Calibration and Correction for Phase Mismatch of an Intensity Analysing System based on the Dual Channel Real-time Frequency Analyzer Type 2133

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Introduction

For accurate measurements of sound intensity, the two channels of an intensity analysing system must be well phase-matched. This Application Note describes the use of the Sound Intensity Calibrator Type 3541 to calibrate a complete intensity analyzing system and how to correct for the inevitable residual phase-mismatch between the two channels.

Instrumentation

The complete sound intensity analysing system shown in Fig. 1 consists of an Intensity Probe Type 3545, a Remote Control Unit ZH 0354, a Dual Channel Real-time Analyzer Type 2133 and a Sound Intensity Calibrator Type 3541. The word "complete" emphasizes that the analyzer not only performs the measurements but also stores the results on disc and performs most of the post-processing tasks that usually require a computer. For example, sound power calculations and corrections for phase mismatch can be calculated directly. For mapping sound intensity and displaying the results on the screen software package BZ 7021 is available on disc. To confirm the integrity of this system, the Sound Intensity Calibrator Type 3541 has been developed.

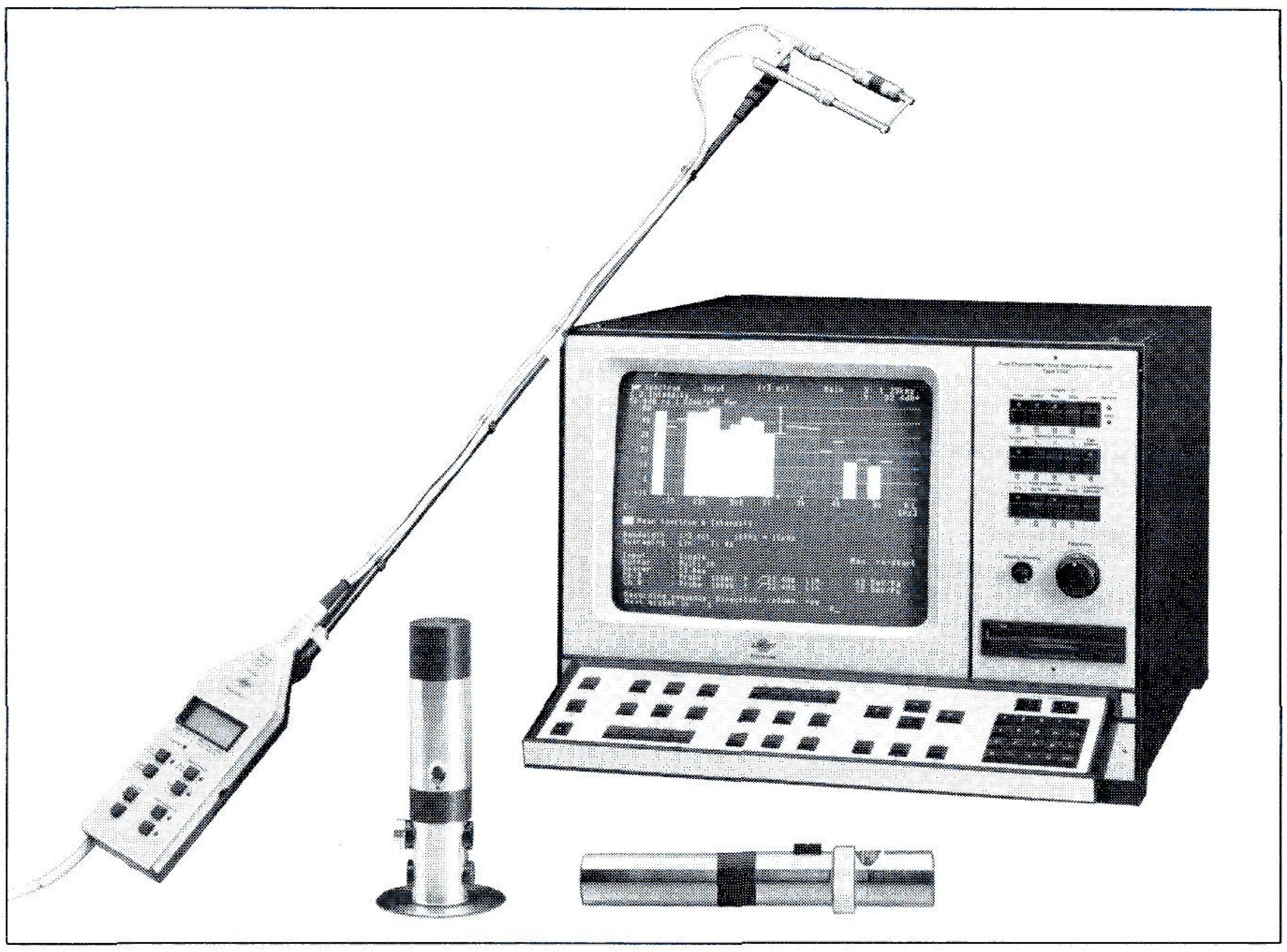

Fig. 1. The complete Intensity Analysing System consisting of the Dual Channel Real-time Frequency Analyzer Type 2133, Intensity Probe Type 3545, Remote Control Unit ZH 0354 and the Sound Intensity Calibrator Type 3541

Sound Intensity Calibrator Type 3541

Type 3541 is a set of instruments consisting of a Pistonphone Type 4220, an Intensity Coupler UA 0914 and a Sound Source ZI 0055. The calibrator has two modes of operation. In the first mode it generates well defined sound signals similar to those existing in a free-field. These are intended for intensity-sensitivity calibration of complete systems, incorporating all components from the microphones to the unit displaying the results. The second mode of operation is for measurement of the system's Residual Pressure-Intensity Index. This index is a measure of phase deviation between the channels or for the systems ability to produce valid results when measurements are made in general sound fields. The system based on 2133 can even use the measured index to improve the measurement accuracy by correction of the results. The calibrator can also be used for sound pressure and particle velocity calibrations (Fig. 2).

