Sept. 8, 1942. L. J. ANDERSON 2,295,376

ELECTROACOUSTICAL APPARATUS

Filed Dec. 28, 1939

Fig. 1.

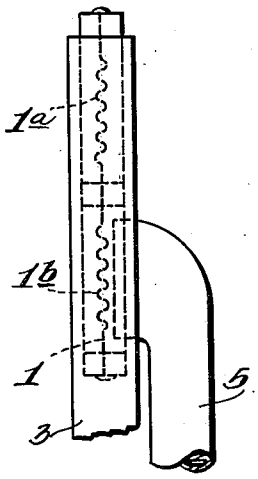


Fig. 2.

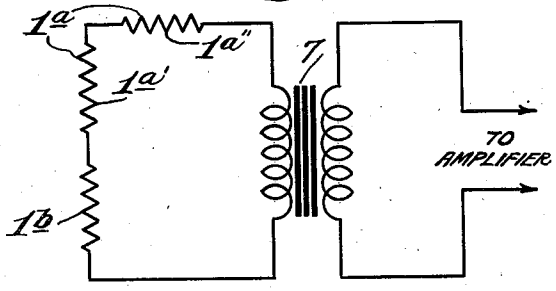


Fig. 3.

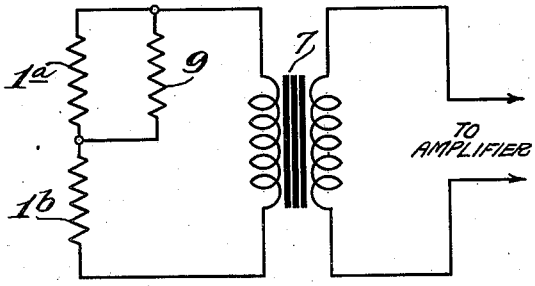


Fig. 4.

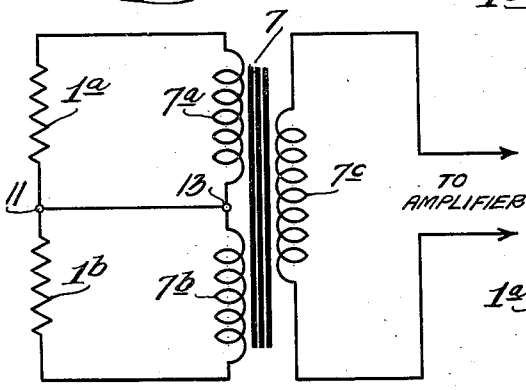


Fig. 5.

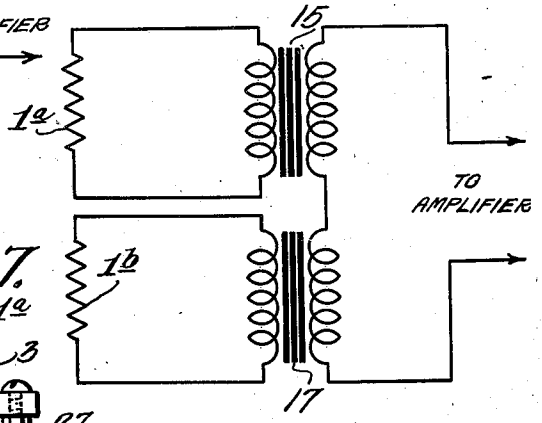


Fig. 6.

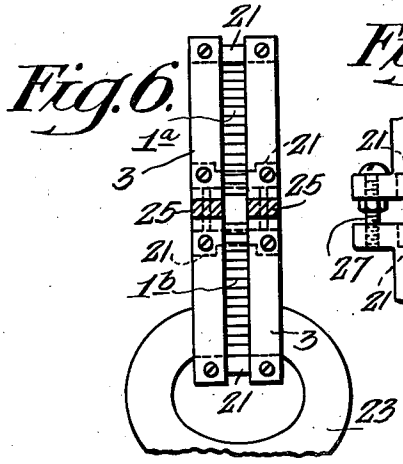
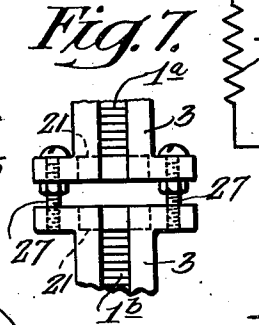


Fig. 7.



