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[54] **MICROPHONE FOR DIGITAL SPEECH TRANSMISSION**
13 Claims, 3 Drawing Figs.

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[50] Field of Search. **179/106, 111, 1 AS**

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ABSTRACT: An arrangement for transforming mechanical or acoustical waves into digital electrical signals is disclosed. The arrangement includes a converter which in principle is a condenser microphone having a diaphragm which is flexible and electrically biased. Also included is a plurality of switching elements (FET's) disposed in a stiff plate which forms a portion of the condenser microphone and arranged so that they are electrically actuated by the electric field associated with the diaphragm depending on the distance of the diaphragm from an individual switching element. Sampling circuits associated with each of the switching elements apply the outputs of the switching elements to a coding matrix and a binary output representative of the condition of the switching elements at any instant is provided. The arrangement of the switching elements along the radius of the diaphragm and the use of exclusive OR circuits in the sampling circuits are also disclosed.

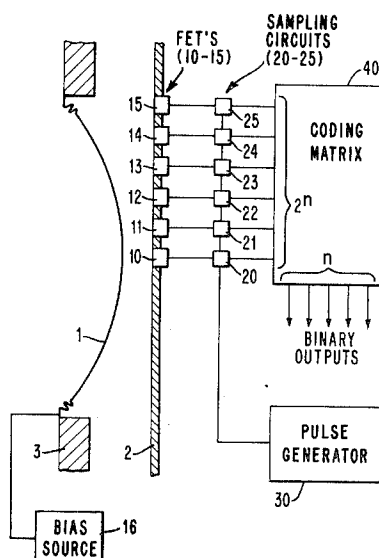


FIG. 1

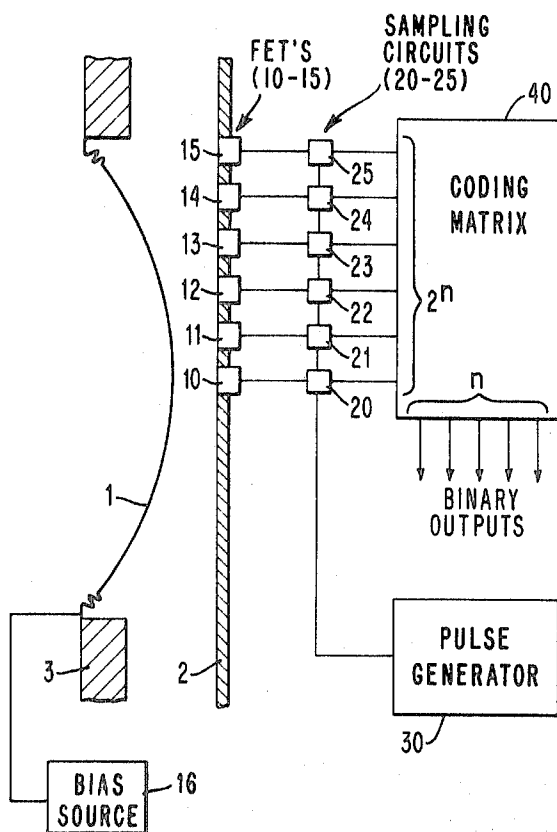


FIG. 2

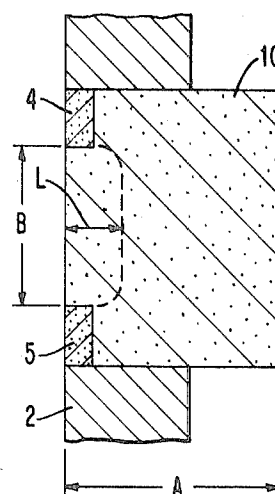
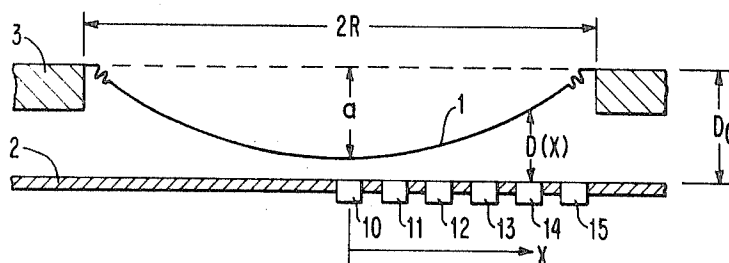


