases are illustrated in Figs.9 and 10, which show the received pulse at various frequencies. The compressor speed is 1000 dB/s. The pulse length (approx. 25 ms) is close to the minimum value (approx. 23 ms for an initial level 10 dB below the steady-state level).

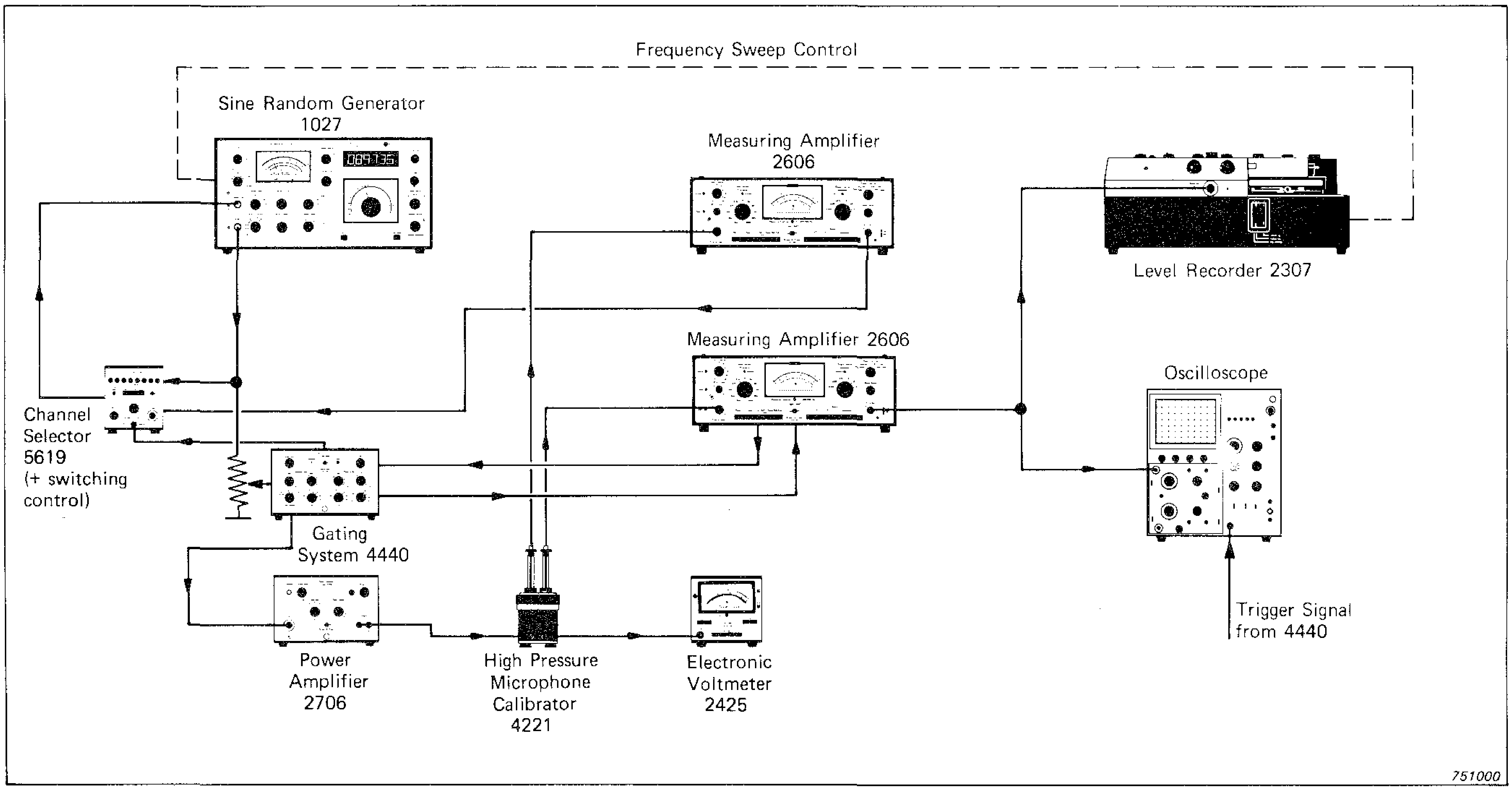

Fig.11. Set-up for automatic frequency response measurements

4.3. Suggested System for Automatic Frequency-Response Measurements

The main purpose of the set-up shown in Fig.6 is to record the pulse waveform. For frequency response measurements (up to 1 kHz), the set-up of Fig.11 is suggested. The potentiometer at the input of the 4440 allows a wider range of generator output voltages than direct connection.

