

TR-13

SMOOTHING THE HEARING AID FREQUENCY RESPONSE

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ABSTRACT

The introduction of transducers with a smooth frequency response has left the resonances in the tubing used to conduct the sound to the ear as the main source of uneven total frequency response. A new approach to applying damping that eliminates cut-and-try methods has been devised. The result is a smooth frequency characteristic independent of the tubing length.

## The Problem

The various devices that make up a hearing aid have undergone a considerable evolution. The reduction in size has been a most obvious manifestation. Less obvious, has been a continuing progress toward components capable of smoother and wider frequency response characteristics. The introduction of the transistor rapidly removed the most important constraints on the amplifier. Later, in 1968, the introduction of suitable piezoelectric ceramic microphones removed the previous limitation resulting from the practical constraints imposed by the magnetic microphone. Then, in 1971, a small receiver, earphone, was introduced with design compromises that provided a bandwidth wider than was previously available.

The more common applications through the use of a sound tube, introduce resonances within the desired sound transmission band. These have to be eliminated if an overall smooth frequency response is to be achieved. Damping has usually been applied to reduce these resonances in the sound delivery system. The effectiveness of damping in the acoustic tubing has gradually changed during the evolution of the miniaturized transducers. Early in-the-hearing-aid receivers circa 1954, were large enough, and the acoustic impedances low enough, that a damping element at the receiver end of the tube gave significant damping. During a period in the evolution that followed, reduction of tubing bore size could be used to some extent to aid in the control of the resonances. In the present smaller size receivers with their inherently high acoustic source impedances, the only effective place to locate a damping element is at or near the point where it enters the ear canal. A damping element there can adequately damp the tubing and receiver resonance. This is generally unsatisfactory because the dissipative element, to be effective, must be made up of small channels and these channels are easily blocked by the excretions from the ear. Thus this solution, while sometimes used, has not found wide acceptance.

## The New Approach

The following discussion explains a sound delivery method that makes the performance of a receiver essentially independent of the length of the sound duct placed between the receiver and the ear canal. Fig. 1 illustrates schematically the physical arrangement frequently used during a hearing aid measurement and Fig. 2 portrays it as an electrical analog. In a typical application  $L_M$  is at least 4.5 cm and the total length of  $L_R$  and  $L_M$  is about 7.5 cm. The characteristic impedance of the tubes is generally of the order of 1500 ohms so that throughout most of the frequency range the 1.4 mfd termination appears as a low impedance. A typical undamped transmission curve with the total length being 7.5 cm is shown in Fig. 3. These are the resonances to be eliminated so as to create a smooth hearing aid response.

For reasons that will be developed, we proceed by remembering that the input impedance of a transmission line is as shown in Fig. 4, and using this, in Fig. 5 we consider the effect of putting an open circuited and short circuited line in parallel. With the constraints that the damping matches the characteristic impedance, and the lines have similar lengths and diameters, a simple result is obtained for the input impedance. Also the transfer impedance of the short circuit line becomes simple as shown in Fig. 6.

The characteristic impedance,  $Z_0$ , of a tube of the order of 2.0 mm diameter varies only slowly within the passband and attenuation is small for the few centimeters of length. Therefore the combination of a receiver, the two tubes with damper elements and a calibrating coupler are approximated by the simplified analog schematic of Fig. 7 or the physical arrangement shown in Fig. 8. This produces the relatively smooth frequency characteristic of the type shown in Fig. 9. The interesting feature is that length has been eliminated as a parameter.

### The Result

The physical schematic that corresponds to the circuit shown as Fig. 5 is illustrated in Fig. 10. How well this works is illustrated by the measured frequency characteristics for lengths of tubing ranging from 0 to 7.5 cm as shown in Fig. 11. The shift in the low frequency asymptote is the expected result of the change in net volume when the length of the tubing is changed. The parallel combination of tubing results in an input impedance of  $Z_0$  which can be used as a suitable termination for an additional length of tubing. This more complicated arrangement illustrated in Fig. 12 is practical as seen from the results of the measurements (Fig. 13) taken with the length ( $L_R$ ) of the extension tubing ranging from 0 to 3 cm. For this experiment the lengths of  $L_M$  and  $L_X$  were each 7.5 cm long. Using the foregoing arrangements the dependence on tubing lengths is made quite small.

The choice of tube diameter, which affects the value of  $Z_0$ , and thus the damping applied to the receiver, can be used as a control over the acoustic performance. The smaller the tube diameter the higher the characteristic impedance of the tube and the higher the damping resistance applied to the receiver. This effect is illustrated in Fig. 14 where the measurements were made with 7.5 cm of tubing in the main branch ( $L_M$ ) and 7.5 cm of the same tubing in the auxiliary branch ( $L_X$ ). The value of damping resistance being chosen to suit the size of the tube. The insertion of the damping resistor must not introduce very much inertance if smooth results are to be obtained.

By this procedure it is possible to conduct sound between the receiver and the ear canal in a way that produces predictable and smooth transfer characteristics. The technique makes it possible to design hearing aids where the frequency response is not altered by the adjustment of the tubing length during fitting.

### The Application

A few ways the practical problem of utilization can be approached will be suggested. In Fig. 15 a schematic application to an eyeglass temple is illustrated. Equal lengths of tubing would be cut at the time of fitting and one installed inside the frame, or a compromised fixed length could be permanently installed. The damping elements would be located in the instrument where they are relatively immune to contamination and would require no attention from the person doing the hearing aid fitting.

The scheme might also be applied to a behind-the-ear hearing aid. One approach is illustrated in Fig. 16 where the complementary tube is partially

molded into the hook with a section of tubing added inside of the instrument to adjust for the variable length of the portion running to the earmold insert.

Also it would be possible to provide for an automatic adjustment of lengths by extending the main sound duct and the complementary duct side-by-side down into the earmold using a tube with a dual channel. One tube would be blocked at the end in the earmold. In such an arrangement a very reliable symmetry could be maintained.

The objective has been to illustrate a method where by following easily understandable design procedures it is possible to stabilize one of the least predictable elements in hearing aid performance. The added complication and the loss of the higher maximum sound pressures that can be generated at the resonant frequencies are the price that is paid for the increased smoothness and predictability.

