United States Patent

Gerard

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[54] **ACOUSTIC SURFACE WAVE DEVICE HAVING IMPROVED TRANSDUCER STRUCTURE**

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[52] **U.S. Cl.** **310/9.8,** 310/8.1, 330/5.5, 333/72

[51] **Int. Cl.** **H01v 7/00**

[58] **Field of Search** 310/8.1, 9.7, 9.8, 8; 330/5.5; 333/30, 72

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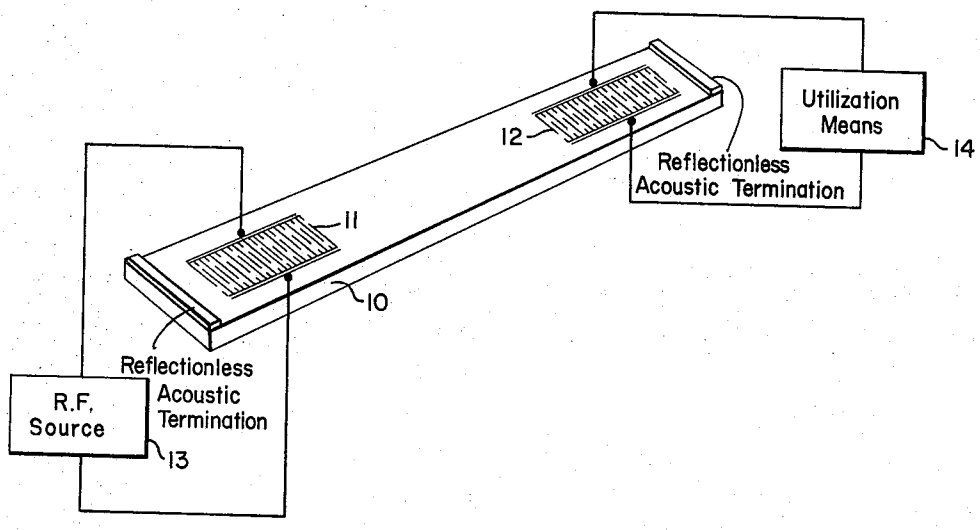
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[57] **ABSTRACT**

An improved transducer structure of the interdigitated electrode type is disclosed. In many microwave acoustic devices it is necessary to convert rf energy to acoustic surface wave energy and vice versa. When the acoustic medium is a piezoelectric substrate, interdigitated electrode transducers are widely employed. When such transducers are amplitude weighted, acoustic wave phase distortion of a serious nature can occur. Such phase distortion is eliminated by the use of an interdigitated transducer having dummy (i.e. non-active) electrodes disposed in the transducer pattern so as to present a substantially uniform metalization density to the propagating acoustic surface wave.

16 Claims, 5 Drawing Figures



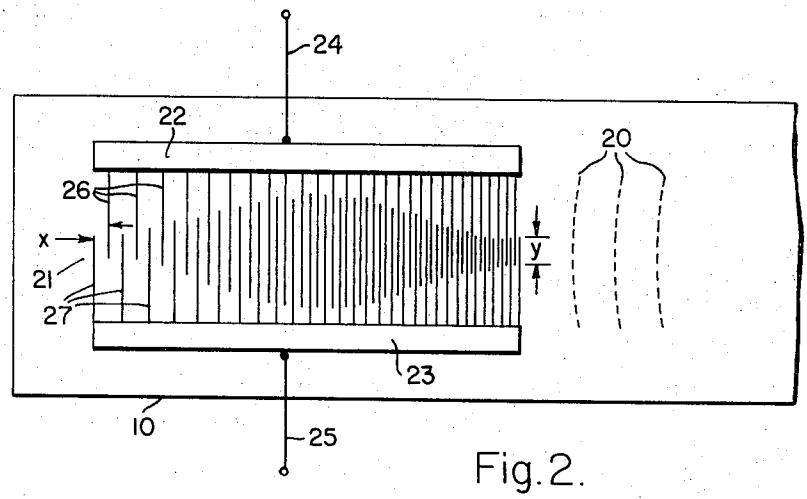


Fig. 2.