The receiving section of the 4440 is connected as an external filter to the Measuring Amplifier and the DC output of the Gating System is fed to a Level Recorder Type 2307.

For most applications, a pulse length of 100 ms and a repetition rate of 1 s will be satisfactory. The receiving gate delay should be selected to be longer than the max. settling time. The gate width can be adjusted within rather large limits (up to the difference between transmitted pulse length and delay).

5. Conclusion

The system described allows compression techniques to be applied to tone-burst measurements where the pulse length is greater than the settling time. The main advantages of the method are:

1) When the system is adjusted, measurements may be made on single tone burst, and the compressor will still operate.
2) The compressor is always working within known limits.
3) The system can be adjusted so that the pulse steady-state level is never exceeded.

With the High Pressure Microphone Calibrator Type 4221, the delay between transmitted and received pulses is negligible. If the delay is not negligible the compressor microphone should be placed close to the excitation source. The signal from the receiver microphone should be measured using the measuring gate of the 4440 with the proper gate delay and width.

Appendix

Compressor Settling Times in Tone-Burst Measurements

Fig.A.1 shows a simple compressor loop where V is the instantaneous voltage at the compressor input and V_B is the balance voltage.

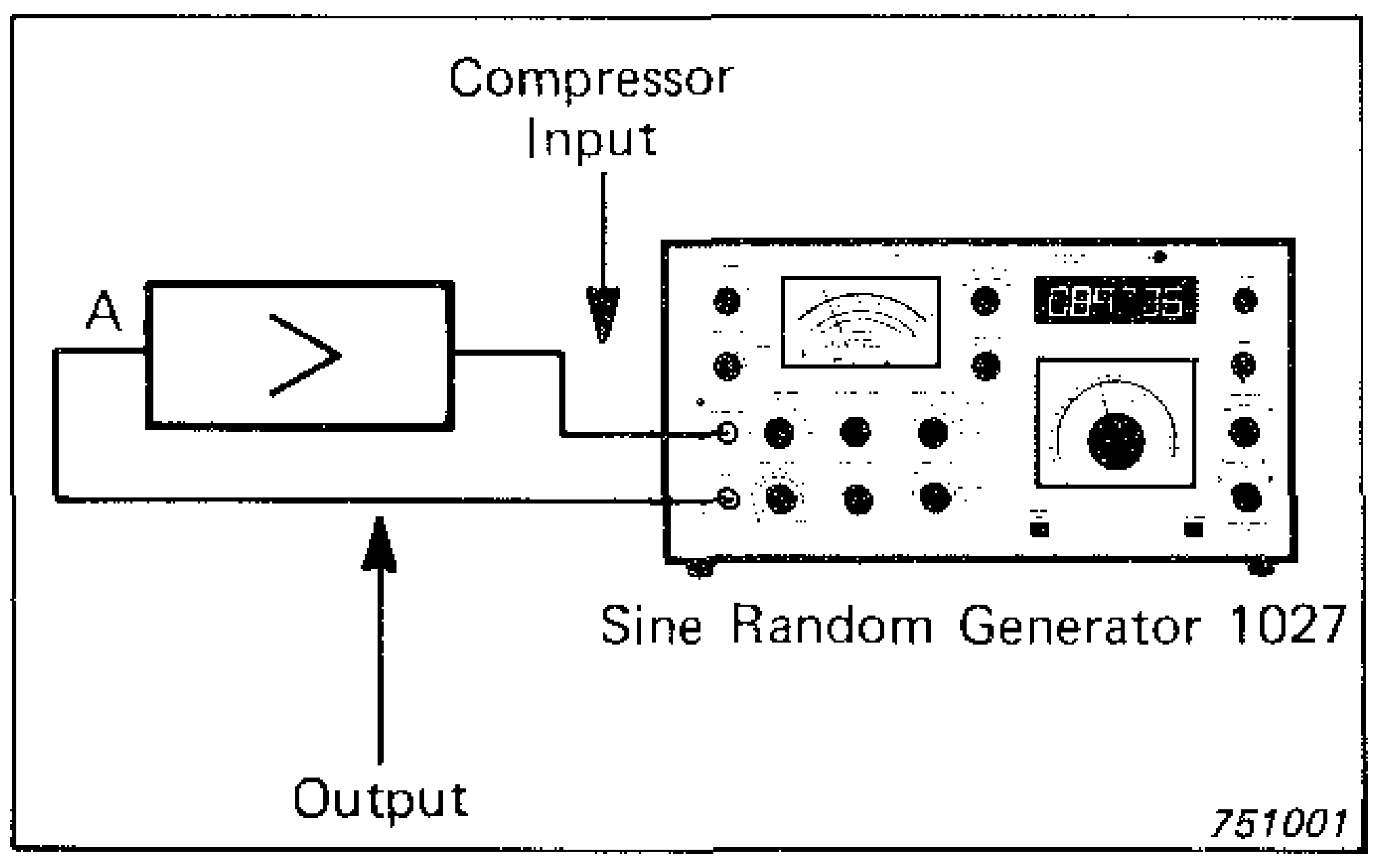

Fig.A.1. Simple compressor loop

For the 1027, the Compressor Speed is defined as the initial slope in dB/s after the gain in the compressor loop has suddenly been decreased by 6 dB. For other level differences, the slope will be different.

Since the compressor circuit uses RC averaging, the rate of change of V compared with V_B will exponentially approach 0, proportional to a certain time constant τ (τ depends upon the COMPRESSOR SPEED selector setting):

$$\tau \frac{d}{dt}\left(\ln \frac{V}{V_B}\right) = \frac{V_B - V}{V_B} \qquad (A.1)$$

$$-\tau \frac{d}{dt}\left(\ln \frac{V_B}{V}\right) = \frac{V_B - V}{V_B} \qquad (A.2)$$

