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SOME IDEAS IN COMPUTERIZED ACOUSTICAL IMPEDANCE MEASUREMENTS.

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ABSTRACT

A new method for measuring acoustic impedance has been developed at the department of Technical Audiology. This new method is using a computer to generate a signal to the impedance measure equipment and to analyse the result gained from it.
The advantages with this method are the improvement in signal to noise ratio and accuracy, and more rapid measurements.
The acoustic impedance is of great importance to the transducer designer. A computer generated signal of harmonic sine-waves supplied with randomized phase has proven very useful in impedance measurements. Averaging over several periods of this signal increases signal to noise ratio and makes measurements at very low levels possible. An unpolarized condenser microphone, fed with a pre-distorted signal over a step-up transformer, is a useful way of getting a low distortion high output signal source. Computerization of acoustical impedance measurements gives improvements in speed and accuracy.

Some ideas in computerized acoustical impedance measurements

Rapid measurements of acoustical impedances are of great importance to the transducer designer. With a knowledge of impedance the expected frequency response under different load conditions can be calculated. Many methods have been described in the literature using sine-waves as signals. With a computer it is possible to use broadband signals.

Two different methods have been studied in this work, one is based on the well-known technique with a sound source of known volume velocity and the other is based on studying standing waves in a tube.

In both methods the same type of signal is used. The output level at 168 discreet frequencies is specified as the input to a 512 points FFT transform. If all frequencies are in phase they add up in the same point in the time domain and a pulse-like signal is created, but if the phase of each frequency is randomized a signal of noise character is generated. When the 512 point real sequence is repeated periodically a true stationary signal of 168 summed sine-waves is generated. A signal of this type has proven to be very useful in acoustical measurements and especially in impedance measurements (fig. 1).

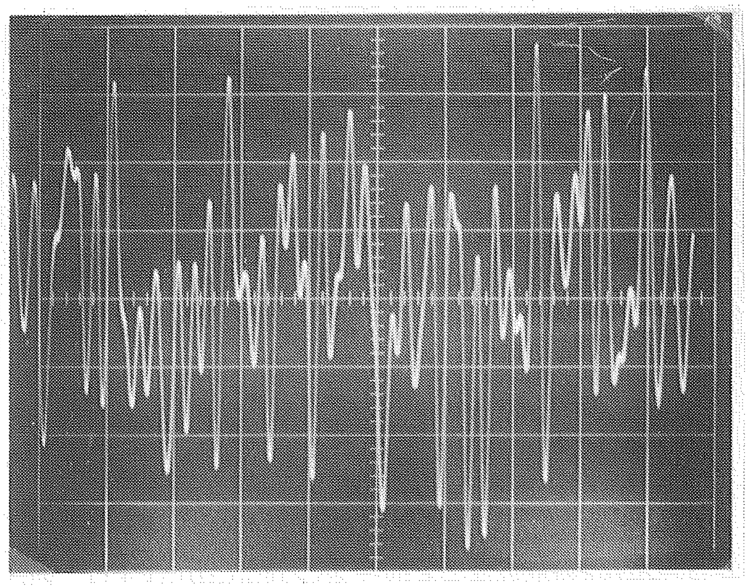


Fig. 1

One of the transducers, especially designed for impedance measurements, avilable on the market is the TESLA institute MA-1 transducer.