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2,295,376

ELECTROACOUSTICAL APPARATUS

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Application December 28, 1939, Serial No. 311,371

9 Claims. (Cl. 179—139)

This invention relates to electroacoustical apparatus, and more particularly to a uni-directional microphone.

In the case of uni-directional microphones employing a ribbon or other conductor mounted for movement in a magnetic field and having a section responsive to the pressure component of a sound wave and another section responsive to the pressure gradient component of the sound wave, as shown, for example, in the Olson and Weinberger Reissue Patent No. 19,115, the requirements of fundamental resonant frequency dictate a certain minimum length of ribbon consistent with proper mechanical design. This minimum usually lies in the order of one inch. When the acoustic line or pipe is coupled to the pressure responsive section of the ribbon, a considerable mismatch in sensitivity between the pressure responsive section and the pressure gradient, or velocity, responsive section may result. This is especially likely to be so if the acoustic line or pipe is of small physical size; that is to say, of small diameter.

The conventional method of dealing with this situation is to retain the mechanical length of the ribbon in the velocity section, but make a portion of the velocity section inactive by extending it beyond the magnetic field. This, of course, assumes that the pressure responsive section of the ribbon has the lower sensitivity, which is usually the case. Extending a portion of the ribbon beyond the air gap or magnetic field is inefficient since it is equivalent to inserting a resistor in series with the active portion of the velocity section.

The primary object of my present invention is to provide an improved uni-directional microphone wherein the aforementioned difficulty is obviated.

More particularly, it is an object of my present invention to provide an improved uni-directional microphone of the type set forth which will have improved sensitivity.

In accordance with one form of my invention, I retain the entire length of ribbon in the velocity responsive section and reduce the impedance of the output circuit of said section. This may be done either by inserting a suitable resistor in shunt with the more sensitive ribbon section, that is, the velocity responsive section in the case assumed above, or by coupling the two ribbon sections to a suitable output transformer and tapping the common junction of the serially connected ribbon sections to a suitable tap on the primary winding of the transformer such that the impedance of the circuit including the velocity responsive section of the ribbon is reduced. Another way of accomplishing this result is to couple each of the ribbon sections to the primary windings of two separate transformers with the ratio of the windings such as to give a reduced impedance in the circuit which includes the velocity responsive section.

In accordance with another form of my invention, I provide a magnetic structure in which the pole pieces associated with the two ribbon sections can be altered so as to provide a weaker magnetic field for one section than the other. By altering the flux densities in the two air gaps, the sensitivities of the two ribbon sections can be made equal.

The novel features that I consider characteristic of my invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, as well as additional objects and advantages thereof, will best be understood from the following description of several embodiments thereof when read in connection with the accompanying drawing, in which

Figure 1 is a side elevation of a conventional form of uni-directional microphone,

Figure 2 is a wiring diagram showing the electrical equivalent of the conventional microphone,

Figure 3 is a wiring diagram according to one form of my present invention,

Figure 4 is a wiring diagram of another form of my present invention,

Figure 5 is a wiring diagram of still another form of my present invention,

Figure 6 is a front elevation of a microphone embodying still another form of my invention, and

Figure 7 is a somewhat modified form of the invention shown in Figure 6.

Referring more particularly to the drawing, wherein similar reference characters designate corresponding parts throughout, there is shown in Figure 1, a conventional uni-directional microphone of the type disclosed in the above identified reissue patent and comprising a conductor in the form of a crimped ribbon 1 mounted for movement in a suitable magnetic field between a pair of pole pieces 3. The ribbon 1 is clamped at its ends and also at its center to provide a pair of serially connected ribbon sections 1*a* and 1*b*. The ribbon section 1*a* is open to the atmosphere both at the front and at the back whereby it is responsive to the pressure gradient component of a plane sound wave. Behind the rib-

bon section 1b is placed an acoustic resistance in the form of a pipe 5 leaving only the front of the ribbon section 1b open to the atmosphere whereby the section 1b is responsive to the pressure component of a plane sound wave.