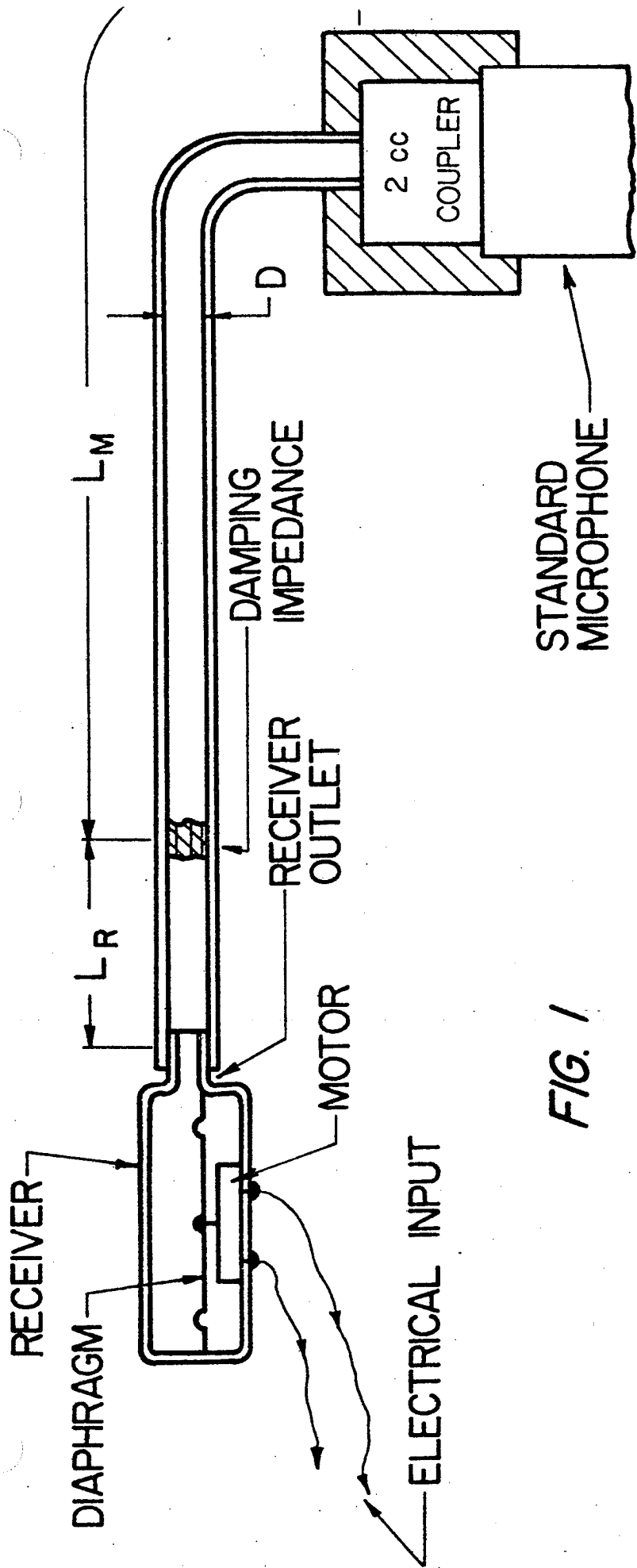


FIG. 1

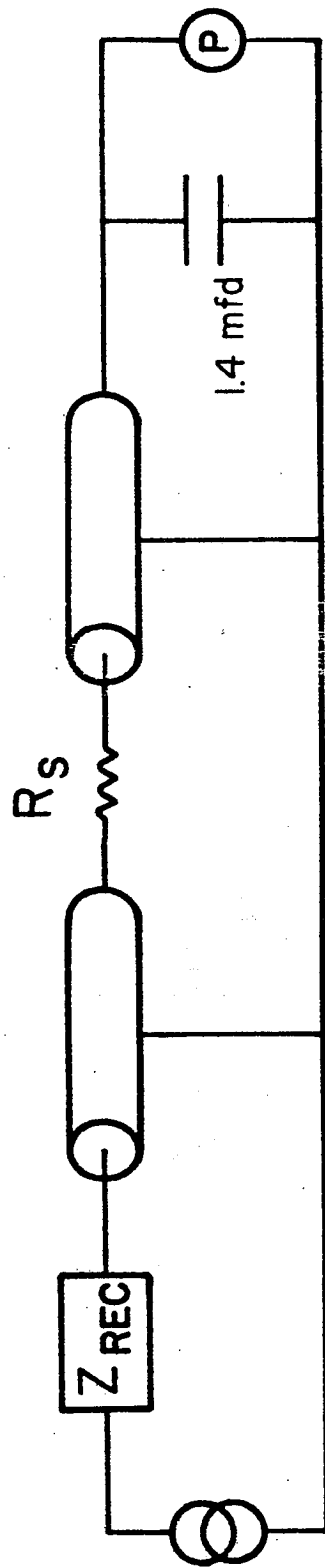
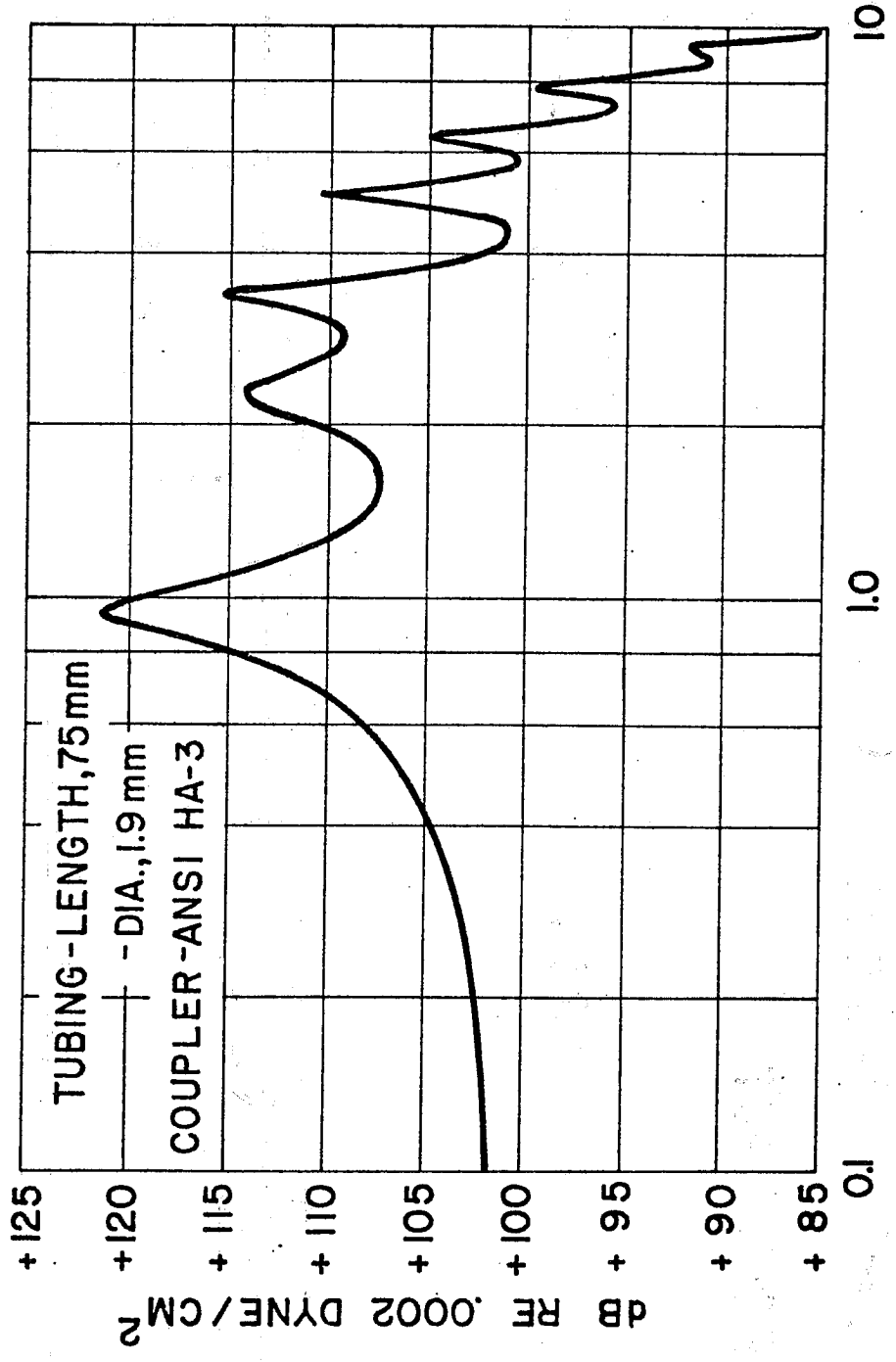
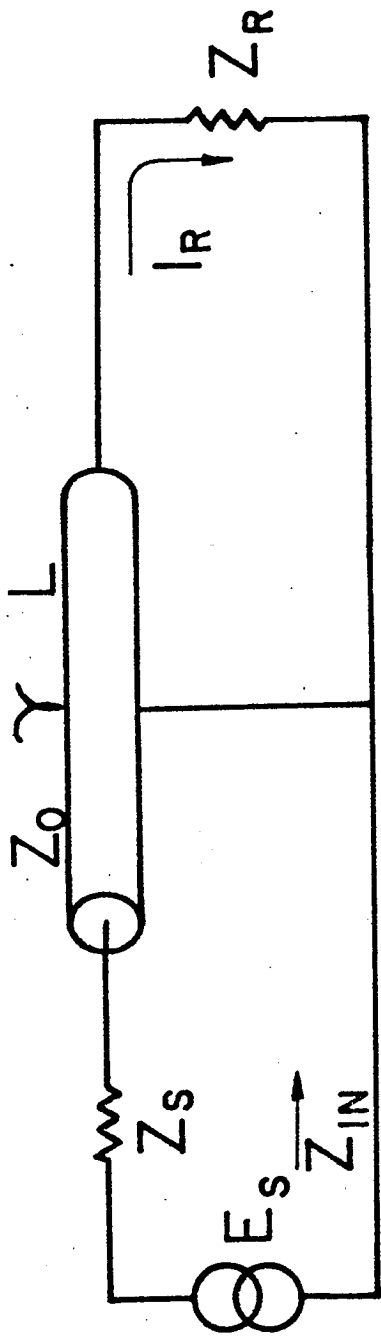