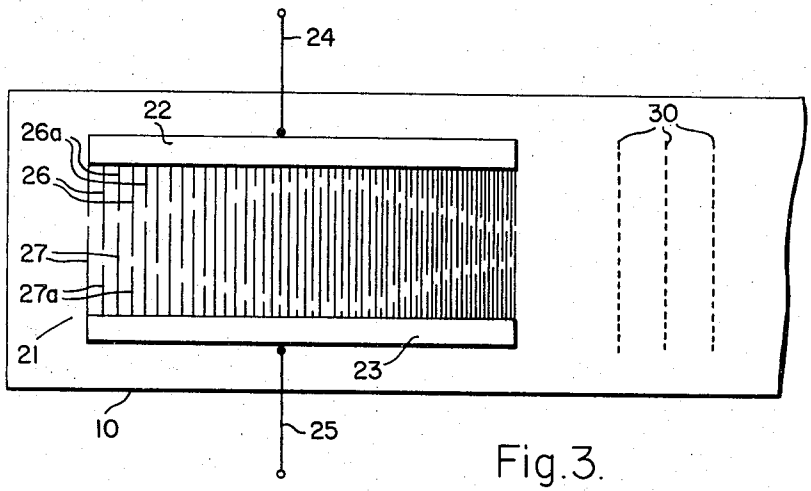


Fig. 3.

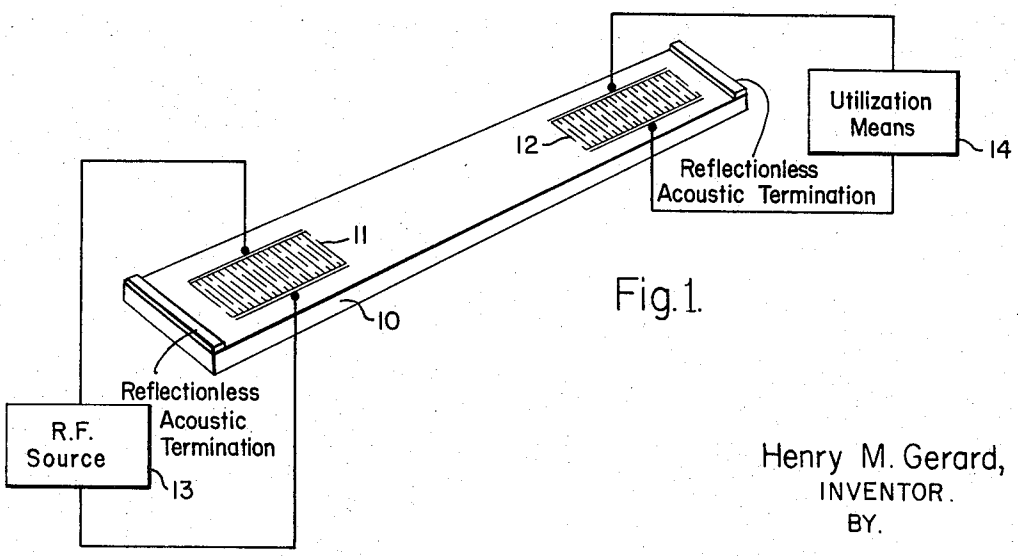


Fig. 1.

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Fig. 4.