Other methods of calibrating intensity systems are free-field waves in anechoic rooms and waves inside standing wave tubes. These methods are essentially for laboratory use as it can be quite difficult to create well-defined free-field waves even in anechoic rooms, and standing wave tubes with the necessary additional equipment are impractical to move to the actual measurement sites.

It should be noted that the coupler has been designed for calibration of microphones equipped with phase correctors* (i.e. Brüel & Kjær Microphone Pairs Types 4181 and 4183, Type 4181 is standard on the Type 3545 probe). One of the advantages of the phase correctors is that they dramatically reduce the vent sensitivity of the microphones. This enables the coupler to have small dimensions because only the diaphragms of the microphones need to be exposed to the sound field in the coupler. Furthermore, small dimensions imply a wide frequency range of operation.

* Patent applied for

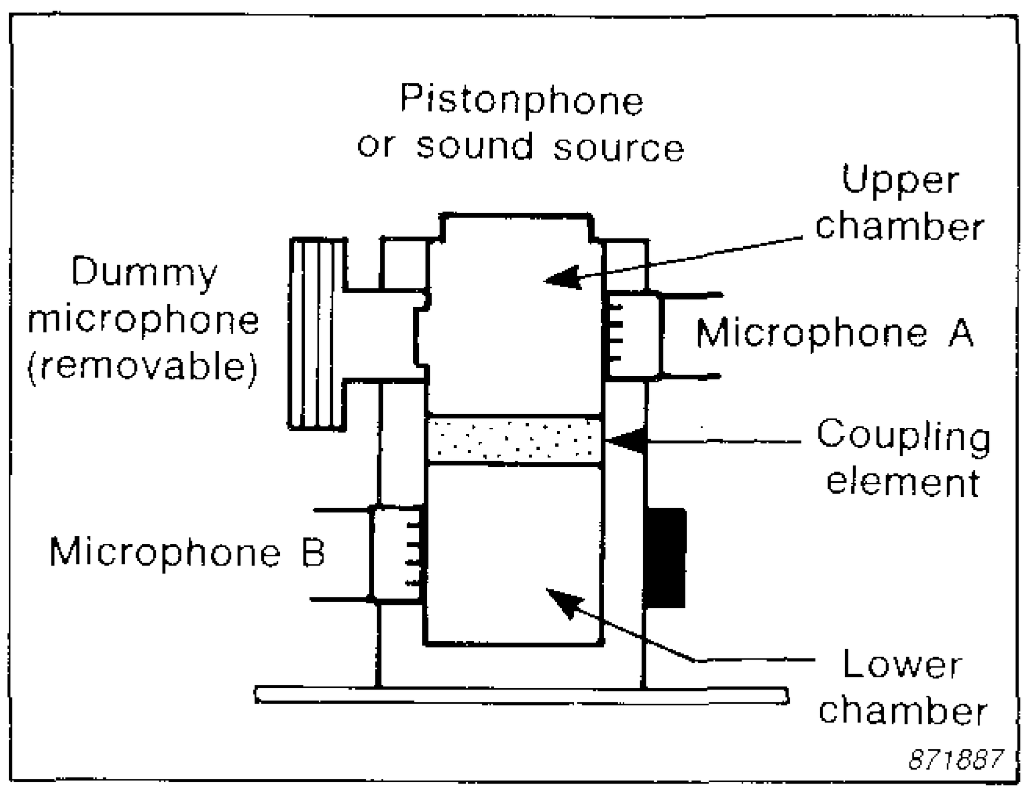

Fig. 2. Cross section of Intensity Coupler UA 0914

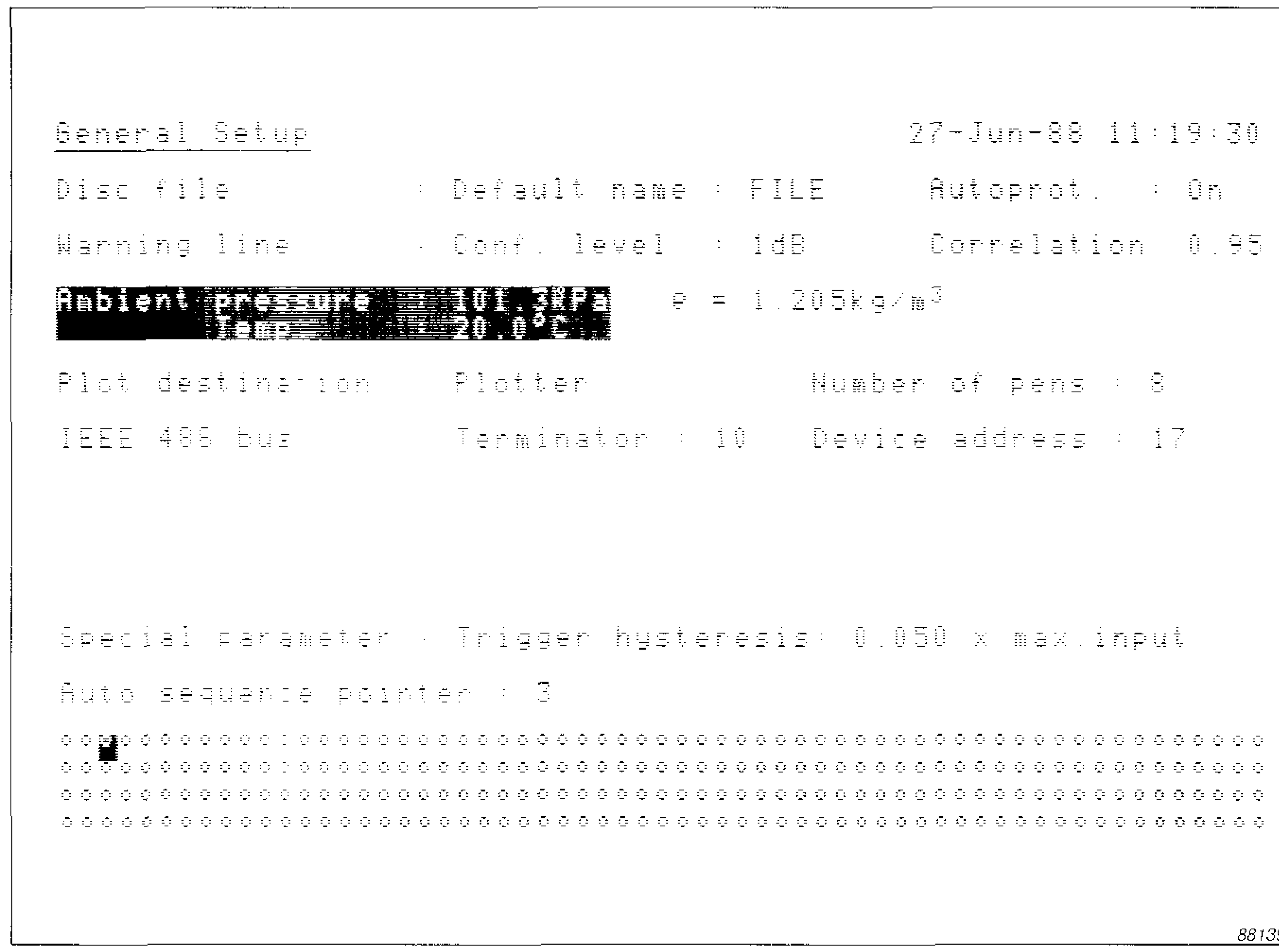

Fig. 3. General Setup. Specification of the ambient temperature and pressure

Calibration Procedure

A full calibration of an intensity system involves:

1. Setting of density of the medium, ρ
2. Setting of spacing between the transducers, Δr
3. Pressure level sensitivity
4. Phase matching between channels
5. Intensity level sensitivity

The measurements 3 to 5 mentioned above can all be performed using the Sound Intensity Calibrator Type 3541. The Type 3541 also enables a particle velocity level calibration to be performed although this is not necessary for usual intensity measurements.

Density of the Medium

For air, the density can be calculated from the ambient pressure, which can be read from the barometer supplied with Type 3541, and the ambient temperature. These values should be keyed into the General Setup of the analyzer which then calculates the density (Fig. 3). If the density of the medium is known then that value can be keyed directly into the analyzer.

Transducer Spacing

The nominal length of the spacer between the two microphones is keyed into the analyzer via the Measurement Setup displayed on the analyzer.

Pressure Level Sensitivity

The autocalibration facility on the analyzer leads users through the pressure amplitude calibration procedure with a series of prompting messages. Fig. 4 shows the pistonphone attached to the intensity coupler and both microphones inserted into the upper chamber. With this arrangement the analyzer can perform the pressure amplitude calibration for both channels simultaneously. The sound pressure level produced by the pistonphone within the coupler is approximately 118 dB instead of the usual 124 dB produced when the pistonphone is used directly on one microphone. This is a result of the volume in front of the pistons being doubled and thus reducing the sound pressure level by 6 dB. The exact value is given on the calibration chart supplied with each Type 3541. The correction to the calibration level which is required to account for the influence of the ambient pressure is indicated on the barometer. This correction must be added to the specified calibration level and the resultant level entered into the analyzer before performing the autocalibration.