FIG. 2



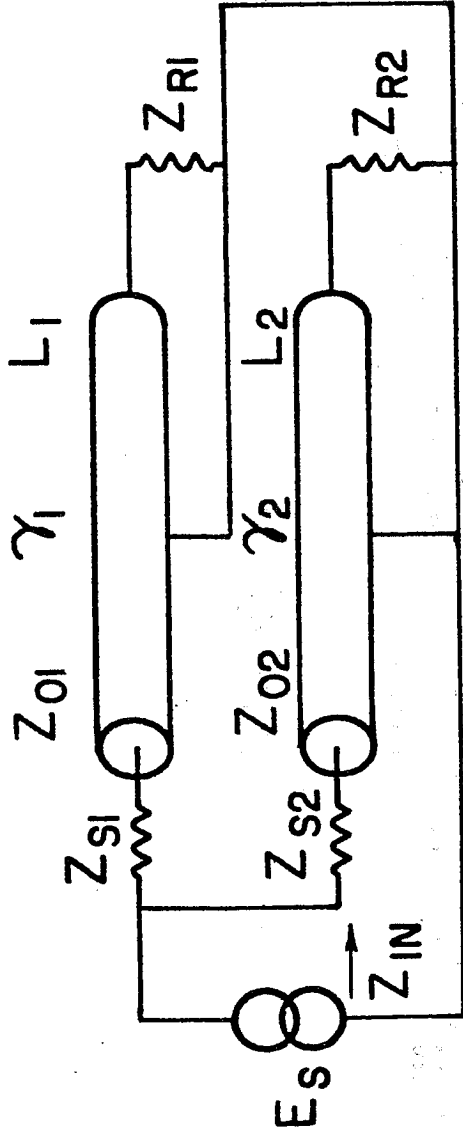
RECEIVER CONNECTED TO A 2cc COUPLER THROUGH  
 TUBING WITHOUT ACOUSTICAL DAMPING

FIG.3



$$Z_{IN} = Z_s + Z_0 \frac{Z_R \cosh \gamma L + Z_0 \sinh \gamma L}{Z_0 \cosh \gamma L + Z_R \sinh \gamma L}$$

FIG. 4



$$Z_{IN} = \frac{Z_{R1} \cosh \gamma_1 L_1 + Z_{O1} \sinh \gamma_1 L_1}{Z_{S1} + Z_{O1} \cosh \gamma_1 L_1 + Z_{R1} \sinh \gamma_1 L_1} + \frac{Z_{R2} \cosh \gamma_2 L_2 + Z_{O2} \sinh \gamma_2 L_2}{Z_{S2} + Z_{O2} \cosh \gamma_2 L_2 + Z_{R2} \sinh \gamma_2 L_2}$$

IF,  $Z_{S1} = Z_{S2} = Z_{O1} = Z_{O2} = Z_0$ ,  $\gamma_1 L_1 = \gamma_2 L_2$ ,  $Z_{R1} = 0$ ,  $Z_{R2} = \infty$

THEN,  $Z_{IN} = Z_0$

FIG. 5

$$\frac{E^S}{I_R} = (Z_R + Z_S) \cosh \gamma L + \left( Z_0 + \frac{Z_R Z_S}{Z_0} \right) \sinh \gamma L$$

FOR THE SHORT CIRCUITED TUBE YIELDS

$$\frac{E^S}{I_R} = Z_0 \cosh \gamma L + Z_0 \sinh \gamma L$$

$$\frac{E^S}{I_R} = Z_0 e^{\gamma L} \quad \text{OR} \quad \left| \frac{E^S}{I_R} \right| \approx Z_0$$