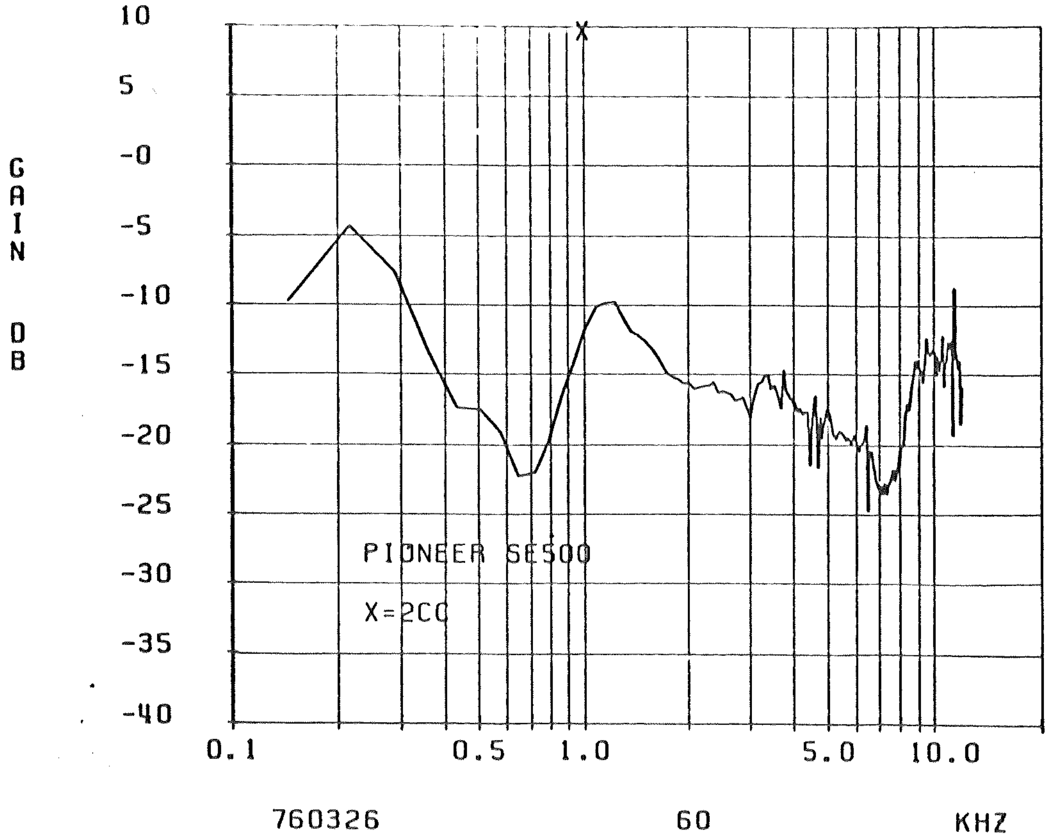
This transducer consists of an electrodynamic "rigid loudspeaker" with a half inch condenser microphone fitted through its center. A separate coil is provided and this is intended for a compressor feed-back loop that keeps the volume velocity constant. The sound pressure level sensed by the half inch microphone represents the modulus of the load impedance and can be registered with a swept sine-wave and a synchronized level recorder.

If the computer calculated signal previously described is used as a transducer input the volume velocity is not constant but can be sensed with the feedback coil. The sound pressure is monitored with the microphone. These two signals can be recorded in a computer with AD converters.

Calculating the complex FFT of both volume velocity and sound pressure level and dividing in the frequency domain gives the complex impedance. From this result both the modulus and the phase can be calculated.

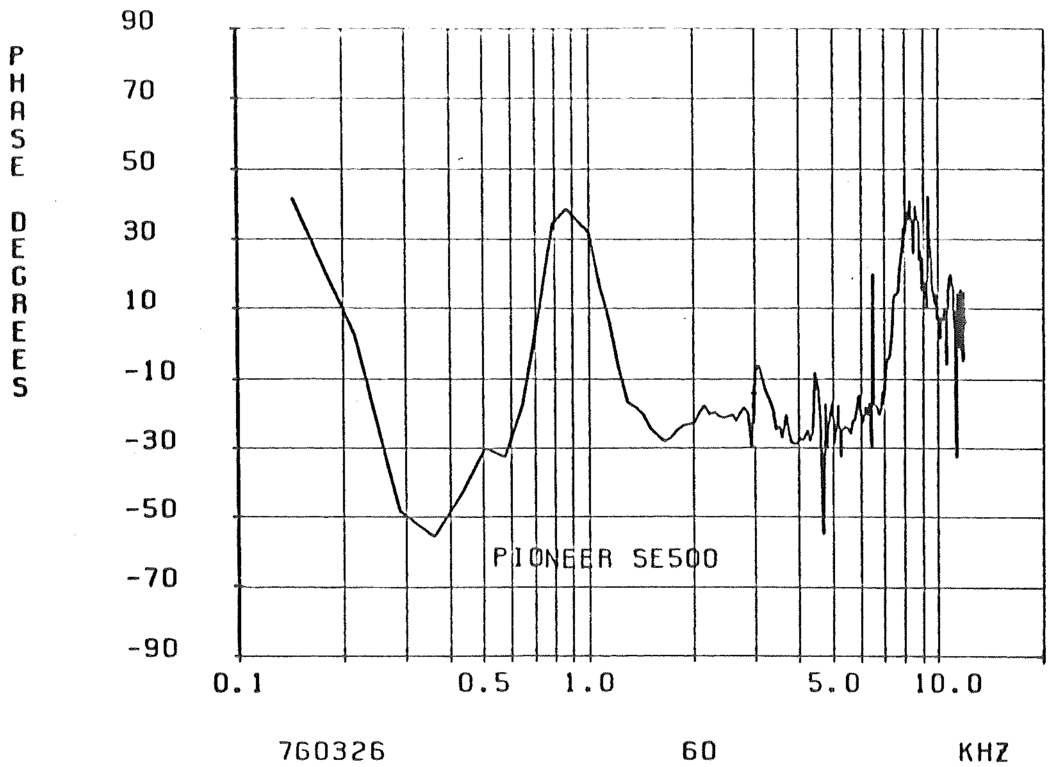
Fig. 2 shows a set-up to measure a headphone and fig. 3 shows the resulting impedance.

