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- (54) **Title:** A PASSIVE RADIO TRIGGERED SWITCH WITH ID FUNCTIONALITY

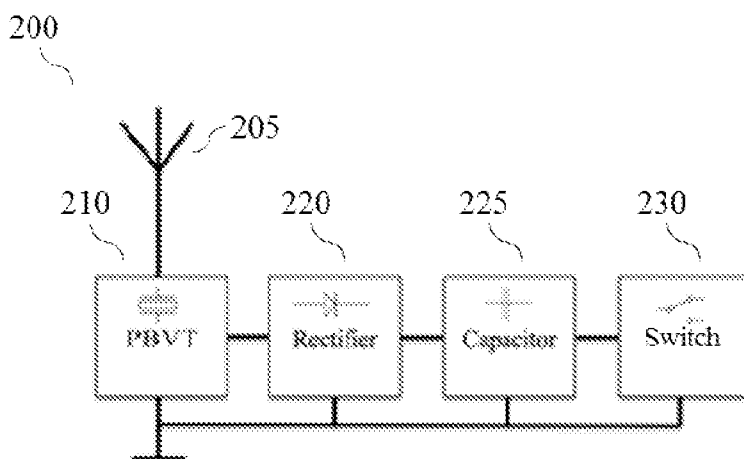


Figure 2a

(57) **Abstract:** The present invention relates to a radio triggered switch according (RTS) comprising a RF antenna, a RF rectifier, an accumulator and a voltage triggered switch. The RTS comprises a piezoelectric bandpass voltage transformer providing piezoelectric voltage transformation and bandpass RF filtering in the same component. The piezoelectric bandpass voltage transformer should have an output electrical impedance is larger than its input electrical impedance.

A passive radio triggered switch with ID functionality**Field of the Invention**

- 5 The present invention relates to a passive radio triggered switch and devices incorporating such switch. In particular the invention relates to a passive radio triggered switch with ID functionality.

10 **Background of the Invention**

- A wide range of applications today make use of remote controls providing ease of use as well as operation and control from a distance. A typical example is consumer electronics (TV, radio and satellite receivers, various video and DVD players, game consoles, etc). Other examples include use of remote control units in industrial environments, RFID applications, wireless sensor networks (WSN), etc. In many of these applications the receiving unit is equipped with a remote controlled switch (RCS) to enable switching the unit from a “stand by” to an “on” state. Such a RCS is typically activated by radio signals or infrared light. In addition, a RCS unit may have ID functionality which is unique for the unit in question and thus provides remote addressing capabilities. Very importantly, however, reception and decoding of the control signal requires that the RCS unit is always in an “on” state, i.e. it consumes presumably low but constant power.

- Typical home appliances such as TV sets are equipped with a RCS unit which in a stand by mode consumes approximately 1W of power. Efforts have been made to reduce this figure to a negligibly small figure. The ideal situation being that the RCS unit does not consume any energy at all. On the other hand, any amount of work (including information processing) amounts to consuming a corresponding amount of energy. Clearly, in the ideal case this energy can only come from the remote control signal and more specifically from the remotely generated radio signal. A remote controlled switch utilizing the energy in the radio signal are hereinafter referred to as a radio triggered switch (RTS). A simple RTS is proposed by Stankovic, REAL-TIME SYSTEMS, Volume: 29, Issue: 2-3, Pages: 157-182 and is schematically

illustrated in FIG. 1a. The simple RTS unit 100 comprises an antenna 105, an input bandpass filter 110, an inductive step-up voltage transformer 115, a rectifier 120 and an accumulator (capacitor) 125. The latter integrates (accumulates) the energy of the signal in the corresponding frequency channel over a period of time and provides a voltage/energy output which is consequently used to trigger a standard electronic switch (not illustrated in the figure). The use of a transformer is necessitated by the exponentially decaying power density of the emitted radio signal with distance in addition to the power limitations imposed by regulations regarding the ISM bands. In other words, power accumulation is the only feasible solution if the energy/voltage at the output capacitor is to reliably trigger low threshold electronics at practical distances. The simple circuit suffers from several deficiencies; for example: very limited range due to existing regulations regarding RF emission limitations, lacks inherent ID functionality (selectivity) unless very narrow band antennas are devised and is prone to jamming.

The above deficiencies have been addressed in the prior art. The range is increased by introducing more advanced energy accumulation for example additional AC/AC voltage transformers or multistage AC/DC rectifiers. It has been proposed to provide an ID functionality by simultaneously broadcasting multiple frequencies, say, N different center frequencies in corresponding, sufficiently small frequency bands, called channels. This, of course, necessitates the use of corresponding bandpass filters in the RTS unit. Each frequency channel thus corresponds to a specific bit in the N-bit ID number. The latter, hence, is hard coded and consists of N elements, called in here frequency bit elements (FBE) which are connected in parallel to the output terminal of the transformer or directly to the antenna if the latter is not present. FIG. 1b. illustrates such a key hard coded to the logical code (0,1). In other words, the key is activated only and only if the interrogation device sends a signal containing frequency f2 and not containing frequency f1.

The prior art publications clearly demonstrates the potential of the RTS. However, the prior art techniques are not suitable for large scale production. The main problems for the practical realization of the prior art technique, such as the circuits illustrated in FIG. 1a-b, are associated with a high fabrication cost and large physical dimensions.

They cannot readily be fabricated with existing silicon based technology, rather a costly combination of different techniques are required. It is finally noted that despite the fact that the above approach would in principle work, in reality no commercial product or even prototype has been demonstrated, possibly due to high fabrication costs stemming from the use of heterogeneous components such as transformers, impedance matching elements, bandpass filters, diodes, capacitors and digital circuitry.

In RFID applications a similar charge accumulation circuit is employed and which charge is subsequently used to drive the RFID circuit itself. In this case, thanks to the large RF power levels available at the antenna output, the voltage transformer is replaced by an AC/DC charge pump allowing "all silicon" implementation, leading to significantly reduced fabrication costs. Also, in this case the use of FBE elements is redundant since ID recognition is done after charge accumulation. Noteworthy, the power levels in RTS applications are almost two orders of magnitude lower and hence AC/DC charge pumps are not suitable due to their low efficiency.

Summary of the Invention

Obviously the prior art radio triggered switches significant improvements in order to be commercially attractive.

The object of the present invention is to provide a method that overcomes the drawbacks of the prior art radio triggered switches. This is achieved by the radio triggered switch defined in claim 1 and the passive multichannel voltage amplifier defined in claim 20.

A radio triggered switch according (RTS) to the invention is provided comprising a RF antenna, a RF rectifier, an accumulator and a voltage triggered switch. The RTS comprises a piezoelectric bandpass voltage transformer providing piezoelectric voltage transformation and bandpass RF filtering in the same component. The piezoelectric bandpass voltage transformer should have an output electrical impedance is larger than its input electrical impedance.

Preferably the piezoelectric bandpass voltage transformer of the radio triggered switch comprises a piezoelectric plate of a piezoelectric material, a capacitive input electro-acoustic transducer and a capacitive output electro-acoustic transducer. The transducers are preferably realized as linear or circular inter-digital transducers.

- 5 The piezoelectric material of the piezoelectric plate is preferably a single crystalline piezoelectric material from the list: quartz, LiTaO_3 , LiNbO_3 , GaAs, GaN, InN. Alternatively the piezoelectric plate is a c-textured thin polycrystalline piezoelectric film of the wurtzite crystallographic structure from the list: AlN, ZnO, $\text{Al}_x\text{Sc}_{1-x}\text{N}$, $\text{Al}_x\text{Y}_{1-x}\text{N}$, GaN, InN, $\text{Al}_x\text{Ga}_{1-x}\text{N}$, $\text{Al}_x\text{In}_{1-x}\text{N}$.