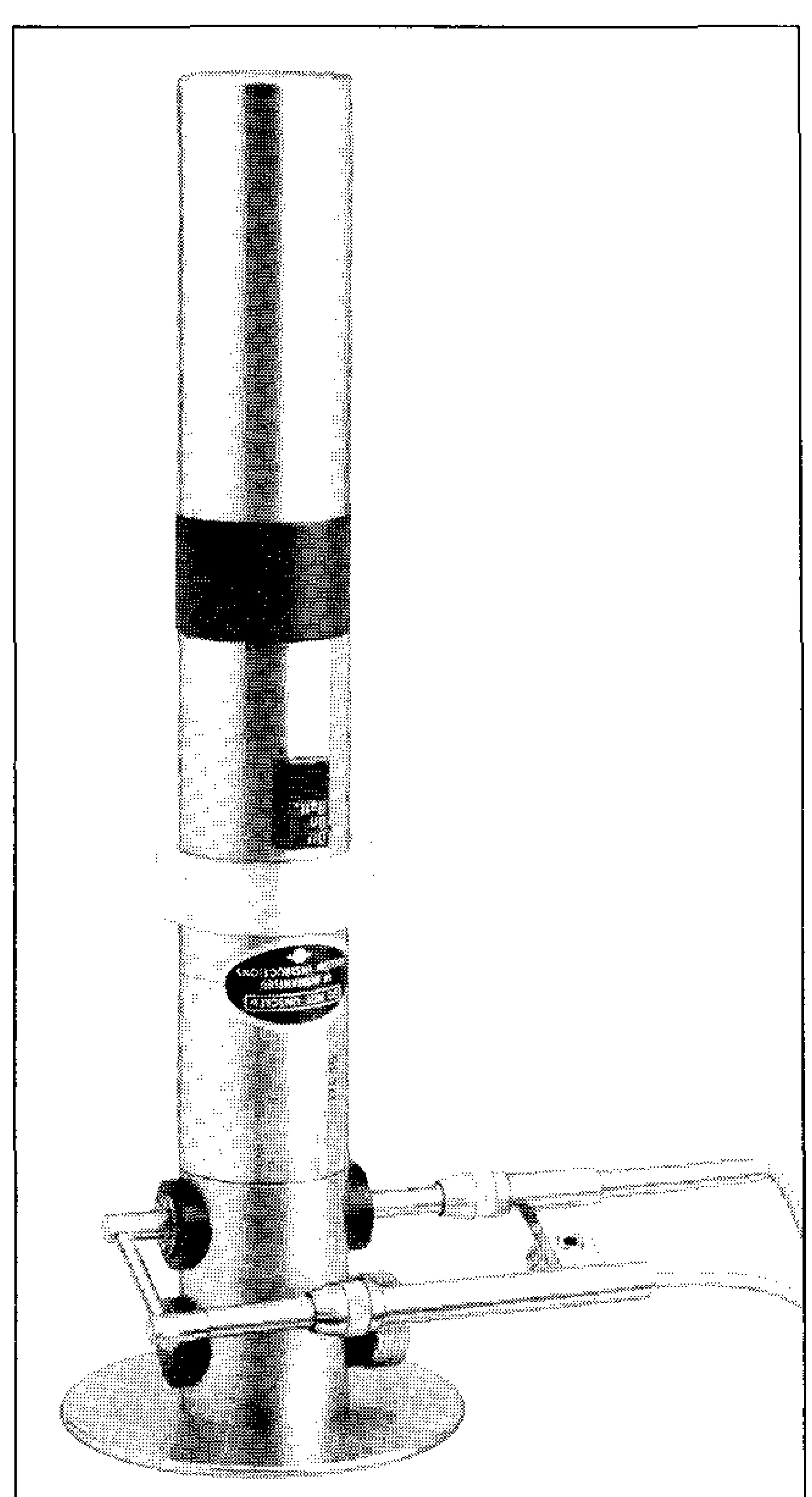

Fig. 4. Arrangement for pressure amplitude calibration

The sensitivity adjustments performed by the analyzer to align the measured sound pressure level to the sound pressure level produced in the coupler are stored as part of the Measurement Setup and used in all further measurements.

The straightforward amplitude calibration described here is usually sufficient for accurate sound intensity measurements in most practical applications. However, in difficult situations where the sound field is highly reactive, an improved dynamic capa-