If the ribbon sections 1a and 1b are of the same length, there results a mismatch in sensitivity when the pipe 5 is added to the system, the section 1b becoming less sensitive. Because of the requirements of fundamental resonant frequency, the full length of each ribbon section must be retained, and to compensate for unequal sensitivity of the two ribbon sections, it has been customary to shorten the pole pieces 3 so that a portion of the velocity responsive ribbon section 1a will extend beyond the magnetic field. The effect of this is equivalent to inserting a resistor in series with the ribbon section 1a, as shown in Figure 2 wherein the two ribbon sections are coupled to a suitable amplifier by a transformer 7, and the velocity responsive ribbon section is divided into its active portion 1a' (that is, the portion thereof lying in the magnetic field) and its inactive portion 1a'' (that is, the ribbon portion thereof extending beyond the magnetic field).

Referring now, to Figure 2, if

R_1=resistance of the pressure section 1b,
R_2=resistance of the active portion 1a' of the velocity section 1a,
R_3=resistance of the inactive portion 1a'' of the velocity section 1a,
$\dot{e}_1$=voltage generated by the ribbon section 1a',
$\dot{e}_2$=voltage generated by the ribbon section 1b,
$\dot{e}_p$=voltage across the primary winding of the transformer 7,
$\dot{e}_0$=voltage across the secondary winding of the transformer 7,
Z_0=impedance of the circuit of the secondary winding of the transformer 7, and
n=the ratio of the turns between the primary and secondary windings of the transformer 7, then

$$\dot{e}_p=\dot{e}_1+\dot{e}_2 \tag{1}$$

$$Z_0=n^2(R_1+R_2+R_3) \tag{2}$$

and

$$K=\frac{\dot{e}_0^2}{Z_0}=\frac{n^2(\dot{e}_1+\dot{e}_2)^2}{n^2(R_1+R_2+R_3)}=\frac{(\dot{e}_1+\dot{e}_2)^2}{R_1+R_2+R_3} \tag{3}$$

where K is the power ratio.

Now, if it is assumed that the sensitivity of the velocity section 1a of the ribbon is twice that of the pressure section 1b if both of the velocity section portions 1a' and 1a'' were active, then, for cancellation.

$$\dot{e}_1=\dot{e}_2 \tag{4}$$

and

$$R_1=R_2+R_3 \tag{5}$$

Substituting (4) and (5) in (3)

$$K=\frac{(2\dot{e}_2)^2}{R_1+R_1}=\frac{4\dot{e}_2^2}{2R_1}=\frac{2\dot{e}_2^2}{R_1} \tag{6}$$

In Figure 3, I have shown one way of increasing the overall efficiency of the microphone. In this case, I retain the whole length of the velocity section 1a within the magnetic field, so that its whole length is active, and shunt a resistor 9 across the velocity section 1a, thereby reducing the impedance of the circuit of this section of the ribbon. Now, if R_1=resistance of the pressure section 1b (as in the previous case),

R_4=resistance of the velocity section 1a,
R_5=resistance of the resistor 9,
$\dot{e}_2$=voltage generated by the pressure section 1b (as in the previous case),
$\dot{e}_3$=voltage generated by the velocity section 1a,
$\dot{e}_4$=voltage across the resistor 9,
$\dot{e}_p$=voltage across the primary winding of the transformer 7,
$\dot{e}_0$=voltage across the secondary winding of the transformer 7,
Z_p=impedance of the primary circuit of the transformer 7,
Z_0=impedance of the secondary circuit of the transformer 7, and
n=the ratio of the turns between the primary and secondary windings of the transformer 7, then

$$\dot{e}_p=\dot{e}_2+\dot{e}_4 \tag{7}$$

$$\dot{e}_4=\frac{\dot{e}_3(R_5)}{R_4+R_5} \tag{8}$$

$$\dot{e}_p=\dot{e}_2+\dot{e}_3\left(\frac{R_5}{R_4+R_5}\right) \tag{9}$$

$$Z_p=R_1+\frac{R_4R_5}{R_4+R_5} \tag{10}$$

$$Z_0=n^2Z_p \tag{11}$$

Substituting (11) in (10),

$$Z_0=n^2\left(R_1+\frac{R_4R_5}{R_4+R_5}\right) \tag{12}$$

Now

$$\dot{e}_0=n\left(\dot{e}_2+\dot{e}_3\left[\frac{R_5}{R_4+R_5}\right]\right) \tag{13}$$