FIG. 6

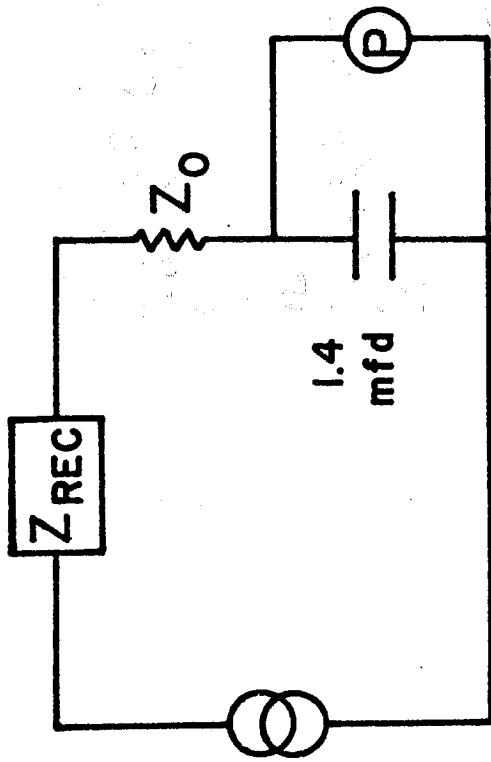


FIG. 7

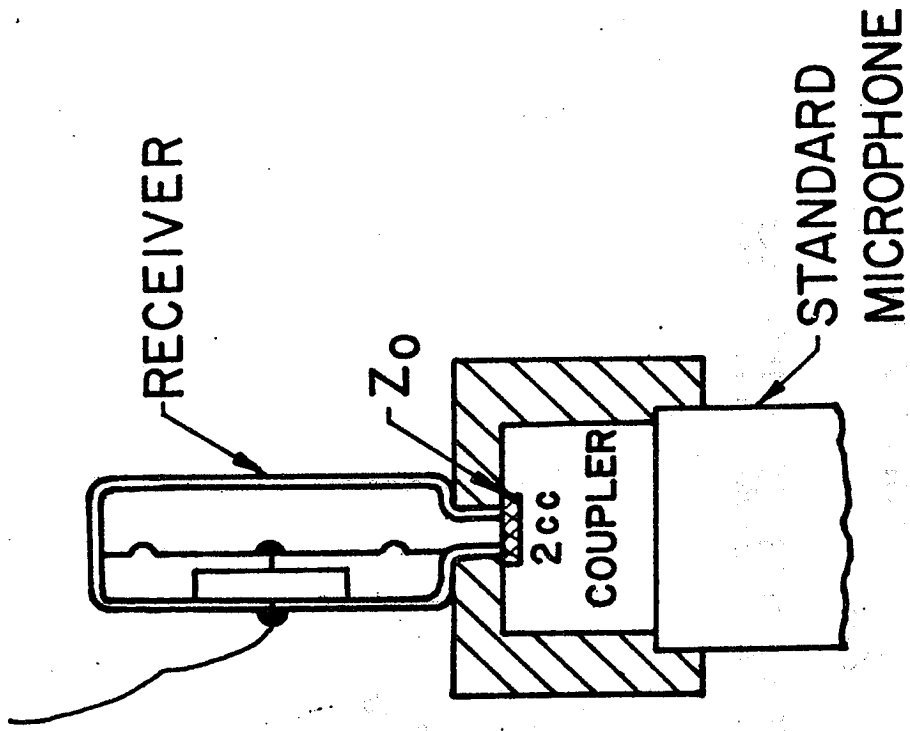
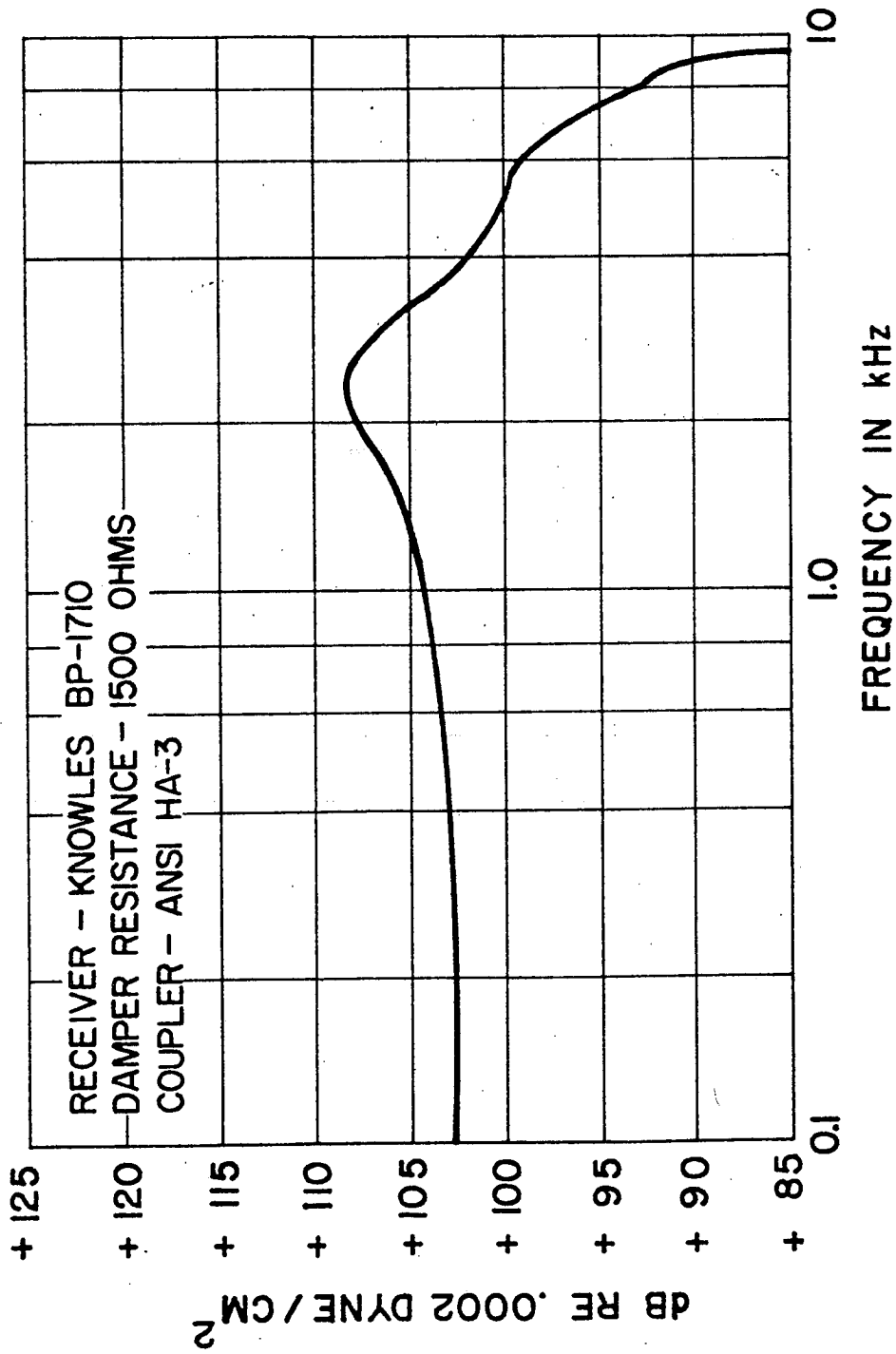