Fig. 2



GAIN DB
10
5
-0
-5
-10
-15
-20
-25
-30
-35
-40
PIONEER SE500
X=2CC
0.1
0.5
1.0
5.0
10.0
760326
60
KHZ

Fig. 3a



PHASE DEGREES
90
70
50
30
10
-10
-30
-50
-70
-90
PIONEER SE500
0.1
0.5
1.0
5.0
10.0
760326
60
KHZ

Fig. 3b

A special feature beside the rapid measurement is the possibility to average over several cycles and thus increase the signal to the noise ratio. This is very useful for measurement of human ear impedance at low levels.

Corrections and calibrations can easily be incorporated in the computer algorithm.

Another interesting way to measure acoustical impedance is the standing wave impedance tube. This approach also benefits from a computerization because of the complex calculations involved.

A tube system with 24 mm internal diameter was designed. In this tube microphones could be installed at different distances from the tube ends. A TDH39 earphone was used to inject the signal at one end of the tube and the unknown impedance was connected to the other end.

Fig. 4 shows some of the parts in the tube system. If the tube is driven with frequencies below the first transversal mode (half wave-length longer than the diameter of the tube) a uniform sound pressure is created over the tube cross section.

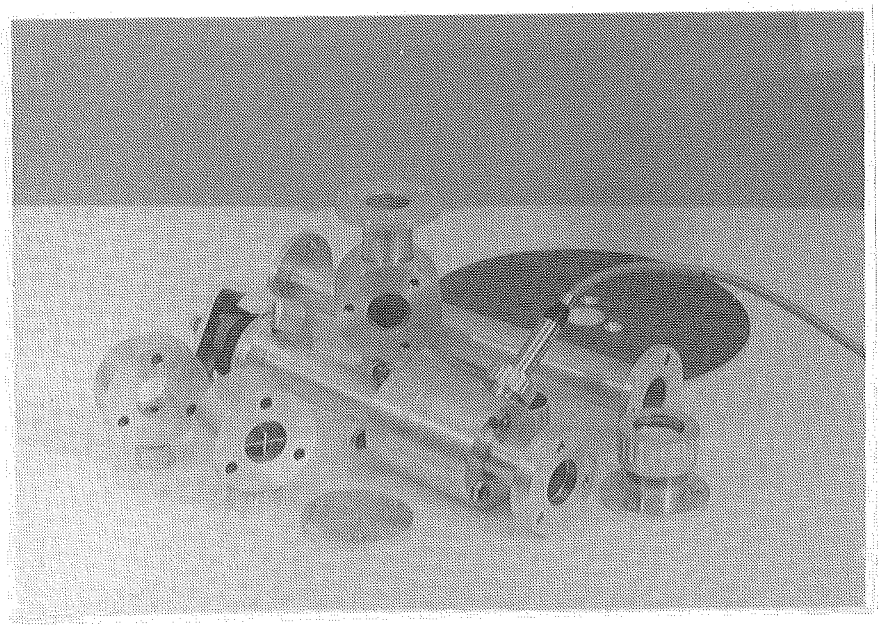


Fig. 4

From the sound pressure monitored with two fixed microphones installed in the tube wall the acoustical impedance at the tube end can be calculated according to:

$$Z = -Z_o \; i \; \frac{P_2 \sin KX_1 - P_1 \sin KX_2}{P_2 \cos KX_1 - P_1 \cos KX_2}$$

Z_o = characteristical impedance of the tube

P_1, P_2 = sound pressure of the two microphones

X_1, X_2 = distance to the microphones from the tube end

Fig. 5 shows a set-up to measure the impedance of the B.&.K. coupler 4153 and fig. 6 gives the results.