and

$$K=\frac{\dot{e}_0^2}{Z_0} \tag{14}$$

Substituting (12) and (13) in (14), and simplifying

$$K=\frac{\left[\dot{e}_2+\dot{e}_3\left(\frac{R_5}{R_4+R_5}\right)\right]^2}{R_1+\frac{R_4R_5}{R_4+R_5}} \tag{15}$$

If it is assumed that the velocity section 1a is twice as sensitive as the pressure section 1b, then

$$\dot{e}_2=2\dot{e}_2 \tag{16}$$

and for cancellation

$$\frac{R_5}{R_4+R_5}=\frac{1}{2} \tag{17}$$

Substituting (16) and (17) in (15) and assuming that the ribbon sections 1a and 1b are of the same length, so that R_1=R_4, then

$$K=\frac{\left[\dot{e}_2+2\dot{e}_2\left(\frac{1}{2}\right)\right]^2}{R_1+\frac{R_1}{2}}=\frac{2[2\dot{e}_2]^2}{3R_1} \tag{18}$$

Now, dividing (18) by (6), the power gain will be

$$\frac{\frac{2[2\dot{e}_2]^2}{3R_1}}{\frac{2[\dot{e}_2]^2}{2R_1}}=\frac{4}{3}$$

In other words, when the whole ribbon section 1a is made active and the resistor 9 is shunted across it, the power gain is 1.33 or about 1.25 db.

Figure 4 shows another way of improving the sensitivity of the system according to this invention while employing the full length of the

velocity section 1*a* of the ribbon. Here, again, the impedance of the circuit of the velocity responsive section 1*a* is reduced relative to that of the circuit of the pressure responsive section 1*a*, but in this case, I accomplish this result by employing a tapped primary winding for the transformer 7 and connect the common junction 11 of the serially connected ribbon sections 1*a* and 1*b* to a tap 13 on the primary winding of the transformer such that this result will be effected. Let

R_1=resistance of the pressure section 1*b* (as before),
R_4=resistance of the velocity section 1*a* (as before),
$\dot{e}_2$=voltage generated by the pressure section 1*b* (as before),
$\dot{e}_3$=voltage generated by the velocity section 1*a* (as before),
$\dot{e}_5$=voltage across the portion 7*a* of the primary winding of the transformer due to $\dot{e}_3$
$\dot{e}'_5$=voltage across the portion 7*a* of the primary winding of the transformer due to $\dot{e}_2$
$\dot{e}_6$=voltage across the portion 7*b* of the primary winding of the transformer due to $\dot{e}_3$,
$\dot{e}'_6$=voltage across the portion 7*b* of the primary winding of the transformer due to $\dot{e}_2$,
$\dot{e}_7$=total voltage across the whole primary winding of the transformer due to $\dot{e}_3$,
$\dot{e}'_7$=total voltage across the whole primary winding of the transformer due to $\dot{e}_2$,
Z_1=impedance looking into the portion 7*a* of the primary winding of the transformer,
Z_2=impedance looking into the portion 7*b* of the primary winding of the transformer, and
X=the turn ratio between the primary winding portions 7*a* and 7*b*.

Assuming that the two ribbon sections 1*a* and 1*b* are of equal length and therefore of equal resistance, then

$$R_1=R_4=\text{some common value } R \tag{19}$$

$$\dot{e}_p=\dot{e}_7+\dot{e}'_7 \tag{20}$$

$$\dot{e}_5=\frac{\dot{e}_3 Z_1}{R+Z_1} \tag{21}$$

$$Z_1=R_X^2 \tag{22}$$

$$\dot{e}_5=\frac{\dot{e}_3 R_X^2}{R+R_X^2}=\frac{\dot{e}_3 X^2}{1+X^2} \tag{23}$$

$$\dot{e}_6=\frac{\dot{e}_5}{X}=\frac{\dot{e}_3}{X}\left(\frac{X^2}{1+X^2}\right)=\frac{\dot{e}_3 X}{1+X^2} \tag{24}$$