FIG. 8



ACOUSTICALLY DAMPED KNOWLES BP-1710  
 RECEIVER MEASURED ON A 2cc COUPLER

FIG.9

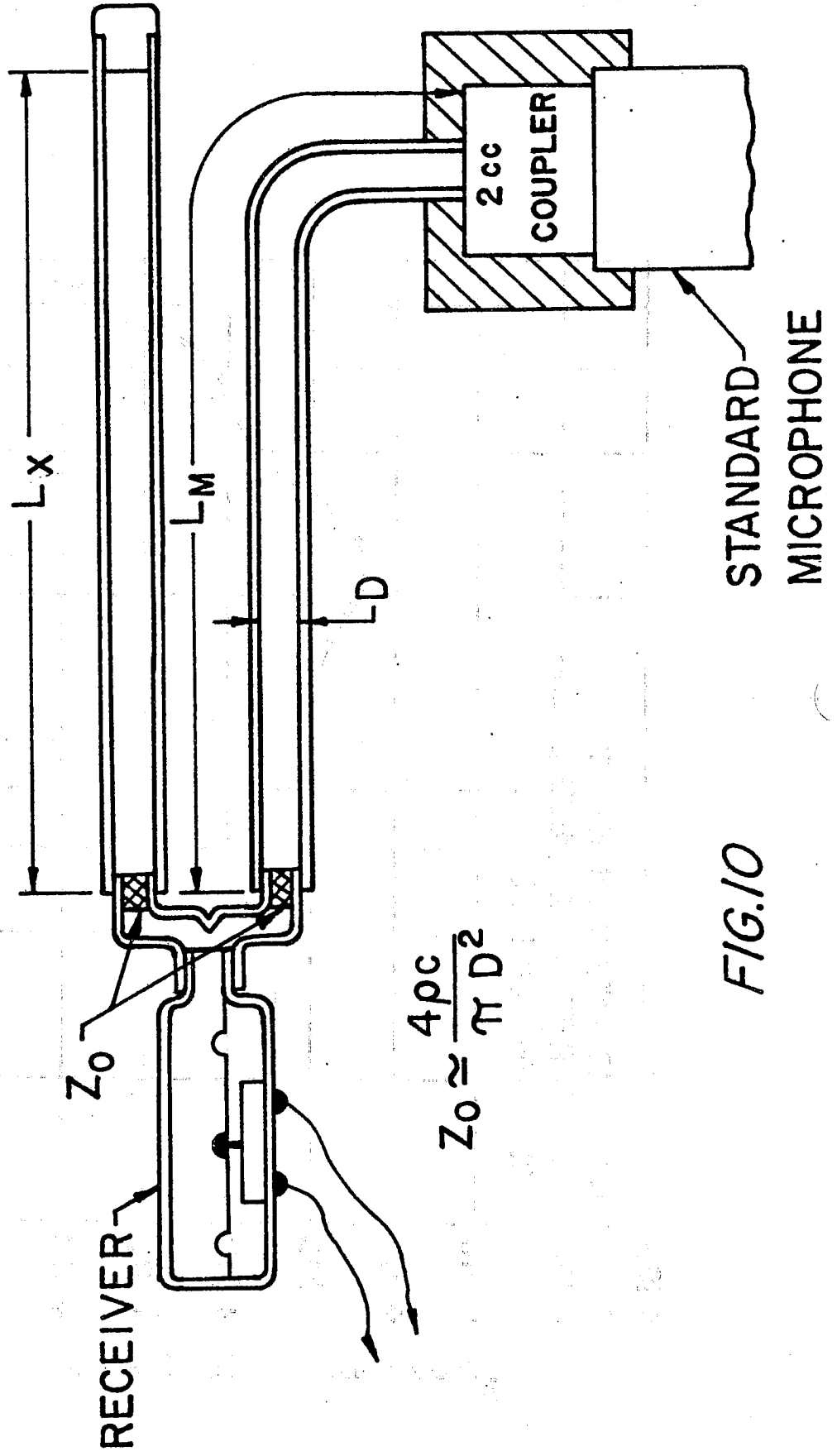
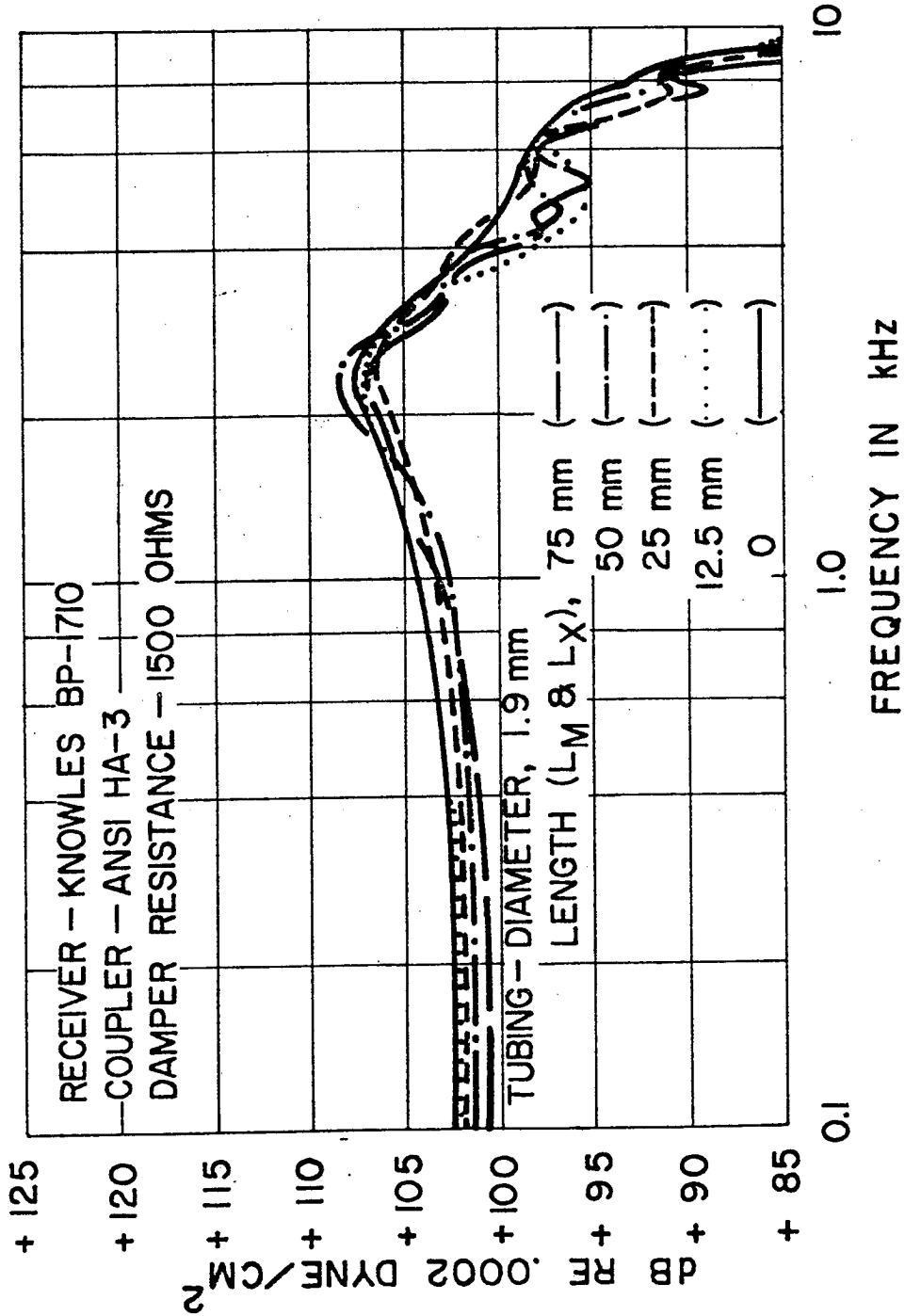