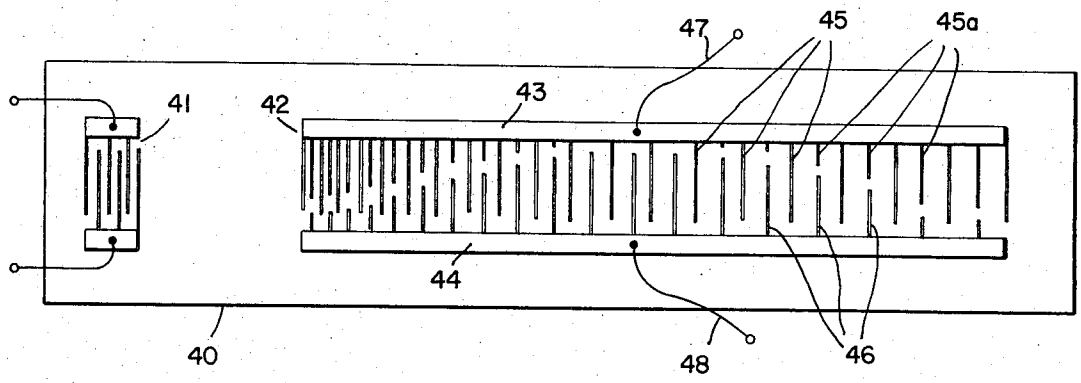
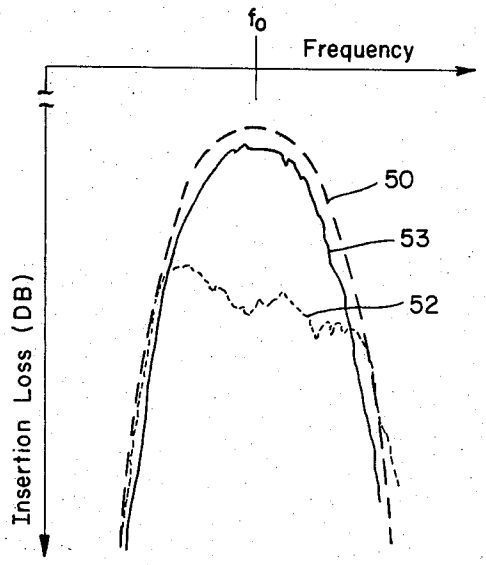

47
45
45a
41
42
43
44
40
48
46

Fig. 5.


f_o
Frequency
Insertion Loss (DB)
50
53
52

ACOUSTIC SURFACE WAVE DEVICE HAVING IMPROVED TRANSDUCER STRUCTURE

RELATION TO GOVERNMENT CONTRACT

The invention herein described was made in the course of or under a contract or subcontract thereunder, with the Department of the Army.

FIELD OF THE INVENTION

This invention relates to acoustic surface wave devices and more specifically to improved electromechanical transducer structures for use with such devices.

DESCRIPTION OF THE PRIOR ART

In recent years there has been a significant upsurge of scientific interest in the field of microwave acoustics. The work in this field has proceeded at a pace which thus far has not permitted the formulation of a consistent nomenclature. The terms "microwave acoustics," "ultrasonics," "microsound," "praetersonics," and "microwave ultrasonics" have been used with varying degrees of interchangeability to designate this technical field. The term "microwave acoustics" has received the sanction of the IEEE and will be used herein. It should be noted parenthetically that even this term is not altogether accurate, for it may also include devices operating below the frequency range of approximately 1,000 MHz which is traditionally regarded as the lower limit of the microwave region.

Because of developments in new materials, widespread interest now exists in microwave acoustic devices wherein the wave energy propagates along the surface of a material much as a ripple on a pond. In fact, if viewed microscopically, the surface of the material supporting these waves would resemble such a pond, complete with wave crests and valleys. One of the great advantages of surface wave devices results from the fact that the surface waves travel much slower than electromagnetic waves in free space. The wavelengths are therefore shorter and components such as delay lines, amplifiers, attenuators, filters, and couplers of microminiature construction can be utilized to modify and process the surface wave energy.

In its simplest form a surface wave microwave acoustic circuit comprises a source of rf energy, a smooth slab-like element or substrate of material capable of supporting propagating surface waves and a utilization device. Electromechanical transducers are coupled to the substrate to convert the rf energy to surface waves in the material and vice versa. Thus configured, the basic surface wave device is primarily useful as a delay line. Frequently, it is desired to modify the propagating surface wave in a manner such as to enhance the operation of the basic devices and to form new devices having unique properties.

In general, piezoelectric materials are utilized in fabricating the surface wave substrate. With such substrates, the input and output transducers commonly take the form of arrays of conductive interdigitated electrodes which are bonded to the substrate surface. By properly designing the transducers, it is possible to obtain delay lines which have response characteristics which are functions of delay time and frequency. Because of these properties, such devices are termed

delay line filters, and find use in a broad range of communications and radar systems.

Because of the many advantages enjoyed by delay line filters they are especially attractive for use in modern radar systems. See, for example, the article "-Surface Wave Delay Lines Promise Filters for Radar, etc." by J. H. Collins and P. J. Hagon, Electronics, Jan. 19, 1970 at pp. 110–122. When used with chirp radar systems, for example, pulse compression and expansion filters can be obtained by utilizing surface wave delay lines with interdigitated electrode transducers having a graded or varying interelectrode spacing.