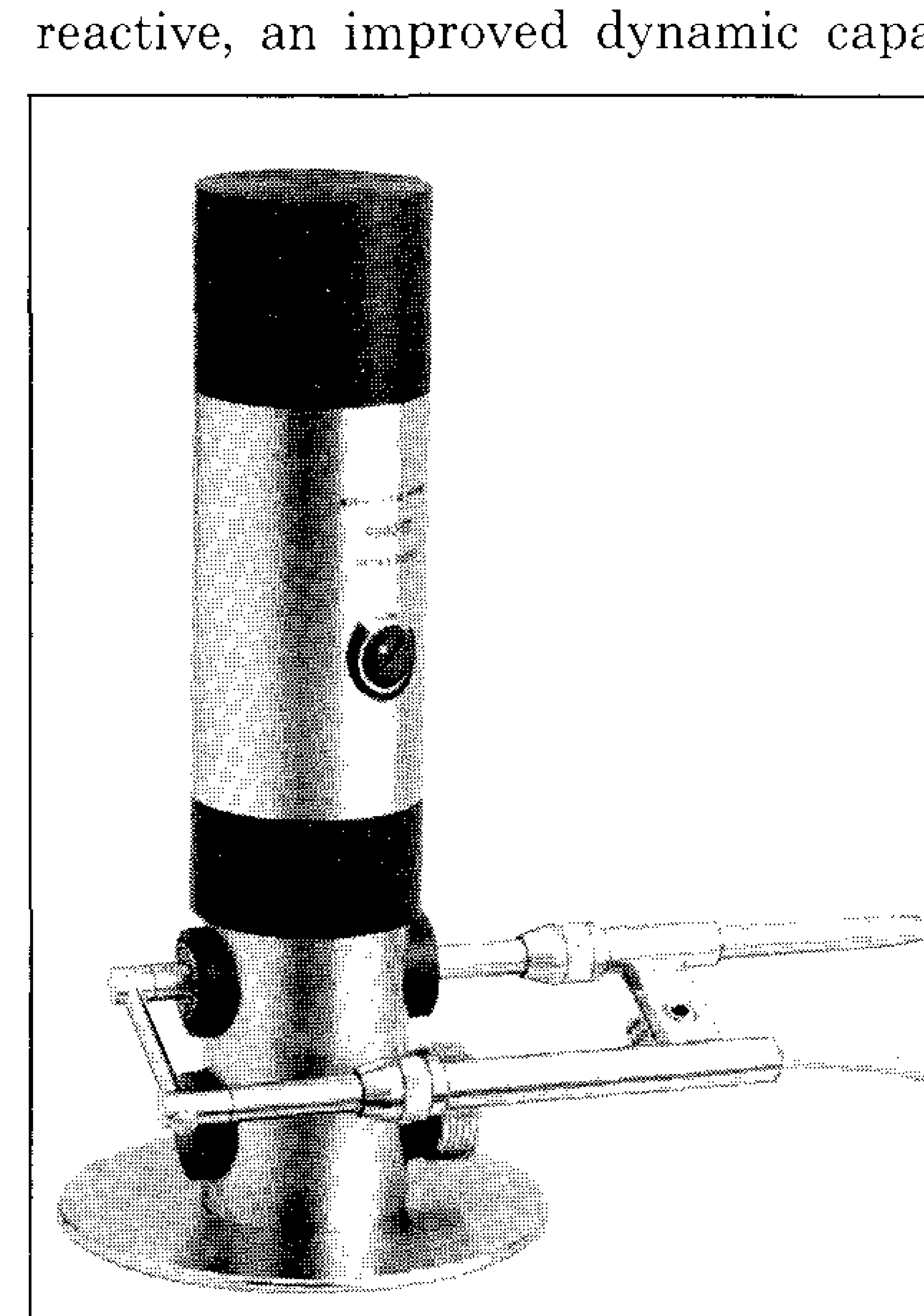

Fig. 5. Arrangement for residual pressure-intensity index measurement

bility can be obtained by correcting for the residual phase-mismatch of the system.

Phase Matching

It must be appreciated that even with phase-matched microphones and an analyzer based on digital techniques that there will always be, however small, a residual phase-mismatch in a practical system. The phase mismatch due to the analyzer alone can be measured by means of one of the six tests included in the analogue self-test routine. In this test, a broad-band noise signal is fed into both direct channels and the complex cross spectrum is measured. The measured phase-mismatch can then be displayed together with the specified maximum phase-mismatch for the analyzer in a special 'tolerance curve' format.

To measure the phase mismatch of the complete system both microphones are placed into the upper chamber of the coupler, as for the amplitude calibration, only this time the Sound Source ZI 0055 is used instead of a pistonphone (Fig. 5). With the same signal incident on both microphones, ideally the same sound pressure will be measured by both. As there should be no phase gradient between the two signals there should be no intensity. No intensity corresponds to an intensity level of minus an infinite number of dB! An intensity analyzer capable of displaying this level cannot be realized as there will always be a residual-intensity level due to a residual phase-mismatch. Thus the difference between the measured pressure and intensity levels, known as the residual pressure-intensity index and designated by δ_{pI_0} in the ISO/DP 9614 draft standard, expresses the residual phase-mismatch.

It is most convenient to obtain the residual pressure intensity index δ_{pI_0} in the ISO/DP 9614 draft standard, using one of the pre-defined Measurement Setups available on the analyzer together with a long linear-averaging time of 2 minutes. Notice in Fig. 6 that the mean spectrum and intensity are measured. Particle velocity, which is necessary for determining intensity, is determined for a point midway between the two transducers. The sound pressure at the same point is the mean of the sound pressures at the two transducers. If the sound pressure from one of the transducers is used then in very reactive environments where large pressure gradients can occur, the calculated intensity can be