$$-\tau \frac{V}{V_B} \times \frac{d}{dt}\left(\frac{V_B}{V}\right) = 1 - \frac{V}{V_B} \qquad (A.3)$$

$$\frac{1}{V} - \frac{1}{V_B} + \tau \frac{d}{dt}\left(\frac{1}{V}\right) = o \qquad (A.4)$$

Assuming that at time $t = o$ the voltage at the compressor input is suddenly changed from V_B to V_o, and considering that for $t = \infty$, $V = V_B$, then:

$$\frac{1}{V} = \left(\frac{1}{V_o} - \frac{1}{V_B}\right) e^{\frac{-t}{\tau}} + \frac{1}{V_B} \qquad (A.5)$$

In the system described in this Application Note, the gain in the compressor loop is alternating between 1 (direct connection of the generator output) and A (connection to the microphone output). Assuming that the steady-state voltage V_B has been reached before each switching, two values of V_o must be considered: at the beginning of the pulse, $V_o = A \times V_B$ and, when switching back to the generator output, $V_o = V_B/A$. In other words, the initial levels are equally spaced apart from the steady-state level in terms of dB values.

Theoretically, an infinite time is required for V to become equal to V_B. However, it is possible to derive the time taken by V to reach a level where the relative error (ϵ in % ($\epsilon = 100 (V_B - V)/V_B$) becomes smaller than some specified value.

Table A.1 gives the relative settling time (t/τ) as a function of the level difference ($\Delta = 20 \log V_o/V_B$) and the relative error.

It is seen that the settling time from a high level to a lower one is shorter than in the opposite case.

When the level difference exceeds 6 dB, the time difference is even bigger between the two cases. The *settling time from a level lower* than the balance level V_B is still governed by Eqn. (A.5) while, as long as the level V is more than 6 dB above V_B, the rectifier in the compressor circuit is clipping, and compression takes place with a constant slope equal to the initial slope that can be derived from Eqn.A.5 (i.e. twice the speed indicated by the COMPRESSOR SPEED selector). When V becomes less than 6 dB above V_B, compression becomes exponential according to Eqn.(A.5). Even though the transition from linear to exponential averaging is progressive, the assumption of two separate processes gives fairly good results. This is illustrated in Fig.A.2.