It is also desirable in many instances to suppress or control filter sidelobe response by varying the transducer interelectrode overlap. The article "Surface Wave Device Applications and Component Developments" by J. Burnsweig, E. H. Gregory and R. J. Wagner, IEEE, Journal of Solid State Circuits, Vol. SC–5, No. 6, December 1970 at pp. 310–319, for example, illustrates transducer patterns of triangular and Gaussian shape.

It has been found, however, that device operation is degraded when utilizing transducers having interdigitated electrodes which do not extend completely across the transverse transducer dimension. This degradation is caused by closely nonuniform metalization of such transducer patterns and results from unequal velocities of different portions of the propagating surface wave. The unequal surface wave velocity in turn results in phase distortion which manifests itself as poor filter response characteristics.

It is, therefore, an object of the present invention to improve the response characteristics of electromechanical transducers of the interdigitated electrode type.

It is a further object of the present invention to provide an improved interdigitated transducer structure having a weighted amplitude versus frequency response characteristic.

It is yet another object of the present invention to improve the response characteristics of surface wave delay line filters.

SUMMARY OF THE INVENTION

In accordance with the principles of the present invention, these objects are accomplished by utilizing "-dummy" elements disposed in the interstices of adjacent active electrodes of an interdigitated electrode transducer. The dummy elements, while being inactive insofar as the transduction process is concerned, provide a more uniform transducer metalization density. The resultant transducer therefore appears substantially homogeneous to the surface wave propagating in the piezoelectric substrate on which the transducer is disposed. Although the transducer appears uniform to the surface wave, its active electrode pattern can be selected for any desired response characteristic.

When the compensated transducers are incorporated in weighted delay line filters, the phase distortion caused by non-uniform surface wave velocities is substantially eliminated. The response characteristics of such filters, therefore, more closely approximate the desired design characteristics.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects and features of the present invention can be more readily understood with reference to the following detailed description taken in conjunction with the accompanying drawings, wherein like reference numerals designate like structural elements and in which:

FIG. 1 is a simplified pictorial view of a surface wave delay line filter in accordance with the present invention;

FIG. 2 is a plan view of a portion of a filter such as that of FIG. 1 but utilizing a transducer of prior art design;

FIG. 3 is a plan view of a portion of the device of FIG. 1 illustrating the improved transducer of the present invention;

FIG. 4 is a plan view of another embodiment of the present invention; and

FIG. 5 is a graphical representation of the insertion loss characteristics of typical pulse compression filters both with and without the compensated interdigitated transducer of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring more specifically to the drawings, FIG. 1 is a simplified pictorial view of a surface wave delay line filter. In FIG. 1 an elongated slab or substrate **10** of piezoelectric material is provided with an input transducer **11** and an output transducer **12**. A source of rf energy indicated generally by block **13** is electrically coupled to input transducer **11**. Source **13** can also include suitable electromagnetic tuning elements as are well known in the art. A utilization circuit indicated generally as block **14** is, in turn, electrically coupled to the output transducer **12**. The piezoelectric material from which substrate **10** is fabricated is of the type suitable for the propagation of acoustic surface waves. Many suitable materials have been employed for this purpose and their characteristics can be found in the recent technical literature. For example, $LiNbO_3$, CdS, ZnO, $Bi_{12}GeO_{20}$ and SiO_2, to mention only a few, have been employed. Depending upon the acoustic loss which can be tolerated in the frequency range of intended operation they can be employed with greater or lesser success.

Generally, the surface of substrate **10** is ground and polished to an optical quality finish in order to reduce surface imperfections to a minimum. Input and output transducers **11** and **12**, which will be described in greater detail hereinbelow, are deposited, bonded or otherwise mechanically attached to the upper polished surface of substrate **10**. Transducers **11** and **12** can be formed of any suitable electrically conductive material such as aluminum or gold. The thickness of the deposited conductive material comprising the transducers is not critical and can typically be on the order of 500 to 1,000 Angstroms or more.