FIG. 3



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MICROPHONE FOR DIGITAL SPEECH TRANSMISSION

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a device for transforming mechanical or acoustical waves into digital electrical signals. A special purpose of this device is the pickup and transforming of acoustical waves directly into digital signals, without the intermediate transformation from mechanical movement into an analog signal, especially in the area of speech transmission.

2. Description of the Prior Art

Usually, acoustical signals are first converted into analog electrical signals by an analog converter such as a conventional microphone. In many cases, as in modern speech transmission, a second step follows in which these analog electrical signals are converted into digital form. One example of this digitalization is the use of pulse code modulation.

In view of the fact that this decoding process needs rather extensive equipment, it has already been proposed to digitalize the electrical signals earlier, i.e. while converting the acoustical signal into an electrical one. By this means, the intermediate process of converting the analog electrical signal into a digital electrical signal is eliminated and the complexity of the system is reduced.

According to Swiss Pat. No. 431,622, a converter is proposed for direct conversion of an acoustical signal into a digital electrical signal, with the converter comprising a flexible diaphragm. This device, however, uses only a small part or a single point of the diaphragm. On the other hand, the vibrating mass of the diaphragm is significantly enlarged by control means which are mechanically coupled with the diaphragm and which may cause an unwanted distortion of the output signal.

In an article by H. C. Nathanson and R. A. Wickstrom, "A Resonant-Gate Silicon Surface Transistor with High-Q Band-Pass Properties," Appl. Phys. Lettrs., Vol. 7, No. 4, pp. 84-86, an insulated gate type of transistor is described. Its frequency-determining element is a simple cantilever beam fabricated over but not touching the semiconductor surface. If the resonant cantilever is polarized with a positive voltage, a motion of this rod is detected by field-effect modulation of the conductivity of a N-type surface inversion layer between two N-type source-drain contacts.

SUMMARY OF THE INVENTION

This invention provides a converter which is in principle a condenser microphone with a flexible and electrically biased diaphragm and which comprises electrical switching elements such as field effect transistors located in the area of the stiff plate within the condenser microphone in a manner that the switching elements can be electrically coupled with the diaphragm, thereby causing a number of switching elements to change their state, the number of those elements being a function of the elongation of the flexible diaphragm.

More specifically, the invention provides a plurality of field effect transistors mounted in a stiff plate, the surfaces of which face an electrically biased flexible diaphragm. Depending on the strength of the electric field, certain of the FET's switch. The distance of the diaphragm from the surface of the FET's controls the field applied to each FET. The FET's are arranged along a radius of the diaphragm. Exclusive OR circuits associated with pairs of FET's define the demarcation line between switched and unswitched devices and provide an output to a decoder which in turn provides a digital output representative of the deflection of the diaphragm at any instant.

The above-described arrangement has the advantage that field effect transistors can be used as switching elements. FET's can easily be integrated into an inexpensive and highly reliable microcircuit. Furthermore, coding circuits can easily be coupled with the output of this device by integrating the whole circuitry into a single chip. Finally, the user will profit on the small size of this device.

It is, therefore, an object of this invention to provide a device for converting mechanical or acoustical waves into digital electrical signals which can be constructed in a very small and simple form.

Another object is to provide an arrangement which does not require a double conversion from an analog acoustical signal into an electrical signal and from the latter into a digital electrical signal.

The foregoing and other objects, features and advantages of this invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic illustration of a condenser microphone with digital output in accordance with the present invention.