- 10 One embodiment of the invention is a multi-channel radio triggered switch comprising two or more radio triggered switches as described above, wherein each of the two or more radio triggered switches are adapted to different center frequencies. Hence, the multi-channel radio triggered switch can provide an ID-functionality.

- A further embodiment of the invention is a passive multichannel voltage amplifier
15 characterized in that it comprises two or more piezoelectric bandpass voltage transformer providing piezoelectric voltage transformation and bandpass RF filtering in the same component, the piezoelectric bandpass voltage transformer having an output electrical impedance is larger than its input.

- Thanks to the device according to the invention it is possible to provide a RTS which
20 are possible to manufacture at reasonable costs. The fabrication cost of the RTS in large volumes is of the order of 10 cents while its physical (on-chip) dimensions are of the order of 1 mm^2 depending on the frequency of operation. The invention also provides RTS with an ID functionality with a minimum of circuit complexity and which is very energy efficient.

- 25 One advantages is that the radio triggered switch according to the invention which consumes none or alternatively negligibly small amounts of energy. It can be used anywhere where one needs to remotely trigger, switch on/off and/or control one or more units with appropriate selectivity, i.e. with intrinsic identification where necessary. It can also be used for power accumulation in passive devices such as
30 RFID where it replaces the AC/DC charge pump or, indeed, as an autonomous power scavenging unit.

A further advantage as compared to Peltier elements, is the efficiency. The vacuum gap device according to the invention can be up to 10-15 times more efficient than conventional Peltier elements.

Embodiments of the invention are defined in the dependent claims. Other objects,
5 advantages and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings and claims.

10 **Brief Description of the Drawings**

Preferred embodiments of the invention will now be described with reference to the accompanying drawings, wherein:

Figure 1a-b illustrates schematically prior art radio triggered switch devices;

Figure 2a-e illustrates schematically different embodiments of the radio triggered
15 switch according to the present invention;

Figure 3a-e illustrates schematically the piezoelectric bandpass voltage transformer which is part of the radio triggered switch according to the present invention;

Figure 4a-b illustrates schematically one fabricated example of the piezoelectric bandpass voltage transformer which is part of the radio triggered switch according to
20 the present invention;

Figure 5 a-d are graphs illustrating the characteristics of the fabricated example of the piezoelectric bandpass voltage transformer;

Figure 6 illustrates schematically a transducer configuration of the piezoelectric bandpass voltage transformer which is part of the radio triggered switch according to
25 the present invention;

Figure 7a-b illustrates schematically oembodiments of the bandpass voltage transformer which is part of the radio triggered switch according to the present invention;

Figure 8 illustrates schematically one embodiment of the bandpass voltage transformer which is part of the radio triggered switch according to the present invention; and

Figure 9 illustrates schematically one embodiment of the bandpass voltage transformer which is part of the radio triggered switch according to the present invention.

Detailed description

The Radio triggered Switch (RTS) according to the present invention is schematically illustrated in FIG. 2a and comprises an antenna 205, a Piezoelectric Bandpass Voltage Transformer (PBVT) 210, a RF rectifier 220 and an accumulator (capacitor) 225. The accumulator 225 is connected to a voltage triggered switch 230, which can be of various known types. The piezoelectric bandpass voltage transformer (PBVT) 210 replaces both the bandpass filter 110 and the inductive step-up voltage transformer 115 of the prior art RTS described with reference to FIG. 1a. The PBVT 210 can be described as a specially designed piezoelectric bandpass filter which has at the same time has very high step-up voltage transformer characteristics. More specifically, the PBVT has a large ratio between the output and the input impedances, for example, but not limited to a ratio above 100. There exists a range of different approaches to designing such electro-acoustic bandpass filters employing various acoustic waves and modes, namely surface acoustic waves (SAW), plate waves (e.g. Lamb and Shear), Leaky SAWs, Surface Transverse Waves (STW), bulk acoustic waves (BAW), interface waves, etc and their various modes and combinations thereof. See for instance *"Crystal filters: design, manufacture, and application"*, Robert G. Kinsman, Wiley, 1987. All these approaches are equally applicable to the current invention. Key to the latter, however, is the requirement for a large ratio between the output and the input impedances within the passband which in turn determines the voltage transformer ratio. This is an additional filter specification in addition to the standard specifications for bandwidth, insertion loss, skirt, out-of-band rejection, etc. Piezoelectric voltage transformers are widely used in various applications, predominantly for power conversion where the limited bandwidth stemming from the resonant nature of the devices represents a drawback rather than a desired feature.

Analogously, the design approaches of such piezoelectric transformers are equally applicable to the present invention to the extent they are compliant with the filter design requirements and specifications. Hence, the PBVT design combines design approaches from both electro-acoustic filters and transformers in addition to
5 disclosing novel ones as discussed below. Noteworthy, the PBVT is a linear device operating at all input powers and hence does not possess a threshold. Hence, it can be used for very feeble signals provided the output voltage generated is sufficient for the intended application. In summary, the current invention suggests the use and design of a new frequency filter component with an increased set of specifications including
10 large voltage step-up transformer ratios.

The actual specifications and their order of priority in the design rules are determined in combination with the antenna output impedance by the specific application, although it is natural that priority is given to the voltage transformer ratio in view of the maximum range required. The high output impedance requirement favors the use
15 of acoustic modes at the output transducer with small electromechanical couplings in addition to a small output static capacitance. Consequently, for designs having an inter-digital transducer (IDT) type of output one of the implementations of the invention requires that the output IDT comprises a single pair of electrodes. The latter can even be split into two serially connected output pairs, doubling in this way the
20 output voltage. However, in cases where applications dictate certain filter specifications which can only be achieved at the expense of the transformer ratio, the rectifier may be replaced by an appropriate charge pump. Preferably, the output impedance of the antenna and the input impedance of the PBVT should be matched for optimum performance. This represents an additional specification for the PBVT
25 component particularly in view of the fact that antennas with both high output gain and impedance are preferred in order to maximize the overall voltage gain in the circuit. Care should be taken to the inherent losses in the PBVT. These influence both its filter and transformer characteristics. For this reason, combinations of materials and acoustic modes which yield high Q-values are preferred. In this context,
30 piezoelectric transformers make use of ferroelectric materials such as of PZT, i.e. materials with very high piezoelectric coefficients which are needed for high power applications. Such materials, however, are very lossy, particularly at RF frequencies

which makes them unsuitable for the current innovation. The integration time interval is another important design parameter which together with the overall voltage gain of the circuit determine the maximum range achievable.

With regard to the antenna 210, in addition to the output impedance considerations
5 given above, it is preferable that it has as high a gain as possible in view of the size limitations dictated by the specific applications. In cases, where omni-directionality is essential omnidirectional or even multiple antennas may be used.

With regard to the RF rectifier 220, a low loss, low threshold, full cycle rectification is preferred.

10 The switch 230 follows previous art with regard to the electronic switch in the cases the latter design involves semiconductor components. Thus, low threshold logical CMOS elements such as AND, NAND, OR, NOR, inverters, etc are typically employed to define the common logical output of the MRST switch (see FIG. 1b) the common output of which is then used to turn the sleeping device on. It is also
15 preferable that these logical elements have a low input capacitance.