FIG.10



DAMPED RESPONSE CHARACTERISTIC WITH  
 VARIOUS TUBING LENGTHS

FIG.11

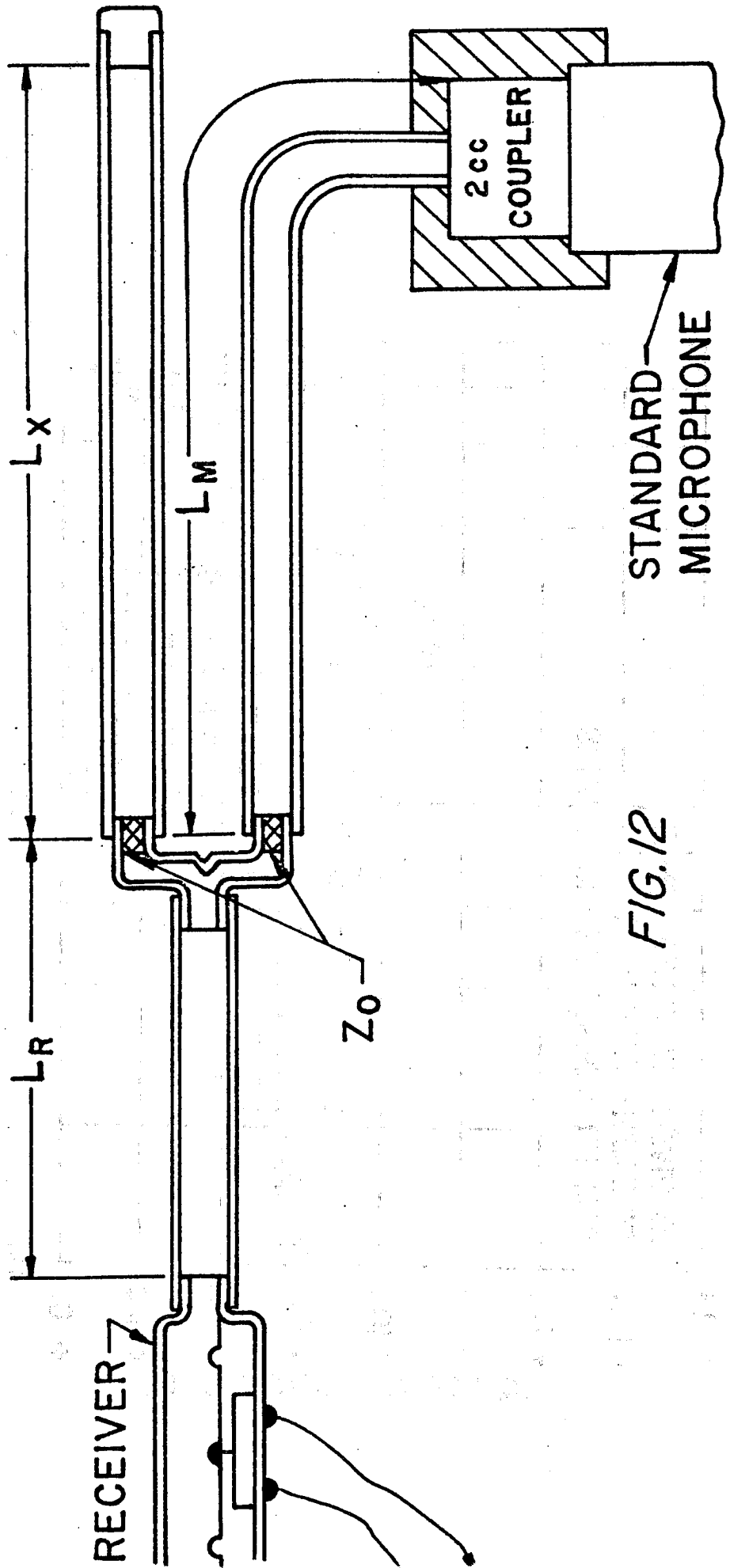