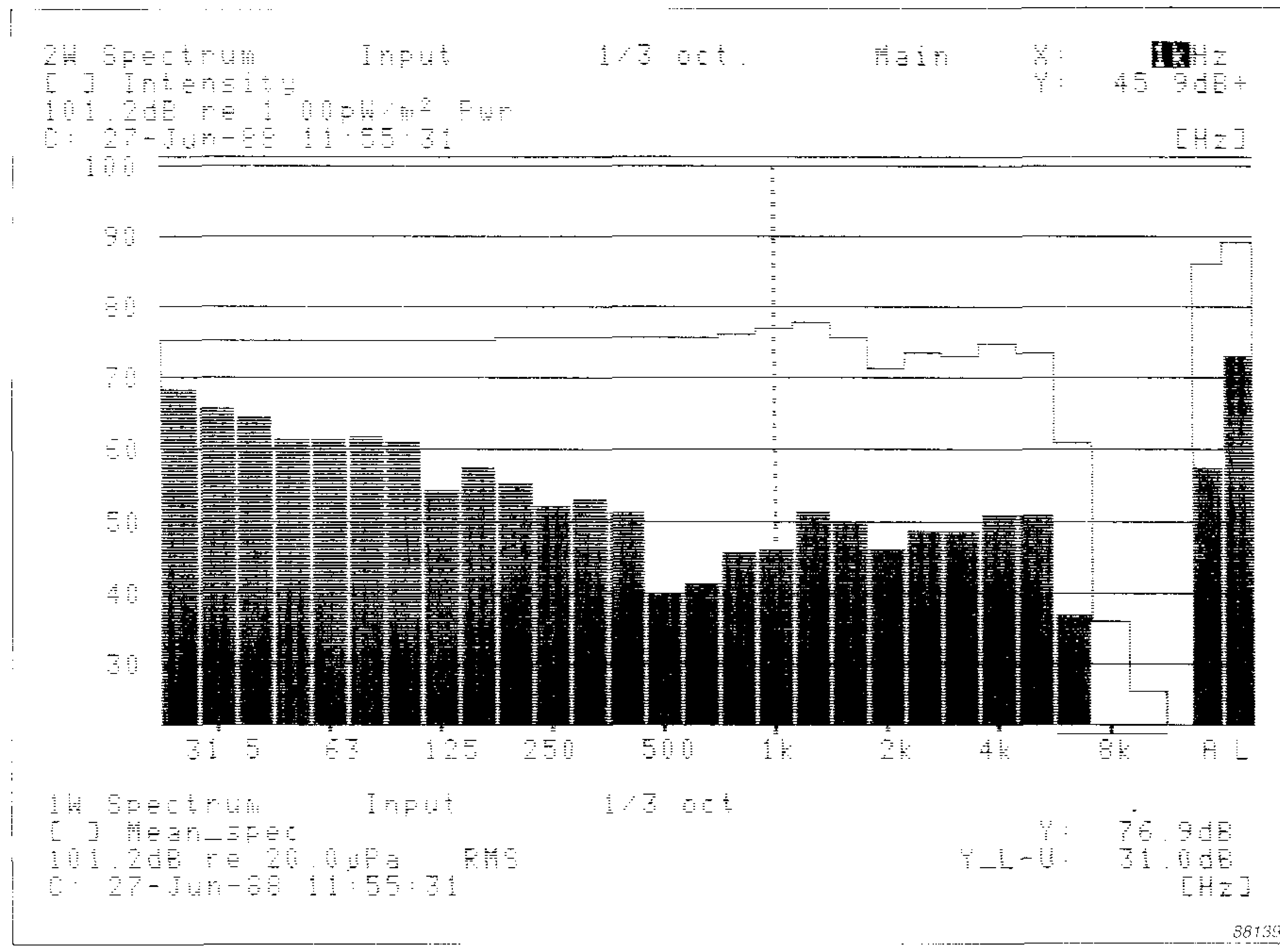

Fig. 6. Pressure levels and intensity levels as measured using the Type 3541 with both microphones of the probe in the upper chamber of the coupler

grossly incorrect. (Ref. [1]).

The result of the residual pressure-intensity index measurement can be stored on disc with a suitable file name.

A Final Calibration

Before the user starts making measurements on the test object, there is yet another test that can be performed. The sound intensity and particle velocity measured by the system can be checked against the calibrated values produced in the coupler by the pistonphone (Fig. 7). For this test, one microphone is inserted in the upper chamber and the other in the lower chamber. In this configuration the coupler simulates the acoustical conditions of a plane wave propagating in a free field. By replacing the pistonphone with the broad-band source the user can check that the sound intensity level and the sound pressure level are equal (as they should be in a free field) up to the cut-off frequency set by the coupler.