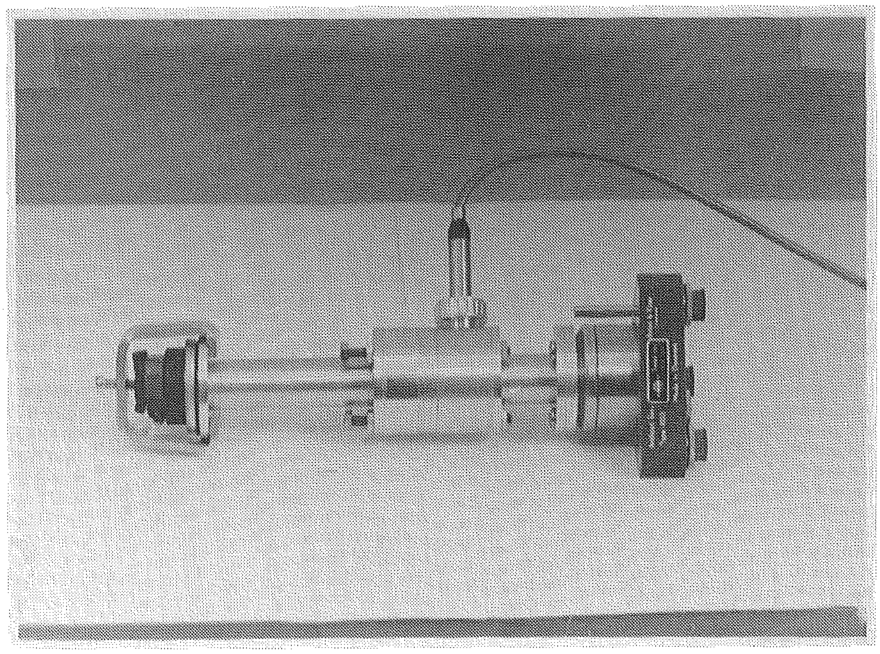


Fig. 5

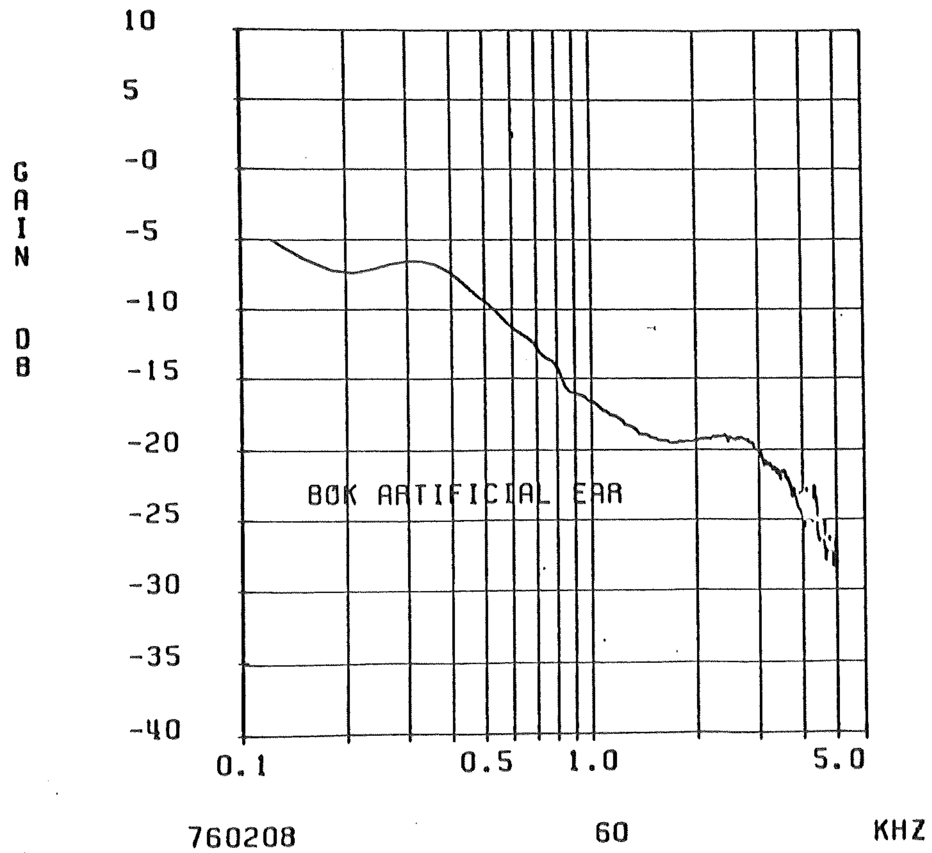

10
5
-0
-5
-10
-15
-20
-25
-30
-35
-40
GAIN DB
BOK ARTIFICIAL EAR
0.1
0.5
1.0
5.0
760208
60
KHZ

Fig. 6a

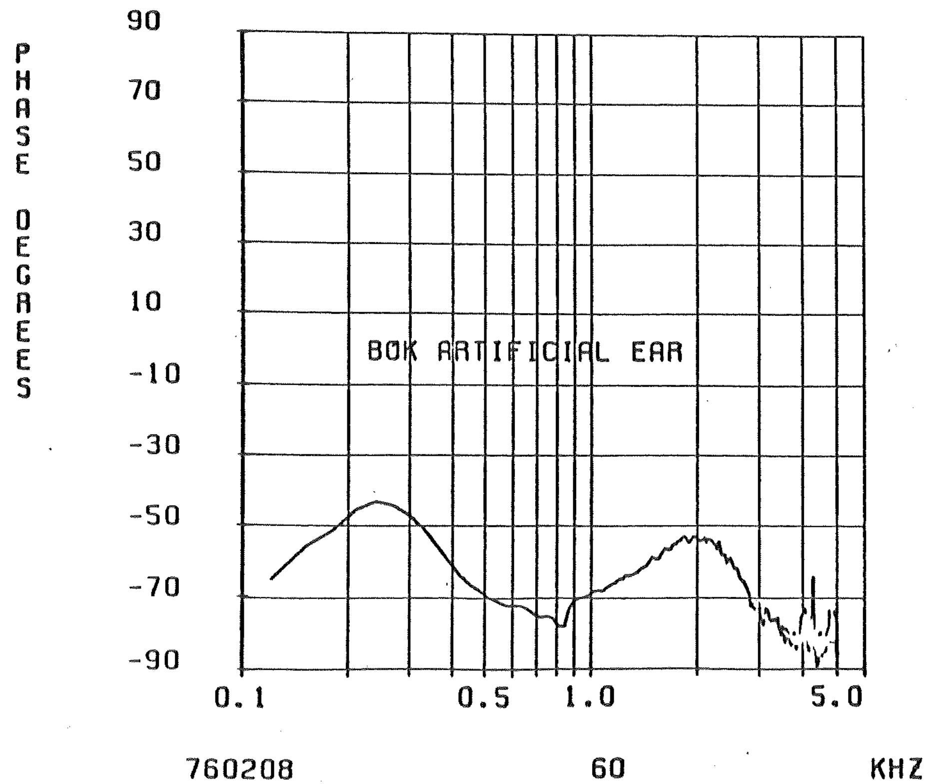

90
70
50
30
10
-10
-30
-50
-70
-90
PHASE DEGREES
BOK ARTIFICIAL EAR
0.1
0.5
1.0
5.0
760208
60
KHZ

Fig. 6b

A smaller tube for impedance measurements in the human ear-canal has been designed (fig. 7). It was a problem to find a small transmitting transducer with enough power output. Finally a 1/2 inch condenser microphone was chosen. In order to get maximum output it was driven without polarization voltage. The input signal then had to be pre-distorted. This can be accomplished by adding a DC voltage equal to the lowest value in the time series and then calculate the square root of each value in the time series. If this signal is complemented with a signal of opposite polarity for the next period there is no need for a DC amplifier and a conventional audio-amplifier with a step-up transformer can be used.