Further, the RTS according to the present invention pertains to the use of both normally open (logical 1) and normally closed (logical 0) voltage triggered switches at the output of each RTS channel in any given MRTS configuration. A typical example of such switches are capacitive MEMS switches. Connected serially, these
20 switches represent the hard coded digital address of the MRTS switch. By way of example, the combination of one normally open and one normally closed switches represents the binary address (1,0). Hence, if frequency f_1 is present and frequency f_2 is not present in the interrogation signal the serially connected switches will close an external circuit and in this way turn the sleeping device on. Clearly, in this case the
25 MRTS switch is totally passive and does not consume any power on the receiver side. The design of the MEMS switches is left to the user since the specific application determines the maximum voltage and the energy accumulated at the output each RTS switch which parameters are subsequently taken into consideration in the MEMS design. Obviously, MEMS switches with both low switching voltages and low
30 capacitances are preferred.

Embodiments of the invention vary depending on the context of the application as described in the following illustrative but not limiting examples, representing different embodiments of the present invention:

i) The RTS switch in a truly passive configuration, illustrated in FIG: 2b.

- 5 For relatively short range applications, say up to a few meters, truly passive configurations are fully feasible. In this case the voltage triggered switch 230 is realized as a low threshold, low capacitance MEMS switch 231. The latter serves as a mechanical switch which is triggered when a certain voltage is attained at the capacitor.
- 10 Resetting the switch is effected through a shunt resistor (not shown) connected in parallel to the capacitor defining together with the latter a time constant much larger than the integration time interval defined by the specific application.

ii) The RTS switch in a semi-passive configuration, illustrated in FIG: 2c.

- For relatively long range applications the power received by the antenna may be
15 insufficient for the circuit to generate the voltage necessary to trigger a MEMS switch for which reason a capacitor connected to a low threshold, low input impedance electronic switch 232 is used instead. Resetting the switch is done analogously to the previous case.

- For very long range (high end) applications even this circuit may be inadequate in
20 which case the rectifier and the capacitor are replaced by an appropriate charge pump (not shown). The efficiency of the latter, however, decreases with voltage amplification which would necessitate even long integration time intervals.

iii) The RTS switch in a MRTS configuration, illustrated in FIG: 2d.

- The RTS switch may be expanded to a multi-channel configuration, referred to as a
25 MRST to provide ID functionality. This configuration may comprise two or more RTS switches connected in parallel all of which can have either of the previous two configurations. FIG. 2d illustrates schematically a MRTS 260 employing the fully passive RTS configuration for a 2-bit MRTS switch.

- The two PBVT components 211 and 212 are connected in parallel to the antenna and
30 are operated at two neighboring frequency channels, f_1 and f_2 respectively where f_1 is

the center frequency of channel 1 while f_2 is the center frequency of channel 2. Further, channel 1 resides in the out-of-band region of PBVT2 and vice versa, channel 2 resides in the out-of-band region of PBVT1. Since both MEMS switches chosen 231 and 232 are “normally off” then the above circuit represents the hard coded (1,1) address. In other words, the sleeping device will be awoken if and only if both frequencies are present in the interrogation signal during the required integration time interval. The implementation of other codes is readily achieved by replacing the corresponding “normally off” MEMS switch with a “normally on” one. Peculiar for the MRTS configuration is that each individual RTS, despite its channel residing in the out-of-band region of the other RTS switch, acts as a parasitic capacitance connected in parallel to the latter, which circumstance needs to be taken into account when designing the individual RTS switches. In reality, all RTS switches are to be designed together onto a single chip as a single component taking into account this type of parasitic impedance. The case where the MRTS switch consists of more than 2 RTS switches is treated analogously. It is also clear from the above example that the number of unique codes is equal to $2^n - 1$ where “n” is the number of channels used. By way of example, let us assume that a specific application requires a 10-bit addressing and operates in the 2.4 GHz ISM band with a bandwidth B of 83.5 MHz. This makes 8.35 MHz per channel or 0.35% fractional bandwidth. Filters with such bandwidths are readily achievable by both SAW and thin film Lamb wave technologies.

The case where the MRTS switch employs electronic switches instead of MEMS switches is treated as illustrated in FIG. 1b above. In other words, the outputs from capacitors are treated as an incoming digital address which compared with a hard coded digital logic which also provides recognition, i.e. the common output is “high” if and only if the incoming digital address and the hard coded address coincide. Clearly, in such an event the common output turns the sleeping device on.

iv) The RTS in an EM scavenging configuration, illustrated in FIG: 2d.

The rectifier 220 may be connected to a charge accumulator such as a large capacitor or a super capacitor or a rechargeable battery 234 or a series of rechargeable batteries. This embodiment does not provide a switching functionality, instead the PBVT 210 is via the rectifier 220 used to charge the accumulator 234. Here again, high end applications may require the use of a charge pump in place of the rectifier.

The PBVT according to the invention is schematically illustrated in FIG. 3a. The PBVT 310 comprises a piezoelectric plate 315, carrier substrate 302 a capacitive input electro-acoustic transducer 320, a capacitive output electro-acoustic transducer 325, the input and output transducers 320, 325 being provided on the same surface of the piezoelectric plate 315 (as illustrated), or alternatively on different surfaces. At least two reflectors 330, 335, or two sets of reflectors, are provided to the piezoelectric plate 315. The piezoelectric plate 315 is preferably a crystalline piezoelectric material from the list: quartz, LiTaO₃, LiNbO₃, GaAs, GaN, InN. Alternatively, and even more preferably the piezoelectric plate 315 is a thin polycrystalline piezoelectric film of the wurtzite crystallographic structure from the list AlN, ZnO, Al_xSc_{1-x}N, Al_xY_{1-x}N, GaN, InN, Al_xGa_{1-x}N, Al_xIn_{1-x}N.

Embodiments of the PBVT component employs either plate or SAW acoustic waves which are typically excited using inter-digital transducers (IDT) both of linear and circular type as illustrated in FIG. 3b and 3c. The inter-digital transducer, shown from a top view, comprises at least two parts of first 321 and second 322 polarity. As is known in the art the period of the IDT determines the wavelength of the acoustic wave λ which together with the acoustic wave velocity v determine the center frequency f of excitation given by: $f=\lambda/v$

A PBVT component according to the invention utilizing plate (Lamb) waves with a linear input and output IDT's is schematically illustrated in FIG. 3d. In this embodiment the input and output transducers 320, 325 are provided as IDT electrode configurations 326, 327 which are provided onto the surface of a thin piezoelectric plate 315 the thickness of which is comparable or smaller than the wavelength λ . The plate 315 is typically a piezoelectric thin film such as AlN, but can also be made of a single crystalline material. A two-port resonator is fabricated by defining acoustic reflectors 330, 335 on either side of the IDT. Typical reflectors represent a set of fingers of the same period as the fingers in the IDT 313 as illustrated in FIG. 3d. The fingers in the reflector are electrically isolated from the signal and are typically under floating potential. Another possibility is to perforate the piezoelectric plate 315 on either side of the IDT along straight lines parallel to the end fingers in the IDT's. Such discontinuities in the membrane act as effective reflectors of the plate wave. In either case the wave is reflected back into the region of generation defining an acoustic

resonator. Since the physical dimensions of the latter are of the order of a few square millimetres the resonator is typically fabricated on a carrier substrate 302. It is, therefore, necessary to provide acoustic isolation of the resonator from the carrier substrate, which as known in the art is done by either defining an air gap 303 between
 5 the resonator and the carrier substrate or by defining an acoustic (Bragg) mirror.

One embodiment, schematically illustrated in FIG. 3e represents a two port resonator where the output IDT 314 is placed in the middle of the input IDT 316, 317 and typically consists of a single output electrode.

A PBVT component according to the present invention was fabricated according to
 10 the schematic layout illustrated in FIG. 4a. The output IDT 414 is surrounded by the two parts 416, 417 of the input IDT. Reflectors are provided as sets of fingers 431, 432 on respective sides of the input IDT 416, 417. FIG. 4b is a photograph of the fabricated resonator.