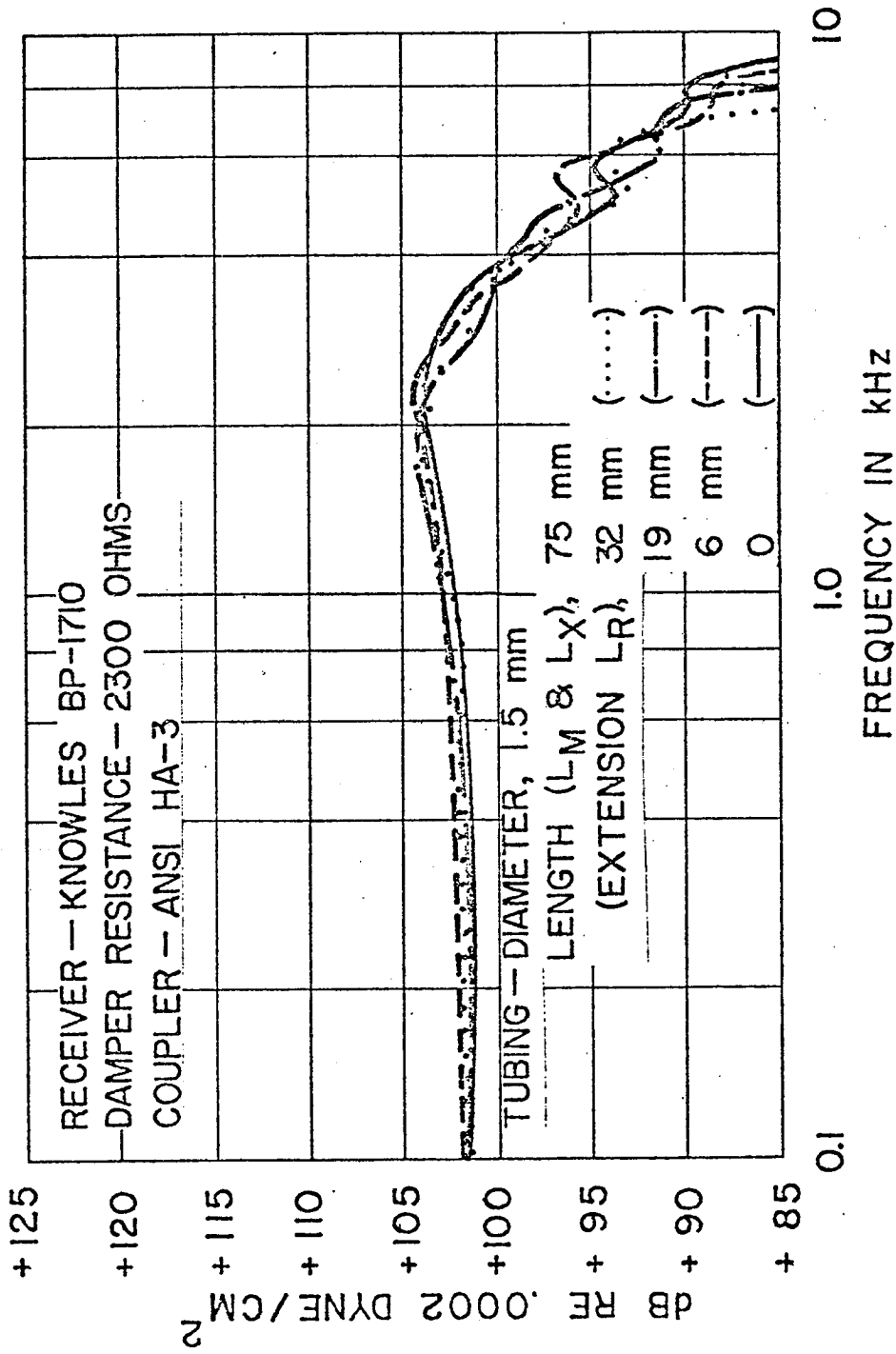
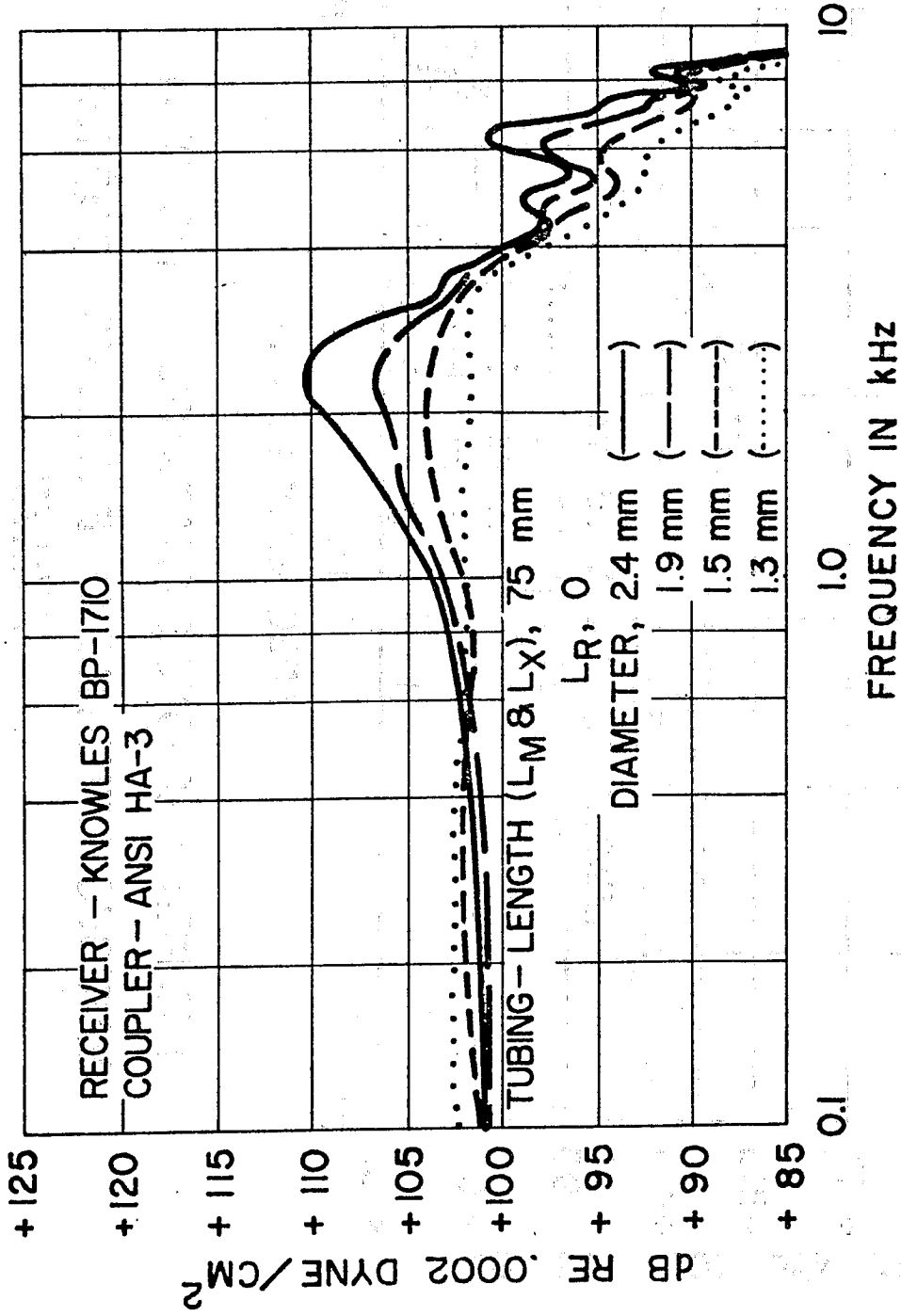