Now

$$\dot{e}_7=\dot{e}_5+\dot{e}_6 \tag{25}$$

Substituting (21) and (24) in (25) and simplifying

$$\dot{e}_7=\frac{\dot{e}_3 X^2}{1+X^2}+\frac{\dot{e}_3 X}{1+X^2}=\frac{\dot{e}_3(X+X^2)}{1+X^2} \tag{26}$$

$$\dot{e}'_6=\dot{e}_2\frac{Z_2}{R+Z_2} \tag{27}$$

$$Z_2=\frac{R}{X^2} \tag{28}$$

Substituting (28) in (27) and simplifying

$$\dot{e}'_6=\frac{\dot{e}_2\frac{R}{X^2}}{R+\frac{R}{X^2}}=\frac{\frac{\dot{e}_2 R}{X^2}}{\frac{RX^2+R}{X^2}}=\frac{\dot{e}_2 R}{R(1+X^2)}=\frac{\dot{e}_2}{1+X^2} \tag{29}$$

$$\dot{e}'_5=\frac{\dot{e}_2 X}{1+X^2} \tag{30}$$

$$\dot{e}'_7=\dot{e}'_5+\dot{e}'_6 \tag{31}$$

Substituting (29) and (30) in (31),

$$\dot{e}'_7=\frac{\dot{e}_2 X}{1+X^2}+\frac{\dot{e}_2}{1+X^2}=\frac{\dot{e}_2(1+X)}{1+X^2} \tag{32}$$

For cancellation, $\dot{e}_7$ must equal $\dot{e}'_7$, whence, from (26) and (32)

$$\frac{\dot{e}_3(X+X^2)}{1+X^2}=\frac{\dot{e}_2(1+X)}{1+X^2} \tag{33}$$

or,

$$\dot{e}_3(X+X^2)=\dot{e}_2(1+X) \tag{34}$$

and,

$$\dot{e}_3 X=\dot{e}_2 \tag{35}$$

Assuming, again, that $\dot{e}_3=2\dot{e}_2$, then

$$X=\frac{1}{2} \tag{36}$$

Substituting (36) in (26),

$$\dot{e}_7=\frac{\dot{e}_3\left(\frac{1}{2}+\frac{1}{4}\right)}{1+\frac{1}{4}}=\frac{\frac{3\dot{e}_3}{4}}{\frac{5}{4}}=\frac{3\dot{e}_3}{5} \tag{37}$$

Then, from the assumption made above leading to (36),

$$\dot{e}_7=2\frac{(3\dot{e}_2)}{5}=\frac{6\dot{e}_2}{5} \tag{38}$$

Since $\dot{e}_p=\dot{e}_7+\dot{e}'_7$ and $\dot{e}_7=\dot{e}'_7$ from the assumption made above leading to (33), then

$$\dot{e}_p=2\dot{e}_7 \tag{39}$$

Substituting (38) in (39).

$$\dot{e}_p=2\left(\frac{6\dot{e}_2}{5}\right)=\frac{12\dot{e}_2}{5}=2.4\dot{e}_2 \tag{40}$$

Now, it can be shown that

$$Z_p=1.8R \tag{41}$$

$$K=\frac{\dot{e}_p^2}{Z_p} \tag{42}$$

Substituting (40) and (41) in (42),

$$K=\frac{(2.4\dot{e}_2)^2}{1.8R} \tag{43}$$

Hence, the gain in efficiency offered by this modification of my invention over the conventional system of Fig. 2, dividing

$$(43)\text{ by }(6)=\frac{\frac{(2.4\dot{e}_2)^2}{1.8R}}{\frac{2\dot{e}_2^2}{R}}=1.6$$

or a gain of approximately 2 db.

In Fig. 5, I have shown a modification of my invention which is similar to that shown in Fig. 4 but employing two separate transformers 15 and 17, respectively, for the ribbon sections 1*a* and 1*b*. The secondary windings of the transformers 15 and 17 may be connected either in series or in parallel depending upon the conditions of use, although the series connection, as shown, is preferred since, under conditions of a loaded output, the series connection gives better results.