Table 1 summarizes the layout topology of the two-port resonator in the preferred
 15 embodiment.

Table 1. *Design layout parameters of fabricated PBVT component*

Plate material	c-textured AlN
Plate thickness	2 μm
Wavelength λ	12 μm
Electrode material	Aluminium
Metallization ratio	0.5
Electrode thickness	0.25 μm
IDT and reflector pitch	6 μm
Aperture	420 μm
Number of fingers in input IDT	30
Number of fingers in output IDT	1
Number of fingers in reflectors	53

At center frequency of 887 MHz the measured input impedance is 25Ω while the impedance of the output is 2600Ω .

FIG. 5a-b shows both the measured transfer filter characteristic (a) and the measured voltage characteristics (b) at center frequency of 887 MHz and open load. The fractional bandwidth at 3 dB is 0.6%. Further, the measured data has been used in an ADS circuit simulator to evaluate its performance in a realistic radio triggered switch as illustrated in 5 c-d FIG. 5c illustrates the simulated circuit in ADS. Input RF source: $Z=25\Omega$, $P=100\mu W$, $f=887\text{Mhz}$. FIG. 5d is a graph over the rectified output voltage at the output capacitor as a function of time at 887 MHz. The lower curve is the simulation without the PBVT while the upper curve is the simulation with the PBVT.

In conclusion, FIG. 5a-b demonstrates clearly the functional characteristics of the fabricated resonator, namely being a bandpass filter and an efficient transformer at the same time with a voltage ratio of 10. FIG. 5c-d demonstrates unequivocally the proper functioning of a PBVT where the voltage and the energy accumulated at the output capacitor are increased 8-fold and 64-fold respectively. Obviously, a full cycle rectification would yield another 2-fold increase of the output voltage and another 4-fold of the output energy. A further 2-fold improvement of the transformer ratio according to the current innovation is achieved by splitting the output electrode into two acoustically connected half-electrodes 613, 614 and an intermediate floating electrode 612 as illustrated in FIG. 6.

The above described PBVT component serves to illustrate one specific implementation. As apparent for the skilled person there exist a range of possible variations and optimizations that can be implemented. For instance, the design of both the input and the output transducers, in the case of Lamb and SAW families, could also be done in a multi-electrode configuration. Specifically, an IDT design could employ an either electrically open (top figure), grounded (middle figure) or electrically floating electrode (bottom figure) defined onto the opposite to the IDT side of the plate as illustrated in FIG. 7a.

In such a multi-electrode configuration the PBVT central frequency is determined by the transducers periodicity “p” and/or by the plate thickness “d”, while the output-to-input impedance ratio is determined by the number N and the width “a” of the electrodes in each transducer in addition to the piezoelectric coupling and dielectric permittivity of the chosen piezoelectric wave and substrate respectively. Energy in the PBVT structure is confined by fixed or distributed reflectors to ensure low loss transformation.

Figure 7b illustrates an alternative embodiment wherein the input and output transducers 626, 614 are provided next to each other, with the reflectors 631, 632 on the outside. Varying the gap between the input and output transducers provides additional design flexibility.

A further possible implementation for the PBVT component is a modification of the Rosen type of piezoelectric transformers[C. A. Rosen, "Ceramic Transformers and Filters," *Proc. Electronic Comp. Symp.*, pp. 205- 211, 1956] and is schematically illustrated in FIG. 8. In this embodiment the PBVT component 810 exhibits a input transducer is a parallel plate capacitor 830 while the output transducer 840 is of similar type. This type transformers require polarization along the thickness of both the input and output capacitors. Therefore, according to the present embodiment, the piezoelectric plate 815 is made of thin piezoelectric films of the wurtzite crystallographic structure with a tilted c-axis relative to the film surface. The synthesis of such films has already been demonstrated experimentally[I.Katardjiev, J.Bjurström, G.Wingqvist, *Production of polycrystalline films for shear mode piezoelectric thin film resonators*, PCT/SE2006/050041, 2006].

Other implementations employing existing design approaches to piezoelectric transformers are also plausible where the preferred implementation would involve the use of thin piezoelectric films as disclosed in the application.

The properties of most piezoelectric materials employed in the art vary with temperature which has the effect of altering the acoustic velocity and hence the resonance frequency of resonant devices. The materials are said to have a negative coefficient of frequency (TCF), that is, the resonant frequency decreases with temperature. This is an undesirable effect since it causes variation of the center

frequency of the PBVT limiting thus the usable bandwidth. This problem is to a large extent alleviated by designing composite resonators where the latter in addition to the piezoelectric layer contains a dielectric material with a positive TCF [*Wingqvist G.; Arapan L.; Yantchev V.; Katardjiev I.," Temperature Compensation of Thin AlN Film Resonators utilizing the Lowest order Symmetric Lamb mode", Proceedings of the ULTRASONICS SYMPOSIUM Page: 1207, year: 2008*]. A common material with a positive TCF often used in this context is SiO₂. Thus, the current innovation makes use of this method to compensate the temperature variation of frequency as illustrated in FIG. 9, wherein a layer of a positive TCF material 903, for example thermally grown SiO₂ has been provided between the substrate 902 and the piezoelectric plate 915.

The invention described above is based on the use and design of the piezoelectric bandpass voltage transformer in combination with other electronic elements. In certain applications the piezoelectric bandpass voltage may be used as an individual component. An embodiment of the invention is a passive multichannel voltage amplifier, wherein two or more piezoelectric bandpass voltage transformers 310 are combined in the same way as the device described with reference to FIG. 2d, but in combination with other electronic elements than the described. All embodiments relating to the different variations of piezoelectric bandpass voltage transformer 310 are relevant also for the passive multichannel voltage amplifier.

While the invention has been described in connection with what is presently considered to be the most practical and preferred embodiments, it is to be understood that the invention is not to be limited to the disclosed embodiments, on the contrary, is intended to cover various modifications and equivalent arrangements within the appended claims.

CLAIMS

1. A radio triggered switch (200) comprising a RF antenna (205), a RF rectifier (220), an accumulator (225), and a voltage triggered switch (230) **characterized by** a piezoelectric bandpass voltage transformer (210) providing piezoelectric voltage transformation and bandpass RF filtering in the same component, the piezoelectric bandpass voltage transformer (210) having an output electrical impedance is larger than its input electrical impedance.
2. The radio triggered switch (200) according to claim 1, **wherein** the piezoelectric bandpass voltage transformer (210) comprises a piezoelectric plate (315) of a piezoelectric material, a capacitive input electro-acoustic transducer (320) and a capacitive output electro-acoustic transducer (325).
3. The radio triggered switch (200) according to claim 2, **wherein** the piezoelectric material of the piezoelectric plate (315) is a single crystalline piezoelectric material from the list:
quartz, LiTaO₃, LiNbO₃, GaAs, GaN, InN.
4. The radio triggered switch (200) according to claim 2, **wherein** the piezoelectric plate (315) is a c-textured thin polycrystalline piezoelectric film of the wurtzite crystallographic structure from the list:
AlN, ZnO, Al_xSc_{1-x}N, Al_xY_{1-x}N, GaN, InN, Al_xGa_{1-x}N, Al_xIn_{1-x}N.
5. The radio triggered switch (200) according to claim 4, **wherein** the c-axis of the thin polycrystalline piezoelectric film forms a non-zero angle with the normal to film surface.
6. The radio triggered switch (200) according to any of claims 3-5, **wherein** the piezoelectric material is combined with a dielectric material to provide temperature compensation.