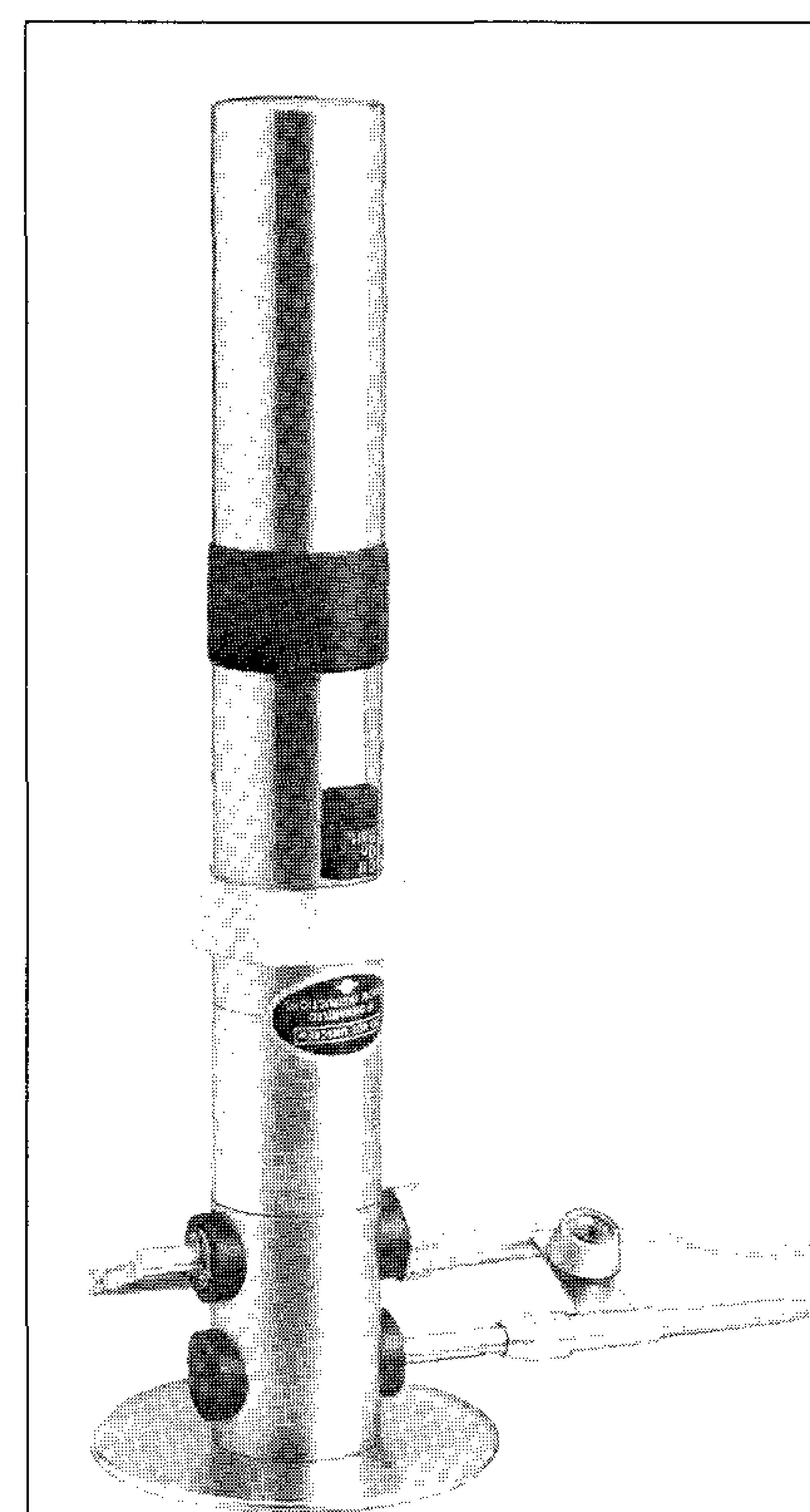

Fig. 7. Arrangement for checking the intensity and particle velocity calculation in the analyzer

Optimisation of the intensity system

The Type 3541 offers the user another advantage. From a measurement of δ_{pI_0}, the user can determine the dynamic capability and hence the useful frequency range for his particular system. By exchanging the positions of the microphones in the probe, recalibrating and remeasuring δ_{pI_0}, the user can determine the optimum configuration of the probe for a given situation.

It could well be that the user's system with a single spacer is adequate over a frequency range which is broad enough for the job in hand where as the probe's specifications might indicate the use of two spacers, one for high frequencies and one for low frequencies.

Correction for Phase Mismatch

When satisfied with the calibration, the user can then perform intensity measurements on the test object. The intensity measurements obtained, $I_{measured}$ will be contaminated by the residual intensity of the system, $I_{residual}$. Thus the corrected intensity will be given by

$$I_{corrected} = I_{measured} - I_{residual} \quad (1)$$

This may be written (Ref. [3]):

$$I_{corrected} = I_{measured} - \frac{p^2_{measured} \cdot I_{coupler}}{p^2_{coupler}} \quad (2)$$

where $I_{coupler}$ and $p^2_{coupler}$ are the intensity and pressure obtained during the residual pressure-intensity index measurement. Equation (2) has been implemented directly in Type 2133 as a pre-defined function so that corrections for phase mismatch can easily be performed even with a live display simply by applying that particular function to the measurements. It's as easy as applying an A-weighting!

A word of caution needs to be said here. If the δpI_0 has been measured with a certain Δr then the spectrum to be corrected should also be measured with the same Δr otherwise equation (2) needs to be modified by multiplying the second term on the right hand side by the ratio of $\Delta r_{coupler}$ to $\Delta r_{measured}$. This is easily done by means of an user defined function.

The necessity for microphones with phase-correctors

Now that a phase correction routine has been implemented in the analyzer one should not jump to the conclusion that any pair of microphones can be used for intensity measurements; that would be a grave mistake. Before one can perform a correction for phase mismatch one needs reliable intensity measurements because the measured pressure intensity index is used for phase correction (eqn. 2). This implies that one needs a high quality probe fitted with phase correctors. The advantages of the phase correctors are that the resulting probe is acoustically exceedingly stable and that the probe measures correctly even in sound fields where these can be a considerable pressure gradient across the probe (e.g. in standing waves). The phase correctors effectively remove the microphones' equalisation vents from the acoustical system thus only the diaphragms of the two microphones in the probe are sensing the sound field. The mean pressure and the particle velocity and hence the intensity are thus calculated from 2 pressure measurements in accordance with the usual finite difference approximation technique.