Surface wave delay lines and surface wave delay line filters of the general type depicted in FIG. 1 have a wide variety of uses as a glance at the current microwave literature will reveal. A typical use for a delay line such as that depicted in FIG. 1 is in the signal processing portions of pulse compression radar systems. In a radar receiver, for example, the delay line may be of the dispersive type for pulse compression of a transmitted "chirp" radar pulse. Although many other uses for the improved transducer structures of the present invention are known, the embodiments will be described in terms of frequency dispersive delay lines.

In addition to providing a time delay between the input and output signals which is a function of frequency it is also frequently desirable to amplitude-weight the filter response characteristic. That is, it is sometimes desirable to design one or both transducers so that with a given amplitude rf input signal the amplitude of the delayed rf output signal is a function of frequency.

In order to achieve both frequency dispersive and frequency dependent amplitude-weighting in such delay line devices, interdigitated transducer structures such as that shown in FIG. 2 have been suggested. FIG. 2 is a plan view, partially broken away, of the input portion of a device such as shown in FIG. 1. The input transducer **21** comprises a pair of interdigitated conductor patterns bonded to the upper surface of piezoelectric substrate **10**. Transducer **21** comprises a pair of elongated conductive pads **22** and **23** which are conveniently connected to the rf source, not shown, by means of leads **24** and **25**, respectively.

Extending partially across the surface of substrate **10** between pads **22** and **23** in the transverse direction are sets of interdigitated conducting electrodes **26** and **27**. As with pads **22** and **23**, electrodes **26** and **27** are deposited, bonded or otherwise mechanically attached to the surface of substrate **10**. As is known in the art, the spacing x between adjacent electrodes **26** and **27** determines the frequency of maximum surface wave excitation. In general, for maximum coupling between the electrical and acoustic wave energy, the spacing x is an integral multiple of an acoustic half-wavelength. The amount of transverse overlap y between adjacent electrodes determines the efficiency of the electromagnetic-to-acoustic transfer, and, therefore, the degree of acoustic coupling.

Due to the variation of transverse electrode overlap y, the maximum weighting for the transducer of FIG. 2 occurs in the longitudinal mid-region of the structure. This variation in overlap y along the transducer has been termed "apodization," and the resultant structures are known as "apodized interdigitated transducers."

In operation, rf energy having frequency components extending over a large range of frequencies is applied to transducer **21** by means of conductive leads **24** and **25**. Due to the relatively large electrode spacing x in the left-hand portion of the transducer, the lower frequency rf energy is converted by means of the piezoelectric effect into mechanical perturbations or surface waves in the upper surface of substrate **10**. The midrange frequency and higher frequency wave energy is similarly converted to propagating surface wave energy in the mid and right-hand regions of transducer **21**, respectively. Due to the bidirectional nature of transducer **21**, a portion of the surface wave energy propagates toward the left where it can be absorbed, if desired, by an absorbing material such as black wax deposited on the upper surface of substrate **10** as shown in FIG. 1.

Measurements made on experimental surface wave filters with apodized interdigitated transducers have been reported. For example, see the above-mentioned article by J. Burnsweig, E. H. Gregory and R. J. Wagner entitled "Surface Wave Device Applications and Component Developments." If operated at sufficiently low frequencies, devices utilizing transducer configurations such as that depicted in FIG. 2 have proven satisfactory for substrate materials having relatively weak electromechanical coupling coefficients. However, at the higher operating frequencies the electrode mass can affect the surface wave velocity and give rise to undesirable phase distortion. Furthermore, if the substrate material has a relatively strong electromechanical coupling coefficient such transducer structures can degrade performance at low as well as high operating frequencies.

More specifically, it has been found that the variation in the amount of metalization of the substrate seen by the surface wave as it propagates beneath the transducer causes velocity variations; that is, as the surface wave propagates beneath the region of the transducer its velocity is decreased by the presence of the conductive electrodes **26** and **27**. Thus, the surface wave velocity is slower along the longitudinal centerline of transducer **21** than in the transverse regions near the edges because there is more metal along the centerline than at the edges. In general, the velocity change is not only determined by the extent of relative metalization seen by the propagating surface wave, but is also proportional to the square of the effective surface wave electromechanical coupling coefficient referred to above. Since the phase difference between the central and edge regions of the propagating acoustic beam is proportional to velocity and path length, a velocity difference of only a fraction of a percent can result in very large cumulative phase distortions. The equi-phase wavefront of the surface wave launched by transducer **21** therefore emerges with a curved shape somewhat as indicated by dotted lines **20**.