7. The radio triggered switch (200) according to claim 2, **wherein** the capacitive input electro-acoustic transducer (320) and the capacitive output electro-acoustic transducer (325) are linear inter-digital transducers.
8. The radio triggered switch (200) according to claim 2, **wherein** the capacitive input electro-acoustic transducer (320) and the capacitive output electro-acoustic transducer (325) are circular inter-digital transducers.
9. The radio triggered switch (200) according to claims 7 or 8, **wherein** the capacitive input electro-acoustic transducer (320) and the capacitive output electro-acoustic transducer (325) are single pair inter-digital transducers.
10. The radio triggered switch (200) according to claim 2, **wherein** the capacitive input electro-acoustic transducer (830) and the capacitive output electro-acoustic transducer (840) forms a parallel plate capacitor.
11. The radio triggered switch (200) according to claim 2, **wherein** the capacitive input electro-acoustic transducer (320) and the capacitive output electro-acoustic transducer (325) have a common electrode.
12. The radio triggered switch (200) according to claim 2, **wherein** the piezoelectric bandpass voltage transformer (210) is a two-port acoustic resonator.
13. The radio triggered switch (200) according to claim 2, **wherein** the piezoelectric bandpass voltage transformer (210) is a multi-port acoustic resonator.
14. A multi-channel radio triggered switch (260) comprising two or more radio triggered switches (200) according to any of claims 1-13, **wherein** each of the two or more radio triggered switches (200) are adapted to

different center frequencies.

15. The multi-channel radio triggered switch (260) according to claim 14, **wherein** the two or more radio triggered switches (200) are connected to a common antenna.
16. The multi-channel radio triggered switch (260) according to claim 14, **wherein** the multi-channel radio triggered switch (260) has a common electrical output.
17. The multi-channel radio triggered switch (260) according to claim 14, **wherein** the multi-channel radio triggered switch (260) first said output is a digital function of the output signals of the individual first said RTS's.
18. The radio triggered switch (200) according to claim 2, **wherein** the accumulator (225) and the voltage triggered switch (230) are replaced by a charge accumulator (234), thereby providing an energy scavenging device.
19. The radio triggered switch (200) according to claim 2, **wherein** the voltage triggered switch (230) is a capacitive micro-electro-mechanical-system switch (231).
20. A passive multichannel voltage amplifier **characterized in** that it **comprises** two or more piezoelectric bandpass voltage transformer (310) providing piezoelectric voltage transformation and bandpass RF filtering in the same component, the piezoelectric bandpass voltage transformer (210) having an output electrical impedance is larger than its input.
21. The passive multichannel voltage amplifier according to claim 20, **wherein** the piezoelectric bandpass voltage transformer (310) comprises a piezoelectric plate (315) of a piezoelectric material, a capacitive input electro-acoustic transducer (320) and a capacitive output electro-acoustic

transducer (325).

22. The passive multichannel voltage amplifier according to claim 20, **wherein** the piezoelectric material of the piezoelectric plate (315) is a single crystalline piezoelectric material from the list:
quartz, LiTaO₃, LiNbO₃, GaAs, GaN, InN.
23. The passive multichannel voltage amplifier according to claim 20, **wherein** the piezoelectric plate (315) is a c-textured thin polycrystalline piezoelectric film of the wurtzite crystallographic structure from the list:
AlN, ZnO, Al_xSc_{1-x}N, Al_xY_{1-x}N, GaN, InN, Al_xGa_{1-x}N, Al_xIn_{1-x}N.
24. The passive multichannel voltage amplifier according to claim 23, **wherein** the c-axis of the thin polycrystalline piezoelectric film forms a non-zero angle with the normal to film surface.
25. The passive multichannel voltage amplifier according to any of claims 23-25, **wherein** the piezoelectric material is combined with a dielectric material for temperature compensation.
26. The passive multichannel voltage amplifier according to claim 20, **wherein** the capacitive input electro-acoustic transducer (320) and the capacitive output electro-acoustic transducer (325) are linear inter-digital transducers.
27. The passive multichannel voltage amplifier according to claim 20, **wherein** the capacitive input electro-acoustic transducer (320) and the capacitive output electro-acoustic transducer (325) are circular inter-digital transducers.
28. The passive multichannel voltage amplifier according to claims 26 or 27, **wherein** the capacitive input electro-acoustic transducer (320) and the

capacitive output electro-acoustic transducer (325) are single pair inter-digital transducers.

29. The radio triggered switch (200) according to claim 20, **wherein** the capacitive input electro-acoustic transducer (320) and the capacitive output electro-acoustic transducer (325) forms a parallel plate capacitor.
30. The passive multichannel voltage amplifier according to claim 20, **wherein** the capacitive input electro-acoustic transducer (320) and the capacitive output electro-acoustic transducer (325) have a common electrode.
31. The passive multichannel voltage amplifier according to claim 20, **wherein** the piezoelectric bandpass voltage transformer (210) is a two-port acoustic resonator.
32. The passive multichannel voltage amplifier according to claim 20, **wherein** the piezoelectric bandpass voltage transformer (210) is a multi-port acoustic resonator.
33. The passive multichannel voltage amplifier according to claim 20, **wherein** each of the piezoelectric bandpass voltage transformers (310) are adapted to different center frequencies and whose inputs are connected to a common antenna.
34. The passive multichannel voltage amplifier according to claim 20, wherein each of the piezoelectric bandpass voltage transformers (310) are adapted to the same center frequency and whose inputs are connected to separate antennas.

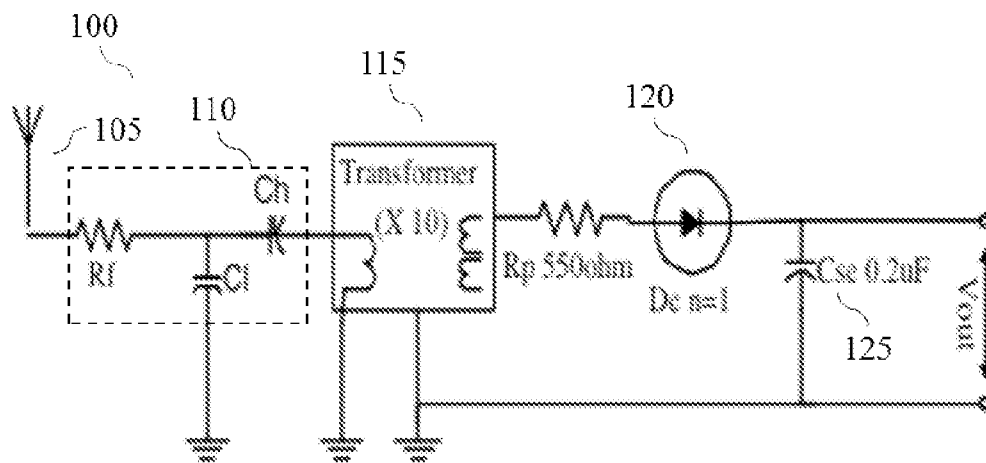


Figure 1a (Prior Art)