If, as in Fig. 4, the resistances of the ribbon

sections 1*a* and 1*b* are equal and have a value R and

$\dot{e}_2$ =voltage generated by the pressure section 1*b*,
$\dot{e}_3$ =voltage generated by the velocity section 1*a*,
$\dot{e}_8$ =voltage across the secondary winding of the transformer 15,
$\dot{e}_9$ =voltage across the secondary winding of the transformer 17,
$\dot{e}_0$ =total output voltage across the secondary windings of both transformers 15 and 17,
Z_8=the impedance looking into the secondary winding of the transformer 15,
Z_9=the impedance looking into the secondary winding of the transformer 17,
Z_0=total output impedance as viewed from both secondary windings of the two transformers,
n_{15}=ratio of turns between the two windings of the transformer 15, and
n_{17}=ratio of turns between the two windings of the transformer 17,

then

$$Z_0=Z_8+Z_9 \tag{44}$$

$$Z_8=(n_{15})^2R \tag{45}$$

and

$$Z_9=(n_{17})^2R \tag{46}$$

Substituting (44) and (45) in (46),

$$Z_0=(n_{15})^2R+(n_{17})^2R \tag{47}$$

Now

$$\dot{e}_0=\dot{e}_8+\dot{e}_9 \tag{48}$$

For a unidirectional microphone, the condition must be met where

$$\dot{e}_8=\dot{e}_9 \tag{49}$$

Now

$$\dot{e}_8=(n_{15})\dot{e}_3 \tag{50}$$

Substituting (49) and (50) in (48),

$$\dot{e}_0=2n_{15}\dot{e}_3 \tag{51}$$

Now, let

$$\frac{\dot{e}_3}{\dot{e}_2}=k \text{ where } k>1 \tag{52}$$

Then, in order to satisfy (49),

$$n_{17}=kn_{15} \tag{53}$$

Substituting (53) in (47),

$$Z_0=(n_{15})^2R+(kn_{15})^2R=(1+k^2)(n_{15})^2R \tag{54}$$

whence the power ratio

$$K=\frac{(\dot{e}_0)^2}{Z_0}=\frac{(2n_{15}\dot{e}_3)^2}{(1+k^2)n_{15}^2R}=\frac{4\dot{e}_3^2}{(1+k^2)R} \tag{55}$$

Assuming that $k=2$, then

$$\dot{e}_3=2\dot{e}_2 \tag{56}$$

Now, dividing (55) by (6), and substituting (56) in the resulting equation, the gain in efficiency of the system of Fig. 5 over the conventional system of Fig. 2 is

$$\frac{\frac{4\dot{e}_3^2}{(1+k^2)R}}{\frac{2\dot{e}_2^2}{R}}=\frac{\frac{4(2\dot{e}_2)^2}{(1+4)R}}{\frac{2(\dot{e}_2)^2}{R}}=\frac{\frac{16\dot{e}_2^2}{5R}}{\frac{2(\dot{e}_2)^2}{R}}=\frac{8}{5}=1.6$$

Here, again, therefore, there is a gain of about 2 *db.* over the conventional system.

In Fig 6. I have shown a still further modification of my invention wherein the field structure associated with the two ribbon sections can be altered so as to provide a weaker magnetic field for one section than for the other. In this modification, the ribbon sections 1*a* and 1*b* may be separated, if desired, and their ends clamped between suitable blocks 21 in a well known manner. One or more magnets 23 associated with the pole pieces 5 supply the necessary flux in the air gap. When properly designed, the flux density in the pole air gap will be uniform. Since, as was assumed in connection with the previous described modifications, the velocity section 1*a* is more sensitive than the pressure section 1*b*, in order to obtain the same output from each ribbon section, it is necessary to make the flux density in that portion of the air gap where the velocity section 1*a* is mounted weaker than in that portion thereof where the pressure section 1*b* is mounted. To accomplish this, I split the pole pieces 3 and insert brass or other suitable non-magnetic blocks 25 therebetween to provide a reluctance. In this way, there will be less flux flowing through the air gap of the velocity section 1*a* than through the air gap of the pressure section 1*b*. The length of the two ribbons or ribbon sections 1*a* and 1*b* are kept the same as before. If desired, the pole pieces 3 may be formed somewhat L-shaped, as shown in Fig. 7, and the adjacent split sections thereof connected by means of a screw 27 or the like of brass so that the sections of the pole pieces may be made adjustable relative to each other and the reluctance thereby varied.