FIG. 2 is a section through one of the FET's 10 to 15 according to FIG. 1.

FIG. 3 defines some of the parameters which are included in the following description.

DESCRIPTION OF A PREFERRED EMBODIMENT

According to FIG. 1, the condenser microphone of the present invention comprises a flexible diaphragm 1 and a stiff plate 2, both of which form the two plates of a condenser. The device further comprises a mounting device 3 for mechanically fixing diaphragm 1. As usual in conventional condenser microphones, flexible diaphragm 1 needs a low resistivity. Therefore, the material of diaphragm 1 is a metal foil or any other metallized flexible material. For illustrative purposes, FIG. 1 shows diaphragm 1 in an elongated position and not in its rest position.

Within the area of stiff plate 2, there are several field effect transistors 10-15, (hereinafter called FET's). As shown in FIG. 2, these FET's comprise source and drain electrodes 4 and 5, respectively. The gate electrode is formed by diaphragm 1 which is positioned opposite stiff plate 2 and electrically biased from bias source 16. The geometrical dimensions of this arrangement will be described later. It may be mentioned at this point that the scope of this invention need not be restricted to use with field effect transistors. It should be evident to those skilled in the art that other switching elements can be used which can be electrically coupled with the flexible diaphragm.

The idea of this device is to arrange the FET's along a line; to bias the flexible diaphragm 1 against stiff plate 2 and to create a relationship between the elongation of flexible diaphragm 1 and the relation of nonconducting to conducting FET's. If a diaphragm which assumes a parabolic shape upon elongation is used, the most effective arrangement of the FET's 10-15 is along a radius of flexible diaphragm 1 if the diaphragm is given a spheric shape. By this arrangement, a small elongation of the diaphragm causes a control of the central part of the FET arrangement by the central part of the diaphragm which works as a gate electrode. During an extensive elongation, the peripheral area of the FET arrangement also will be controlled by the diaphragm. If a great number of FET's is provided in such an arrangement, an evaluation of the number of conducting elements can be related to the number of nonconducting elements and will provide a good criterion for the elongation of the diaphragm. A large number of these elements will produce a better ratio for this value. It will be advantageous if the number of these elements is equal to the number of quantization levels which is needed in a special arrangement to be described hereinbelow.

The scope of this invention is not restricted to this special form of diaphragm which is shown in FIG. 1. Other forms may be used if the sensors or FET's 10-15 are arranged in a form that meets the requirements described above.

According to FIG. 1, FET's 10-15 are followed by sampling circuits 20-25, respectively which are controlled by a sam-

pling control circuit 30. Each output of sampling circuits 20-25 is fed to a coding matrix 40 which converts, in this example, 2^n sampled input signals into n binary output signals. The sampling control 30 comprises a clock which triggers the sampling circuit 20-25 so that their output signals are received serially by the coding matrix 40. According to FIG. 1, 2^n quantization levels are wanted which are sensed by 2^n FET's and sampled by 2^n sampling circuits 20-25.

The above-mentioned ratio of the number of conducting elements to the number of nonconducting elements can be evaluated in the following manner. At a special value for the elongation of the diaphragm, one part of the FET arrangement is in the conducting state while another part is nonconducting. Between these two parts, a line of demarcation can be defined which varies with the elongation of the diaphragm. Using this fact, it is sufficient to sample the position of this line of demarcation. This is done by the sampling circuits 20-25 as shown in FIG. 1 if they incorporate EXCLUSIVE OR circuits. By means of such circuitry, two adjacent sensors are compared by providing an output signal only if one of the sensors is in a conducting state and the other one is in the nonconducting state. This results in receiving an output signal only from that sampling circuit which is wired with the sensors defining the line of demarcation.

The coding matrix 40 may be of any form which provides the special code wanted for the following computation or transmission of the digital speech signal. For the special purpose shown in FIG. 1, the coding matrix contains $2^n \times n$ elements. The scope of this invention is not restricted to the special form of this coding matrix. It should be evident to those skilled in the art that any other form of coding matrix may be used to provide any desired coded signal.