FIG. 12

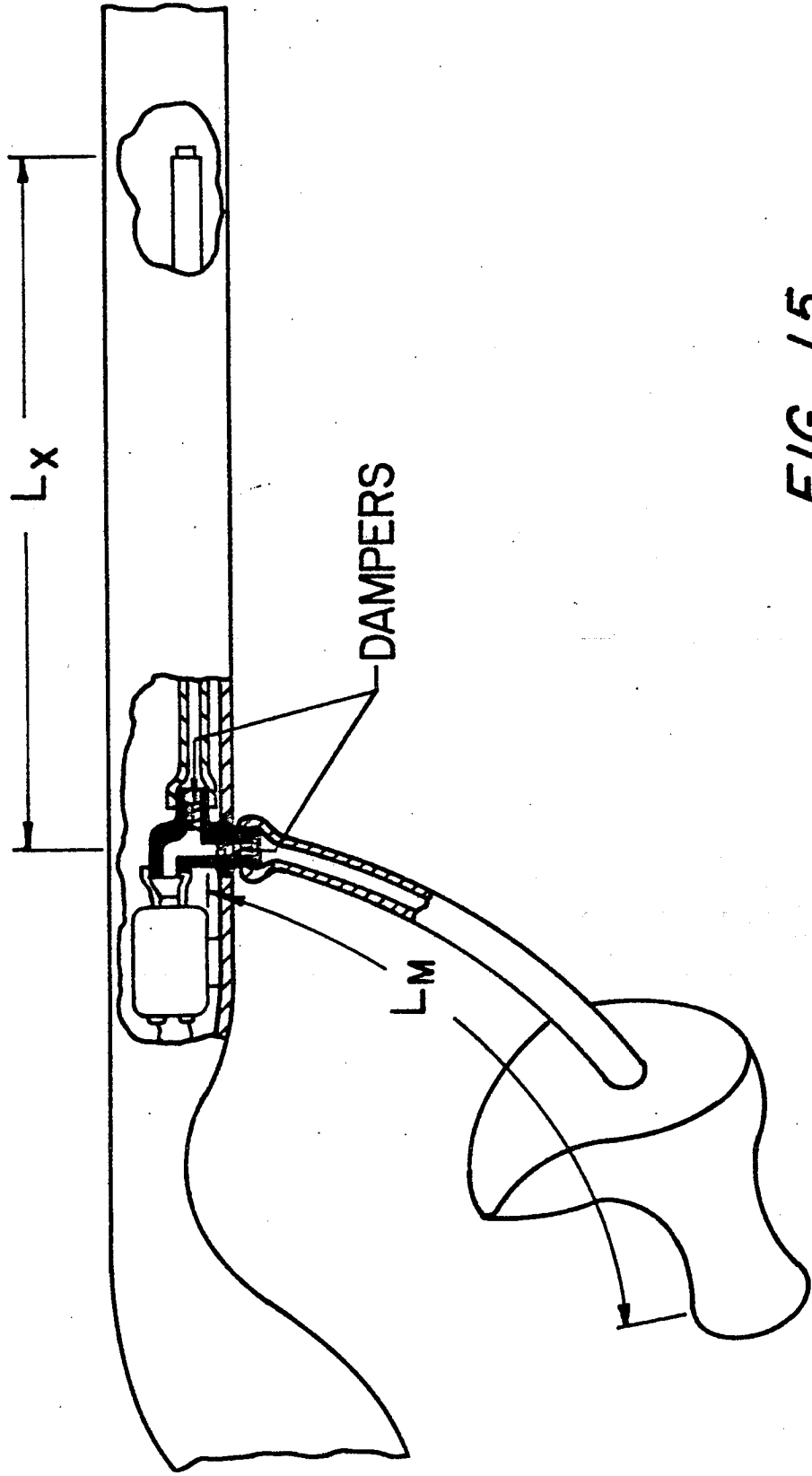


DAMPED RESPONSE CHARACTERISTIC WITH  
 VARIOUS LENGTHS OF EXTENSION TUBING  
 FIG.13



DAMPED RESPONSE CHARACTERISTIC WITH  
VARIOUS TUBING DIAMETERS

FIG.14



*FIG. 15*

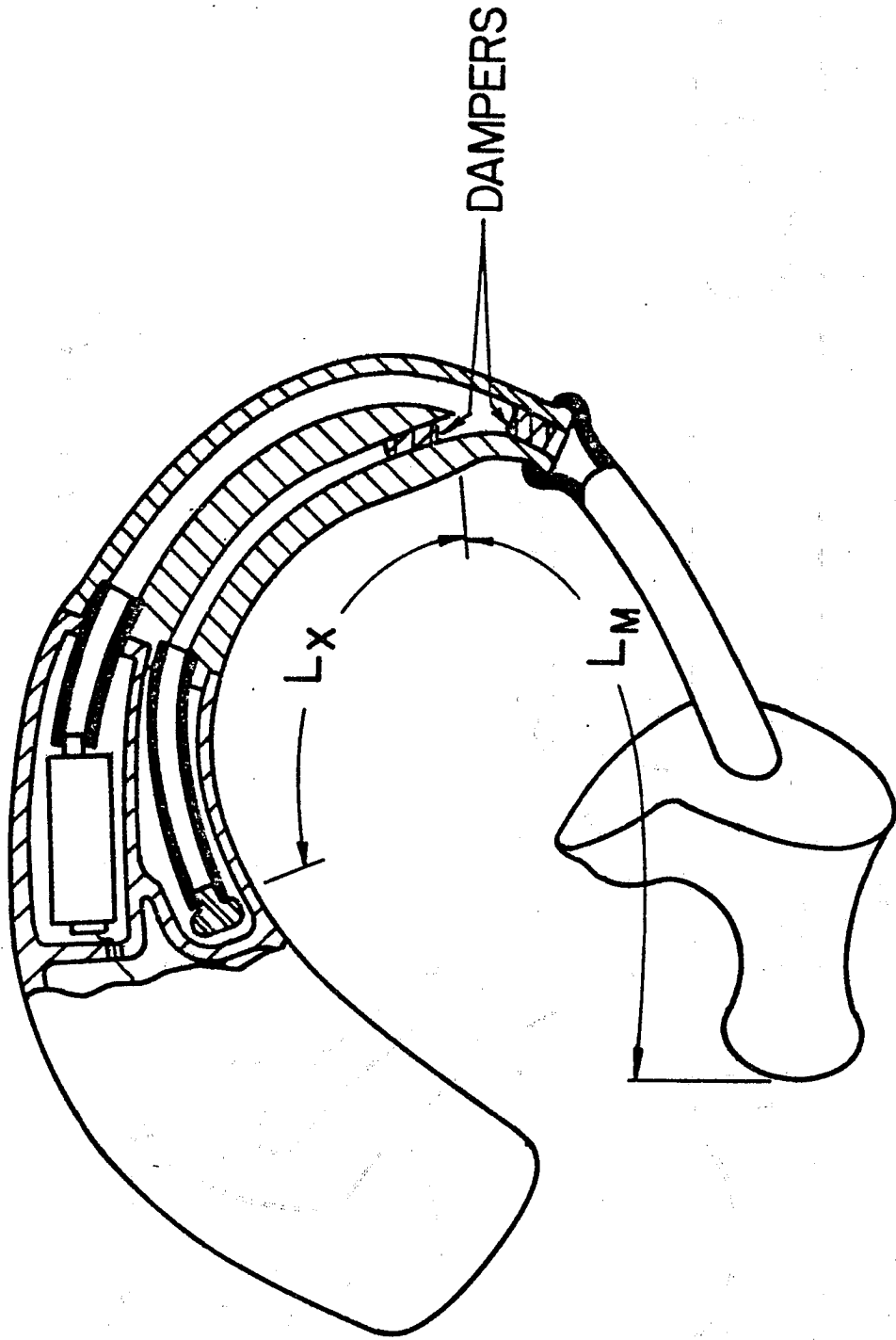


FIG. 16