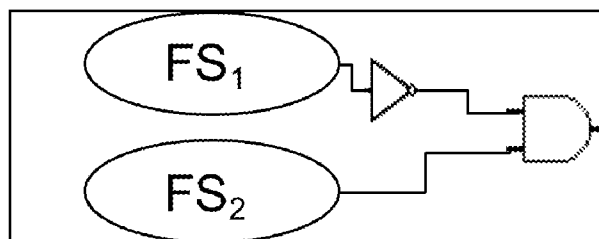
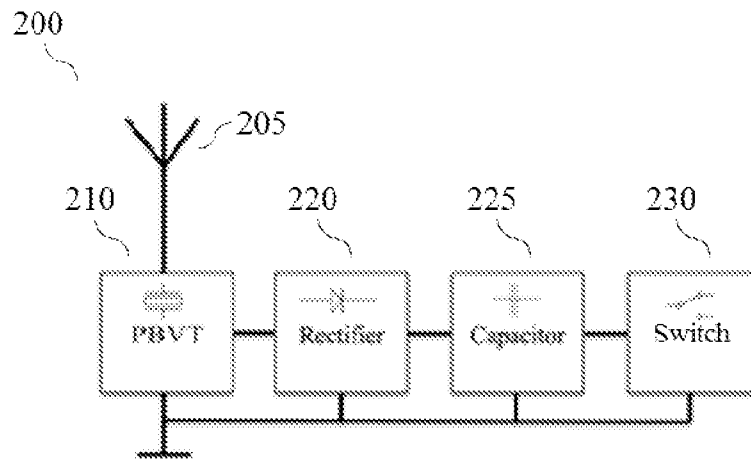
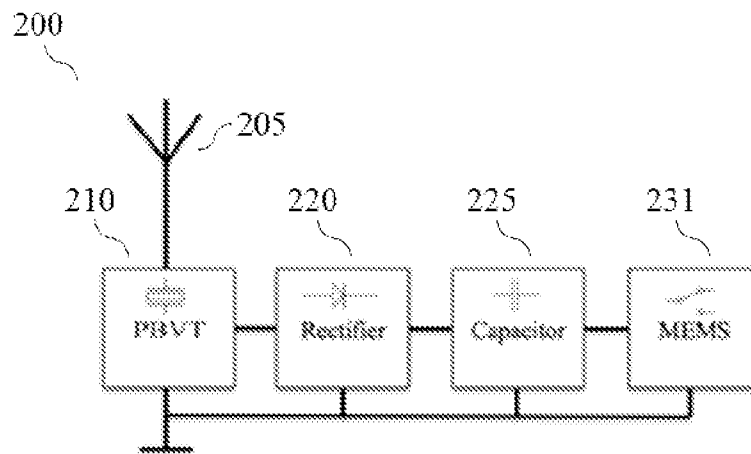
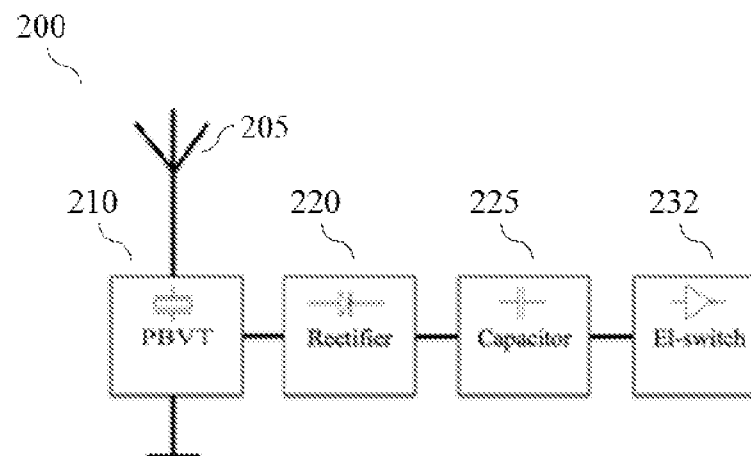


Figure 1b (Prior Art)