In the following, a more detailed description of the invention is given. As shown in FIG. 3, the diameter of unstressed diaphragm 1 (shown dotted) is $2R$. The distance of unstressed diaphragm 1 from stiff plate 2 containing the sensors 10-15 is D_0 . The maximum elongation of diaphragm 1 is a . Assuming diaphragm 1 elongates into a parabolic form, distance D between diaphragm 1 and a field effect device located at a distance X from the center is:

$$(1) D(x) = D_0 - a + (a/2R)x^2$$

From Poisson's equation:

$$\psi'' = -\rho/\epsilon$$

wherein ψ is the potential produced by a distribution of charge density ρ and ϵ is the dielectric constant. ψ'' is the second derivative of the potential ψ , it follows that a field strength $F(N, L)$ at the semiconductor surface is necessary to deplete a layer of thickness L and doping level N which has the value

$$F = (q/\epsilon)NL$$

when q denoting the electron charge, and ϵ the dielectric constant of the semiconductor. The channel between source and drain electrodes may be N-doped. If a voltage U_{SD} is applied across the field effect device, the current per unit length of this device is:

$$(2) \quad I = \frac{\sigma}{B} \left(A - \frac{\sigma F}{qN} \right) U_{SD} \\ = \frac{\sigma}{B} \left(A - \frac{\epsilon \mu F'}{\sigma} \right) U_{SD}$$

where μ is the mobility, σ the conductivity, A the thickness of the device, and B the length of the channel as shown in FIG. 2.

The pinch-off condition is reached when:

$$A - (\epsilon F/\sigma) \leq 0 \\ F \geq A\sigma/\epsilon\mu$$

For instance, with $A=10^{-4}$ cm., $\sigma=1$ Ohm $^{-1}$, $\epsilon=10^{-12}$ ASec/Vcm. and $\mu=3,000$ cm. 2 /Vsec, a field strength of 3.10^4 V/cm. would be required which is quite normal for condenser microphones if the biasing voltage is $U_0=30$ V and $D_0=10^{-3}$ cm. If the channel is N-doped as mentioned above, the biasing voltage U_0 must be negative relative to stiff plate 2 which has the same potential as the FET's. In this case, a depletion layer will in the channel of the FET.

By differentiation of equations (1) and (2), respectively, it follows:

$$dD/dx = 2a/R^2 x,$$

and

$$dI/dF(\epsilon\mu B)U_{SD}$$

On the other hand, it follows for any point on the diaphragm having a distance D from the stiff plate and having a field strength F as a result of the biasing voltage U_0 :

$$dF/dD(1/(U_0 D^2))$$

This last equation is the differential of the field strength F with respect to distance D where $F=U_0/D$ and wherein U_0 is the potential difference between two plates spaced apart by a distance D . The differential of the field strength with respect to distance indicates that when the voltage between the two plates is assumed constant, the field strength F varies with the square of the variations of the distance D of membrane 1 with respect to the rigidly mounted field effect devices.

A combination of the three equations results in:

$$\frac{dI}{dx} = \frac{2a\epsilon\mu U_0 U_{SD}}{BR^2 D^2(x)} \cdot x$$

This formula yields to a variation of current with respect to the distance x of the field effect device from the center. For the following values, $U_{SD}=5$ V, $B=4.10^{-4}$ cm., $R=1.5$ cm., it follows for a conventional condenser microphone in which $D(x)$ can be replaced by D_0 and for a relative distance $x/R=0.1$:

$$dI/dx = 15 \text{ mA/cm.}^2$$

For a device of $250\mu\text{m.}$ length, it follows:

$$dI^*/dx = 400 \mu\text{A/cm.}$$

A digitalization in 250 levels requires a device distance of $1.5\text{cm.}/2506.10^{-3}\text{cm.}$ The difference in current level between adjacent devices is then $2.4\mu\text{A.}$ Such a current level can be processed by discriminating networks. The sensitivity is increasing towards the periphery by a factor of 10, thus yielding steps in current levels of $24\mu\text{A.}$