As the distorted surface wave reaches the output transducer it is converted to an rf output signal. However, due to the averaging or integrating effect of the output transducer, which is designed to accept an undistorted wavefront, the rf output is degraded. If the output transducer is a mirror image of the input transducer **21**, the wavefront of the propagating surface wave energy is even further degraded. Again, this problem is most severe in materials such as $LiNbO_3$ which exhibit a strong coupling coefficient and is less severe in materials such as quartz which has a relatively low coupling coefficient.

In FIG. 3 there is shown an improved transducer structure in keeping with the present invention which overcomes the above-described problem. The transducer pattern of FIG. 3 is apodized or weighted in the same manner as that shown in FIG. 2. However, dummy elements **26***a* and **27***a* have been provided in the interstices of the transducer pattern to provide a substantially uniform metalization density as seen by the propagating acoustic surface wave energy. Dummy elements **26***a* are disposed between active electrodes **26** and dummy elements **27***a* are disposed between active electrodes **27**.

In FIG. 3 dummy elements **26***a* and **27***a* are shown as being attached to pads **22** and **23**, respectively. It is not required, however, that these elements be conductive, or that they be conductively joined to the pads or to each other. What is required is that the dummy elements present substantially the same effective loading to the propagating surface wave as the missing electrode portions.

It is seen that dummy elements **26***a* and **27***a* are inactive insofar as the transduction mechanism is concerned since they are at the same potential as their immediately adjacent electrodes **26** and **27**, respectively. Their presence, however, provides a substantially uniform metalization density to surface wave energy, thus eliminating the differential surface wave velocity problem of the transducer structure of FIG. 2. The portions of the surface wave energy near the edges of the transducer "see" substantially the same amount of overlying metalization as the central portions. The acoustic velocity is therefore substantially uniform for the entire wavefront and the emerging wavefront is linear as indicated by dotted lines **30**.

Although the most convenient method of fabricating the compensated transducer of FIG. **3** is with the use of the same conductive material for the active electrodes and the dummy elements, it is a matter of design choice. The dummy elements can be formed of a different material, either conductive or nonconductive. If a different material is used, however, the width or thickness of the dummy elements may have to be changed from that of the active electrodes in order to compensate for the difference in effective surface wave loading of the different materials.

In FIG. **4** there is shown a plan view of another embodiment of the present invention. The device of FIG. **4** represents a typical weighted pulse compression filter. The filter of FIG. **4** comprises a piezoelectric substrate **40** having a relatively broadband unweighted interdigitated input transducer **41** disposed on the upper surface thereof. The output transducer **42** comprises conductive pads **43** and **44** with transversely extending electrodes **45** and **46**. The active electrodes **46** are apodized, whereas active electrodes **45** are substantially uniform in length. The entire output transducer structure **42**, however, furnishes a weighted output response with respect to frequency just as do those illustrated in FIGS. **2** and **3**.

In the case of the asymmetrical electrode structure of this embodiment, only one set of dummy elements **45***a* is required. Dummy elements **45***a* are disposed in the interstices between active electrodes **45** and are conductively attached to pad **43**.

In operation, broadband rf energy applied to input transducer **41** is converted to surface wave energy, a portion of which propagates axially along the surface in the direction of output transducer **42**. This surface wave energy is reconverted to rf energy of the output transducer **42** and extracted therefrom by means of conductive leads **47** and **48**. By virtue of the narrower electrode spacing in the left-hand region of the output transducer **42**, the high frequency energy undergoes the least time delay. The low frequency energy, on the other hand, undergoes the greatest time delay. Also, since the transducer is weighted, the mid-frequency response of the transducer is greatest and tapers off for both the high and low frequencies. Phase distortion arising from the differential surface wave velocity in

output transducer 42 is minimized by the inclusion of dummy elements 45*a*.