*Figure 2a**Figure 2b**Figure 2c*

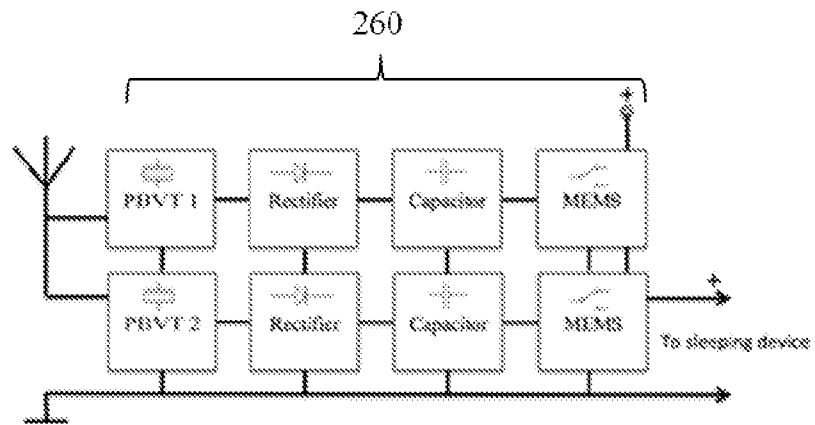


Figure 2d

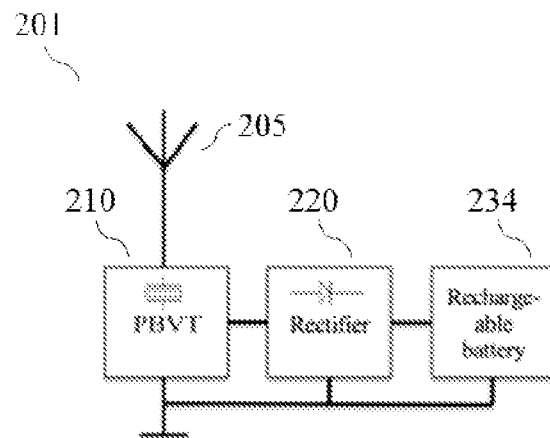


Figure 2e



Figure 3a

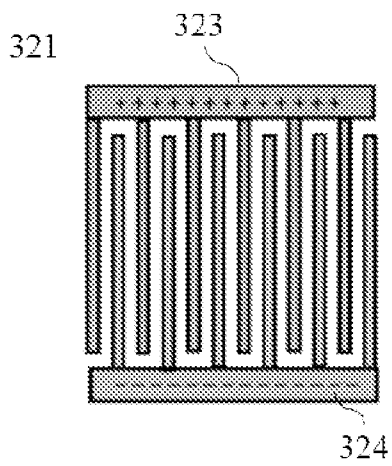


Figure 3b

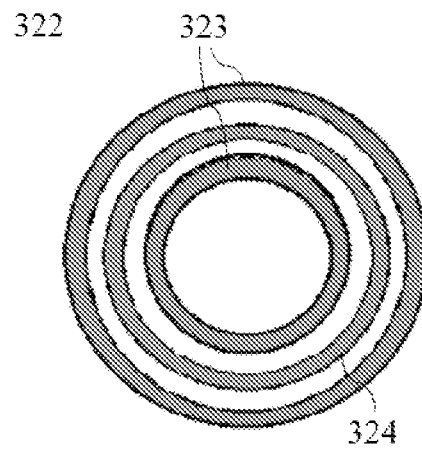


Figure 3c

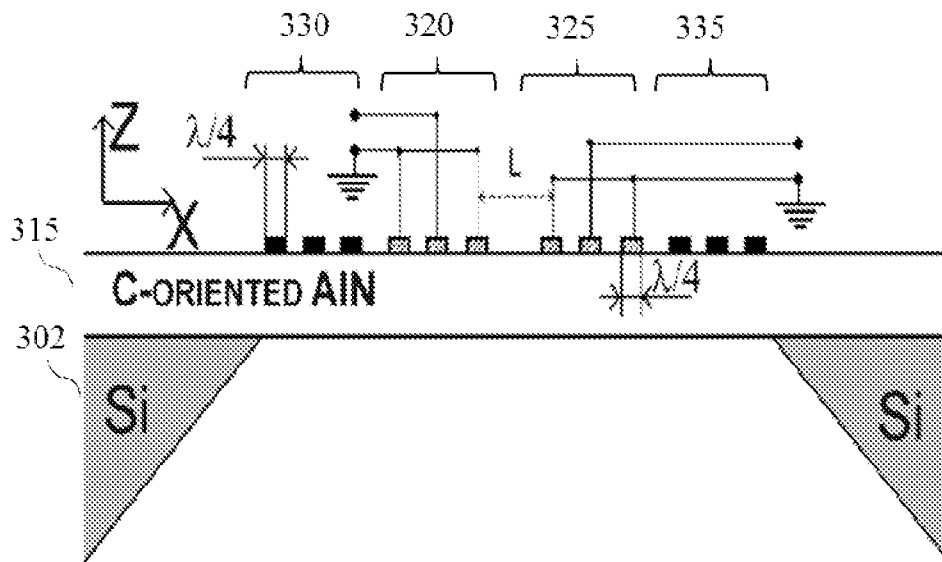


Figure 3d

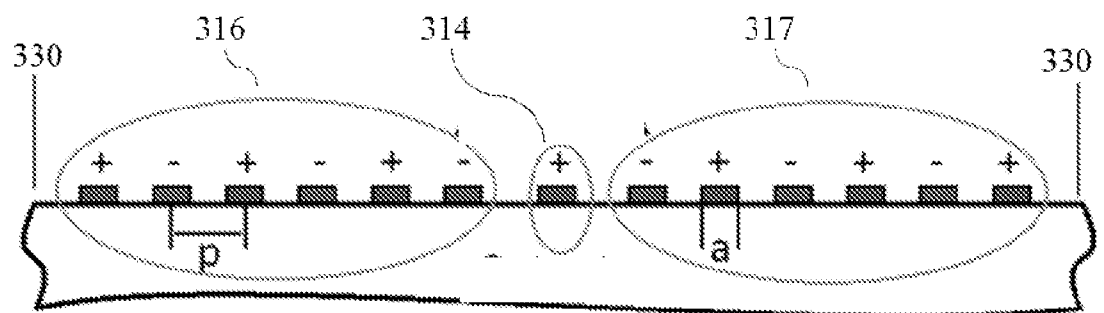
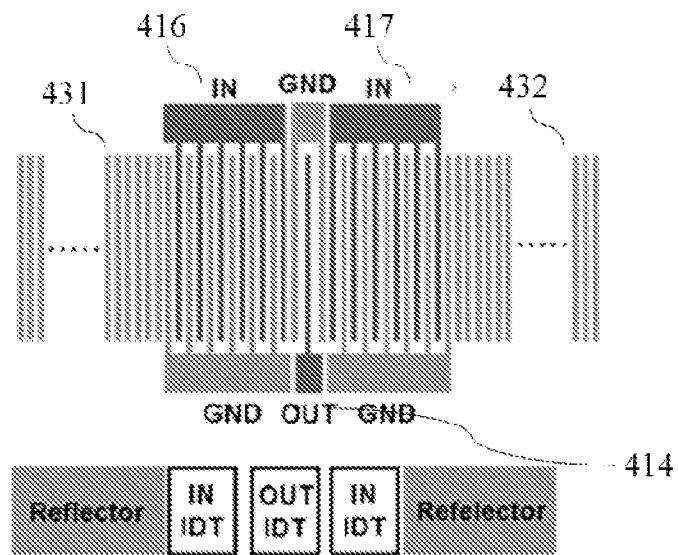
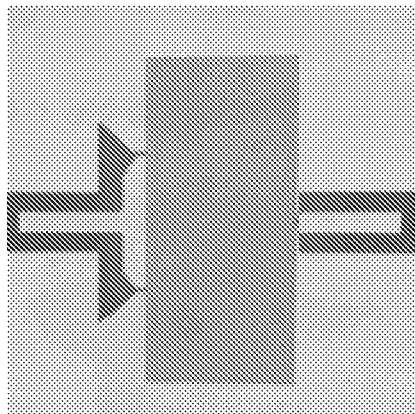
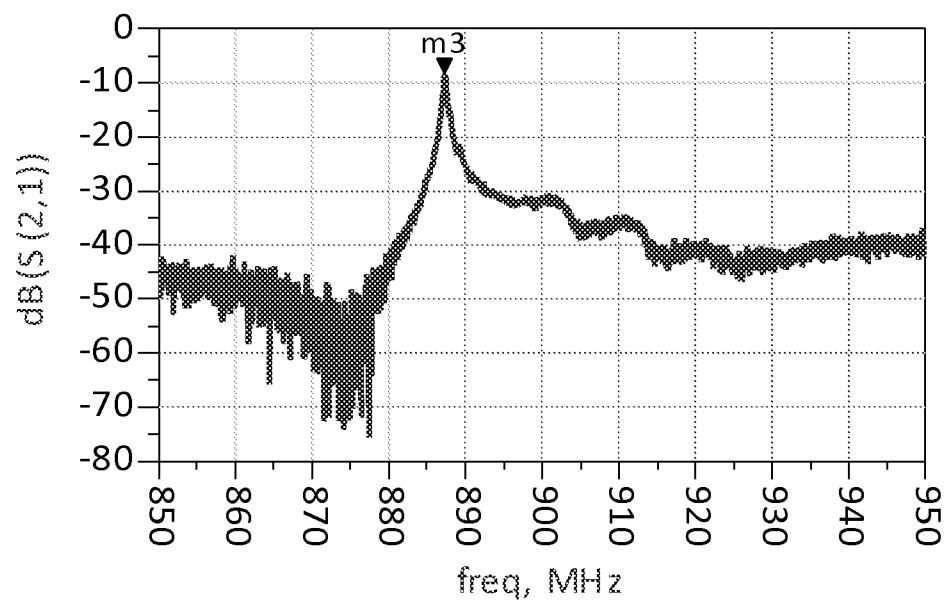
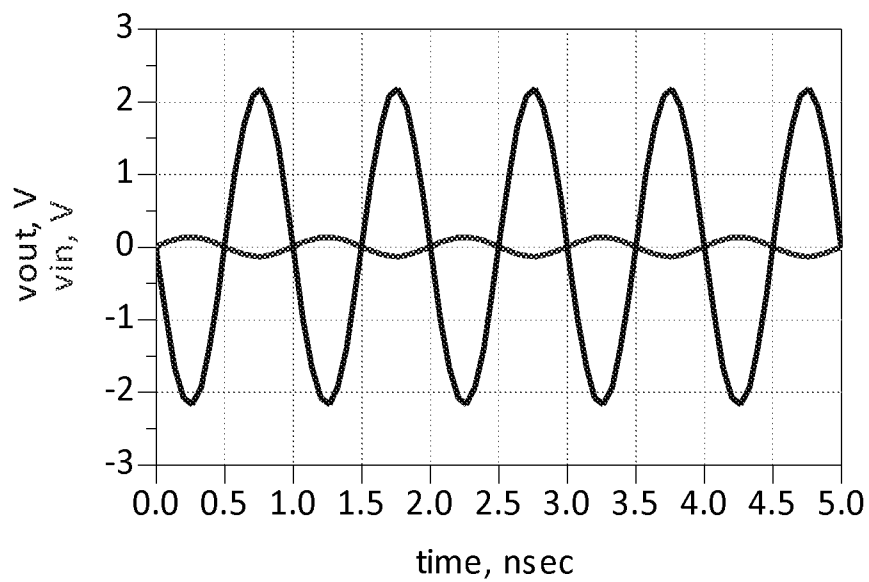
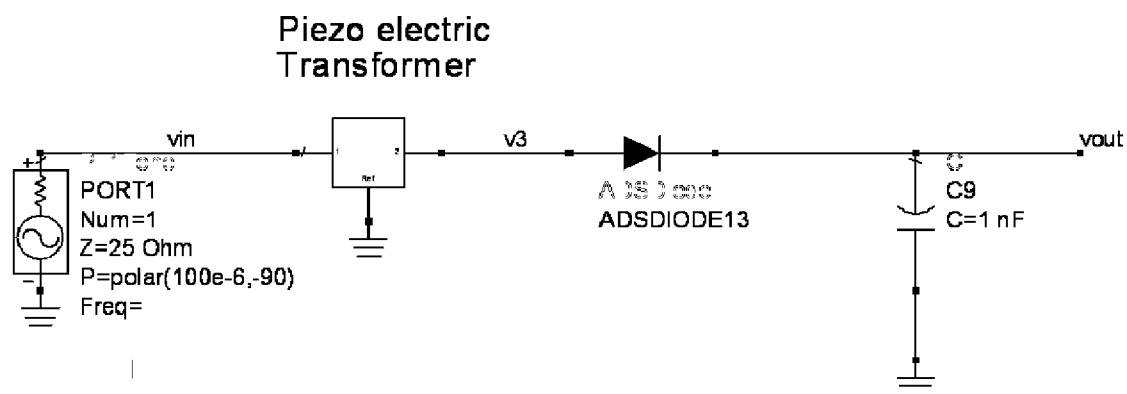
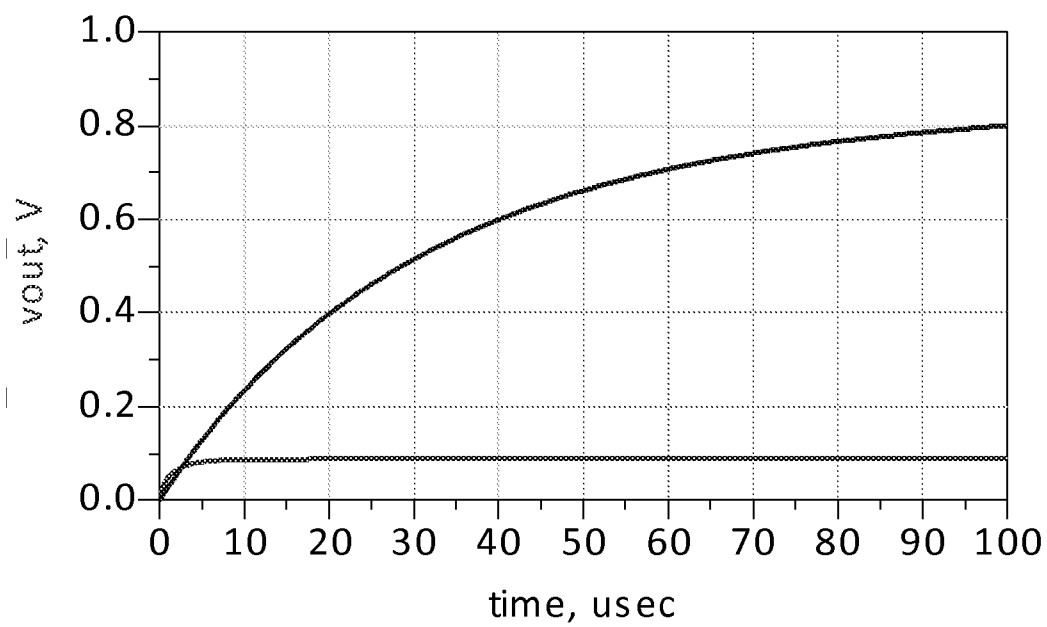