Since the FET's can be realized in very small sizes, the whole circuitry comprising the sampling circuit and the coding matrix can be integrated into one single semiconductor chip and can be fabricated in common steps. One possibility for fabricating this circuitry is the Mesa technique. For the device shown in FIG. 1 it would be advantageous to exceed a critical distance between the sensors 10-15 and the coding matrix 40 on one side and the flexible diaphragm 1 on the other side to suppress unwanted effects originating in the electrical field between the flexible diaphragm and the stiff plate 2.

From the computations shown above, it is evident that the device is relatively insensitive to variations of the biasing voltage U_0 . If variation, however, exceeds a critical value, it will be necessary to provide a constant voltage source which causes the flexible diaphragm to adjust into an exactly defined rest position. Furthermore, it is possible to control the constant voltage source by the FET's per se. In this case, the two sensors which define the above-mentioned line of demarcation at normal pressure will be connected with a minimum/maximum control of the biasing voltage U_0 .

If the flexible diaphragm is mechanically coupled with a pressure-sensitive element, this device can be used for measuring small relative pressure variations.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in the form and detail may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A device for transforming mechanical or acoustical waves into digital electrical signals comprising:

a stiff member,

a plurality of field effect transistors mounted in said member, each transistor containing source and drain regions, and

a unitary vibratory gate electrode of flexible material disposed in spaced relationship with the surfaces of said

transistors, the distance between portions of said gate and the surface of each of said transistors, in response to acoustic or mechanical waves, being different to govern the conductivity condition of each of said transistors.

2. A device according to claim 1 wherein said field effect transistors are mounted in said stiff member along a line corresponding to a radius of said unitary gate electrode.

3. A device according to claim 1 further including means responsive to the conductivity condition of said plurality of field effect transistors for converting their conductivity condition into digital electrical signals.

4. A device according to claim 3 wherein said means responsive to the conductivity condition of said plurality of field effect transistors includes a plurality of sampling circuits each connected to at least a corresponding field effect transistor,

means for sequentially gating each of said sampling circuits, and

a coding matrix having a plurality of inputs equal to 2^n and a plurality of binary output connections equal to n .

5. A device according to claim 4 wherein each of said sampling circuits is an exclusive OR circuit, the inputs of which are connected to adjacent field effect transistors.

6. A device according to claim 4 wherein said means for sequentially gating each of said sampling circuits is a pulse generator.

7. A device for transforming mechanical acoustical waves into digital electrical signals comprising:

an electrically biased vibratory gate diaphragm,

a stiff plate disposed in facing spaced relationship with said gate diaphragm, and

a plurality of electric field responsive switchable elements mounted in said stiff plate each of said elements being capable of assuming one of an OFF and ON condition, the distance of portions of said diaphragm relative to each of said switchable elements being different in response to mechanical or acoustic waves.

8. A device according to claim 7, wherein said switchable elements are field effect transistors.

9. A device according to claim 7 wherein said switchable elements are mounted in said stiff plate along a line corresponding to a radius of said diaphragm.

10. A device according to claim 7 further including means connected to said plurality of switchable elements for converting the condition of said switchable elements into discrete digital electrical signals.

11. A device according to claim 10 wherein said means for converting includes coupled to said switchable elements for sampling their condition,

means for gating said sampling means, and

a coding matrix having a plurality of inputs equal to 2^n and a plurality of outputs equal to n .

12. A device according to claim 11 wherein said sampling means includes an exclusive OR circuit, the inputs of which are connected to adjacent switchable elements.

13. A device according to claim 11 wherein said means for gating said sampling means is a pulse generator.

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