Δ (dB)	−6			−3			+3			+6		
ϵ %	10	3	1	10	3	1	10	3	1	10	3	1
$\frac{t}{\tau}$	2,2	3,5	4,6	1,3	2,6	3,7	1,15	2,3	3,4	1,7	2,8	3,9

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Table A.1. Settling time relative to compressor time constant

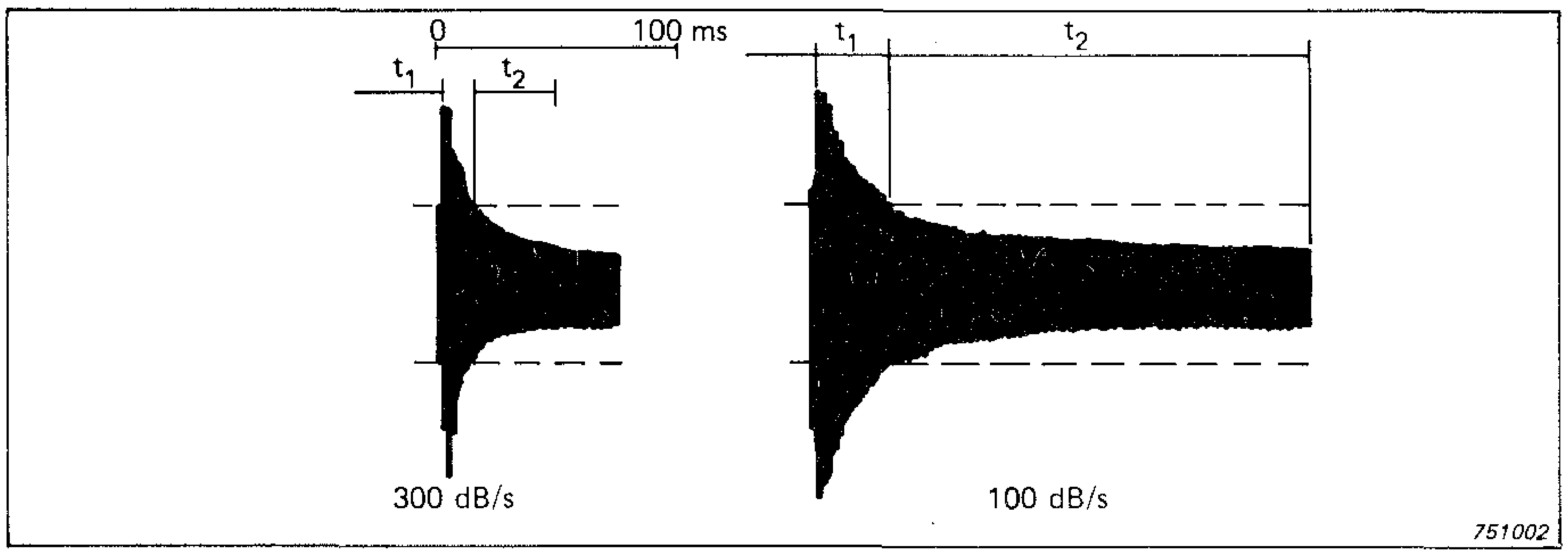

Fig.A.2. Comparison of recorded and calculated settling times

In both cases, V_o is taken to be equal to the maximum level reached at the lowest compression speed, i.e. approx. $5 V_B$ (see Fig.A.2). From the beginning of the pulse, the time t_1 necessary to reach the transition level ($2 V_B$) is given by:

$$t_1 = 20 \log \frac{V_o}{2 V_B} \times \frac{1}{2C} \qquad (A.6)$$

where C is the COMPRESSOR SPEED selector setting.

In the case of Fig.A.2, this gives

$$t_1 = 20 \log 2,5 \times \frac{1}{2C} \qquad (A.7)$$

$$t_1 = \frac{4}{C} \qquad (A.8)$$

i.e. t_1 = 13,3 ms for C = 300 dB/s
and t_1 = 40 ms for C = 100 dB/s

The settling time t_2 from $2 V_B$ to V_B (ϵ = 1%) is given by:

$$t_2 = 3,9\,\tau \qquad (A.9)$$

As $\tau = 4,35/C$ (see section 6.3 of the 1027 Instruction Manual).

$$t_2 = \frac{17}{C} \qquad (A.10)$$

i.e. t_2 = 56,6 ms for C = 300 dB/s
t_2 = 170 ms for C = 100 dB/s

t_1 and t_2 have been indicated on Fig.A.2 for comparison with the actual curves.

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