FIG. 5 is a graphical representation of the insertion loss versus frequency characteristics of pulse compression filters similar to that of FIG. 4. The experimental filters comprised a Y-cut, Z-axis propagating lithium niobate substrate having input transducers of the type shown in FIG. 4 and output transducers of the type shown in FIGS. 2 and 3.

Curve 52 represents the insertion loss of the filter utilizing an uncompensated transducer of the FIG. 2 variety. The output transducer was apodized to give a Hamming weighted response curve as indicated by broken line 50 centered about at mid-band frequency f_o. As can be seen, the insertion loss for the uncompensated transducer departs substantially from the ideal response and is, in fact, unsuitable.

Curve 53 represents the insertion loss characteristic for a similarly weighted filter but with a compensated output transducer of the type illustrated in FIG. 3. As is readily seen, the insertion loss characteristic with the improved transducer of the present invention corresponds closely with the idealized design curve 50.

In all cases it is understood that the above-described embodiments are merely illustrative of but a small number of the many possible specific embodiments which can represent applications of the principles of the present invention. Numerous and varied other arrangements can be readily devised in accordance with these principles by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. An acoustic surface wave device comprising, in combination:
- a piezoelectric substrate capable of supporting propagating acoustic surface wave energy;
- at least one electromechanical transducer coupled to a surface of said substrate at a first region thereof;
- said transducer comprising a plurality of substantially parallel spaced-apart conductive electrodes, alternate ones of which are conductively connected to form two interdigitated electrode arrays, the transverse overlap between adjacent electrodes varying along the longitudinal direction of said arrays; and
- compensating elements disposed in the interstices of the array electrodes in the non-overlapping regions thereof.

2. The device according to claim 1 wherein said compensating elements are electrically nonconductive.

3. The device according to claim 1 wherein said compensating elements are electrically conductive.

4. The device according to claim 3 wherein said compensating elements are conductively coupled to the array electrodes longitudinally adjacent thereto.

5. An acoustic surface wave device comprising, in combination:
- a piezoelectric substrate capable of supporting propagating acoustic surface wave energy;
- at least one electromechanical transducer coupled to a surface of said substrate at a first region thereof;
- said transducer comprising a pair of elongated spaced-apart conductive members;
- a first plurality of longitudinally spaced electrodes extending transversely between said conductive members;
- a first end of alternate ones of said electrodes being conductively connected to one of said conductive members to form first and second arrays of interdigitated electrodes, a portion of the electrode members of at least one of said arrays having apodized second ends; and
- a plurality of compensating elements disposed in the interstices between the electrodes of said arrays in the regions of said apodization.

6. The device according to claim 5 wherein said compensating elements are electrically nonconductive.

7. The device according to claim 5 wherein said compensating elements are electrically conductive.

8. The device according to claim 7 wherein said compensating elements are conductively coupled to the array electrodes longitudinally adjacent thereto.

9. An electromechanical transducer for an acoustic surface wave device comprising, in combination:
- a pair of elongated spaced-apart conductive members;
- a first plurality of longitudinally-spaced electrodes extending transversely between said conductive members;
- a first end of alternate ones of said electrodes being conductively connected to one of said conductive members to form first and second arrays of interdigitated electrodes, a portion of the electrodes of at least one of said arrays having apodized second ends; and
- a plurality of compensating elements disposed in the interstices between the electrodes of said arrays in the regions of said apodization.

10. The transducer according to claim 9 wherein said compensating elements are electrically nonconductive.

11. The transducer according to claim 9 wherein said compensating elements are electrically conductive.

12. The transducer according to claim 11 wherein said compensating elements are conductively coupled to the array electrodes longitudinally adverse thereto.

13. An electromechanical transducer for an acoustic surface wave device comprising, in combination:
- a plurality of substantially parallel spaced-apart conductive electrodes, alternate ones of which are conductively connected to form two interdigitated electrode arrays, the transverse overlap between adjacent electrodes varying along the longitudinal direction of said arrays; and
- compensating elements disposed in the interstices of the array electrodes in the nonoverlapping regions thereof.

14. The transducer according to claim 13 wherein said compensating elements are electrically nonconductive.

15. The transducer according to claim 13 wherein said compensating elements are electrically conductive.

16. The transducer according to claim 15 wherein said compensating elements are conductively coupled to the array electrodes longitudinally adverse thereto.

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