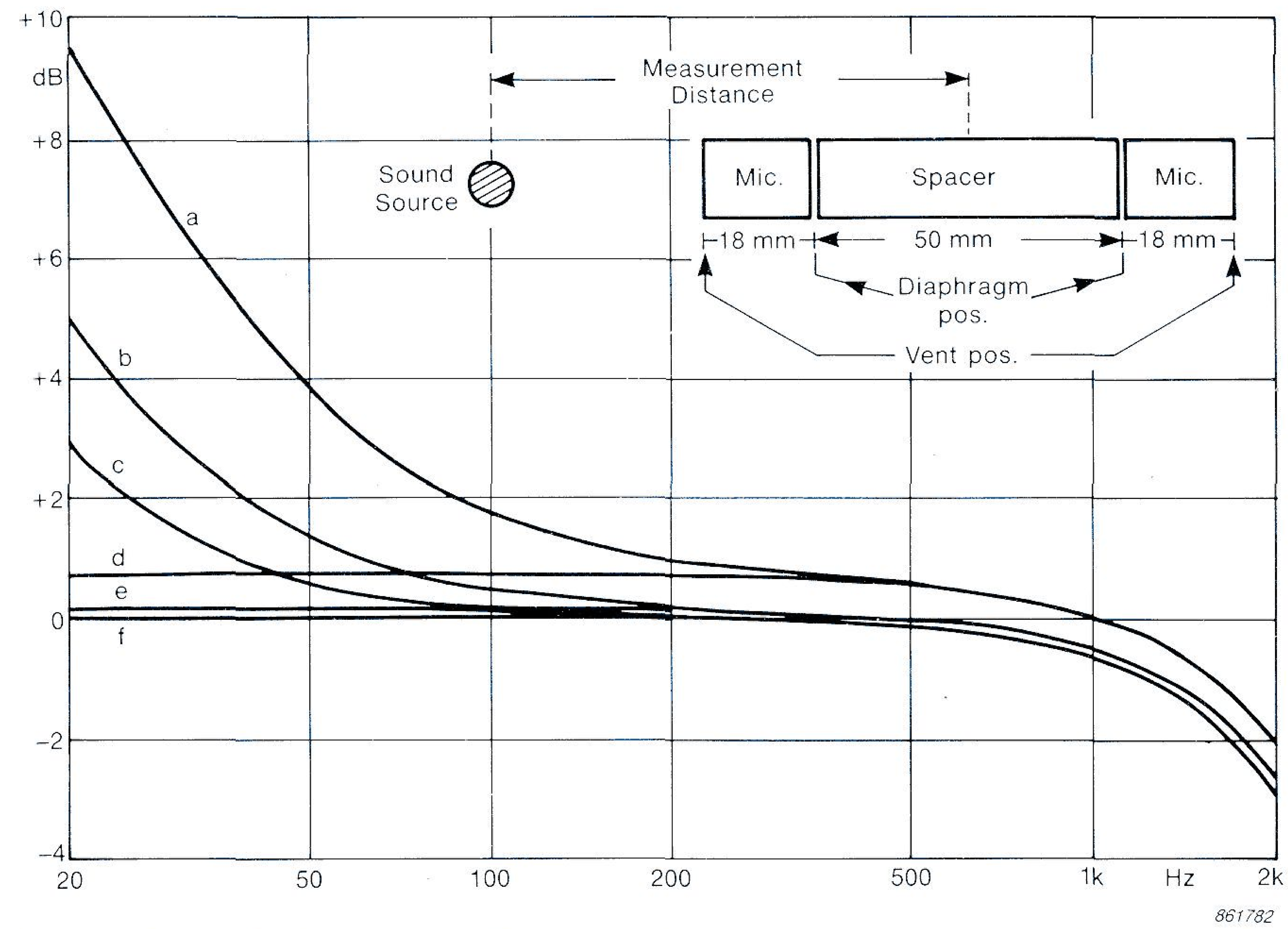

Fig. 8. Intensity Probe Frequency Responses close to a Point Source when equipped with Traditional Microphones of 2 Hz cut-off frequency and with New Microphones
a), b) and c) Traditional Microphones; source distances are 63 mm, 125 mm and 250 mm respectively
d), e) and f) New Microphones; same distances respectively.
The curves which are calculated are valid for the indicated distances between source and centre of spacer

In situations where the pressure at the microphone's pressure equalisation vent has an effect on the pressure at the diaphragm, (e.g. for microphones without phase correctors in a complex sound field) the measured intensity will be incorrect and thus cannot be used to perform a correction for phase-mismatch. A correction for phase mismatch is therefore only permissible when phase-correctors are employed and in the frequency range where the effects due to pressure gradients are negligible (Fig. 8).

Conclusion

This Application Note has illustrated how the Sound Intensity Calibrator Type 3541 enables a complete intensity analysing system to be calibrated according to known sound pressure, sound intensity and particle velocity levels. It has also been shown how a measurement of the residual pressure-intensity index of the system enables corrections to be made for phase mismatch thus yielding an even greater dynamic capability for the system.

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