Figure 3e

*Figure 4a**Figure 4b*

*Figure 5a**Figure 5b*

*Figure 5c**Figure 5d*

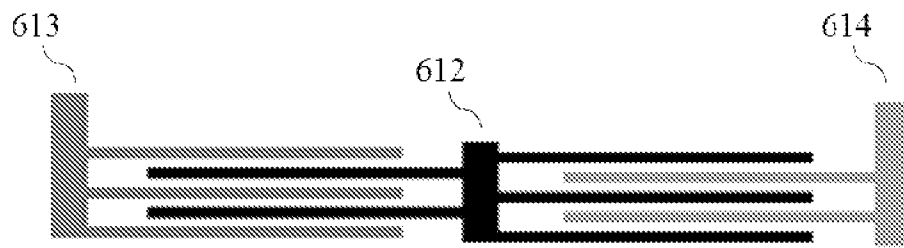


Figure 6

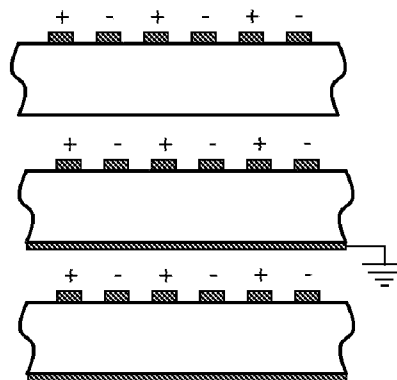


Figure 7a

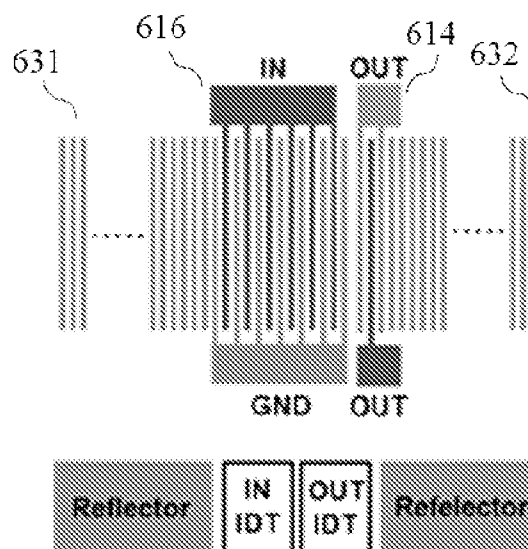
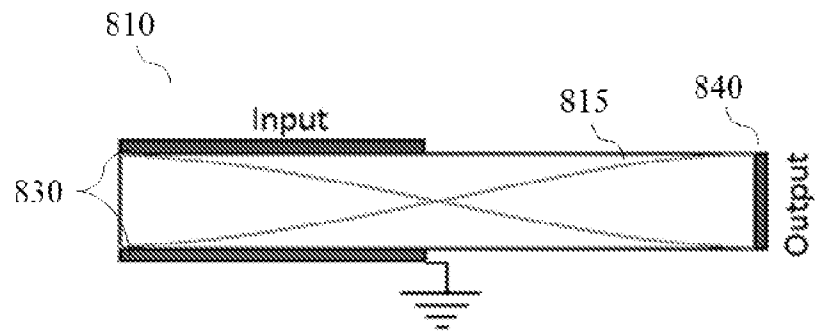
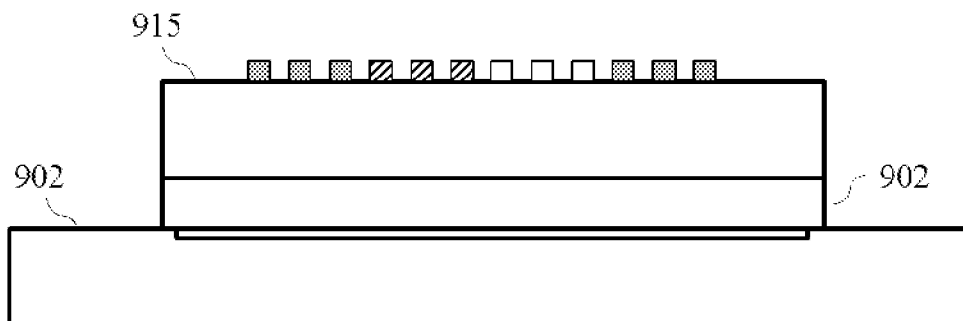


Figure 7b

*Figure 8**Figure 9*