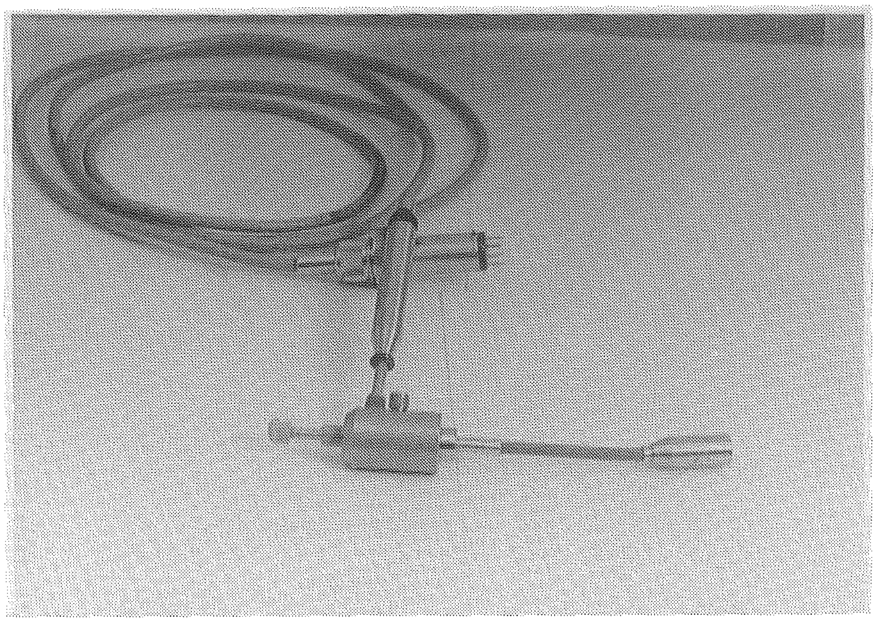


Fig. 7

In our set-up the maximum sound pressure level was about 90 dB. But measurements could be performed at much lower levels because averaging over several periods increased signal to noise ratio.

In a small tube like this it is no longer possible to consider it to be without loss. Tube losses add complexity to the algorithm for impedance calculation.

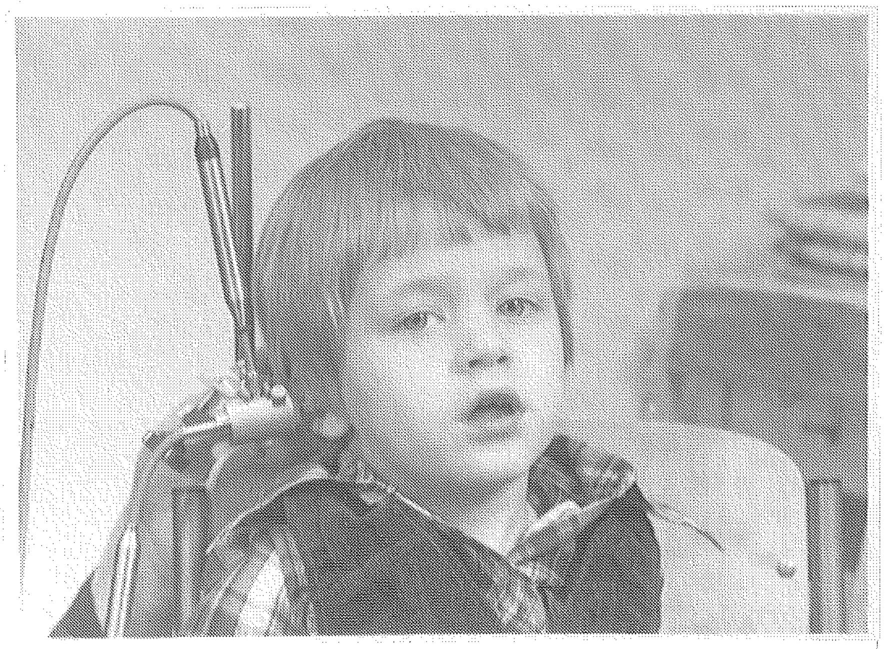


Fig. 8

Fig. 8 shows the set-up for an ear-drum impedance measurement.

CONCLUSION

The acoustic impedance is of great importance to the transducer designer. A computer generated signal of harmonic sine-waves supplied with randomized phase has proven very useful in impedance measurements. Averaging over several periods of this signal increases signal to noise ratio and makes measurements at very low levels possible. An unpolarized condenser microphone, fed with a pre-distorted signal over a step-up transformer, is a useful way of getting a low distortion high output signal source. Computerization of acoustical impedance measurements gives improvements in speed and accuracy.