From the foregoing description, it will be apparent that I have provided an improved unidirectional microphone which has greater sensitivity than conventional microphones of this type. Although I have shown and described several modifications of my invention, it will be apparent to those skilled in the art that many other modifications, as well as changes in those herein described, are possible. I therefore, wish it to be understood that I do not intend to be limited except insofar as is made necessary by the prior art and by the spirit of the appended claims.

I claim as my invention:

1. In a sound translating system employing a unidirectional microphone having a conductor movable in a magnetic field, said conductor having two sections of unequal sensitivities, the method of increasing the overall sensitivity of said system which comprises reducing the effective impedance of the more sensitive of said conductor sections.

2. In a sound translating system employing a unidirectional microphone having a conductor movable in a magnetic field, said conductor having two sections of unequal sensitivities, the method of increasing the overall sensitivity of said system which comprises shunting a resistance across the more sensitive section whereby to reduce the overall impedance of the circuit of said last named section.

3. In a sound translating system employing a unidirectional microphone having a conductor movable in a magnetic field, said conductor having two sections of unequal sensitivities, the method of increasing the overall sensitivity of said system which comprises coupling said sections to the primary winding of a transformer and connecting the common ends of said sections to a tap on said primary winding such that the circuit of the more sensitive one of said sections has a lower impedance than the circuit including the other of said sections.

4. In a sound translating system employing a

unidirectional microphone having a conductor movable in a magnetic field, said conductor having two sections of unequal sensitivities, the method of increasing the overall sensitivity of said system which comprises coupling each of said sections to the primary winding of a pair of transformers and so choosing the ratio of the turns of the winding in circuit with the more sensitive one of said sections to the turns of the winding in circuit with the less sensitive one of said windings that the impedance of said first named circuit will be less than the impedance of said second named circuit.

5. In a sound translating system, the combination of a uni-directional microphone having a sound wave pressure responsive element and a sound wave pressure gradient responsive element, said elements being serially connected, and an output transformer therefor, said elements being connected to the primary winding of said transformer, and the common junction of said elements being connected to a tap on said transformer such that the impedance of the circuit of said pressure gradient responsive section is lower than the impedance of the circuit of said other element.

6. In a sound translating system, the combination of a uni-directional microphone having a sound wave pressure responsive element and a sound wave pressure gradient responsive element, said elements being serially connected, a pair of output transformers, said first named element being connected to the primary winding of one of said transformers, and said second named element being connected to the primary winding of the other of said transformers, and the secondary windings of said transformers being connected together, the ratio of the turns of said first named primary winding to the turns of said second named primary winding being such that the impedance of the circuit of said second named element is lower than the impedance of the circuit of said first-named element.

7. In a sound translating system employing a uni-directional microphone having a pair of conductors movable in magnetic fields, one of said conductors being responsive to the velocity component and the other to the pressure component of a sound wave and said first named conductor being more sensitive than said second named conductor, the method of increasing the overall sensitivity of said system which comprises reducing the effective impedance of said first named conductor.

8. In a microphone system, the combination of means providing a magnetic field, a pair of vibratile conductor sections disposed in said magnetic field and arranged to be actuated by sound waves, one of said sections being capable of producing a greater voltage than the other of said sections in response to sound waves, and means connected in shunt relation with said first named section for lowering the impedance thereof an amount to substantially equalize the voltage outputs from said sections.

9. In a microphone system, the combination of means providing a magnetic field, a pair of vibratile conductor sections disposed in said magnetic field and arranged to be actuated by sound waves, one of said sections being capable of producing a greater voltage than the other of said sections in response to sound waves, and a transformer having two primary windings connected one to each of said sections, respectively, the ratios of transformation of said windings differing to such an extent and in such direction that the effective impedance of said first named section, as viewed from the secondary winding of said transformer, is lowered and the overall sensitivity of said system is increased.

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