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(54) **Frequency divider with variable capacitance.**

(57) A frequency divider (10) includes an inductor (L) connected in parallel with a variable capacitance (C) to define a resonant circuit for detecting electromagnetic radiation (34) at a first predetermined frequency and for responding to said detection by transmitting electromagnetic radiation (38) at a second frequency that is one-half the first frequency, with the circuit being resonant at the second frequency when there is zero voltage across the capacitance. The variable capacitance includes a lamination of an insulation material (12) and a semiconductor material (14) disposed between metal terminals (16, 18), such that as a voltage applied across the terminals (16, 18) varies, a concentration of charge carriers in a region (24) of the semiconductor material adjacent the insulation material (12) varies to thereby vary the value of said capacitance.

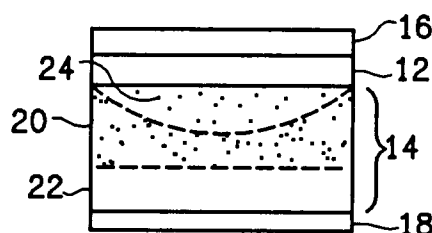


FIG. 2B

BACKGROUND OF THE INVENTION

The present invention generally pertains to frequency dividers and is particularly directed to frequency dividers of the type that are included in tags that are used in presence detection systems for electronic article surveillance (EAS) applications.

Frequency dividers for EAS applications are described in U.S. Patent No. 4,670,740 to Fred Wade Herman and Lincoln H. Charlot, Jr., U.S. Patent No. 5,065,137 to Fred Wade Herman and U.S. Patent No. 5,065,138 to Ming Lian and Fred Wade Herman.

The frequency dividers described in the above-referenced patents include a varactor diode in a resonant circuit for converting electromagnetic radiation of a first predetermined frequency into electromagnetic radiation of a second frequency that is one-half the first frequency.

The frequency divider described in the '740 patent consists of a single resonant circuit consisting of an inductor and a varactor diode connected in parallel with the diode to define a resonant circuit that detects electromagnetic radiation at a first predetermined frequency and responds to said detection by transmitting electromagnetic radiation at a second frequency that is one-half the first frequency, wherein the circuit is resonant at the second frequency when the voltage across the diode is zero. A varactor diode is a diode having a relatively high rate of change of capacitance with respect to change of voltage characteristic, dC/dV , at the zero-crossing axis. The efficiency of a frequency divider including a varactor diode depends upon how much the capacitance value of the diode varies with the junction voltage across the diode, with the frequency divider being more efficient at higher values of dC/dV .

However, a varactor diode starts to conduct in a forward direction when a positive voltage is applied to its anode relative to its cathode, such that the forward current in a varactor included in a resonant circuit of a frequency divider contributes a loss of energy that reduces the conversion efficiency of the frequency divider. The forward current increases exponentially with the junction voltage applied across the anode and cathode of the diode and eventually becomes so overwhelming as to prevent frequency division.

SUMMARY OF THE INVENTION

The present invention provides a frequency divider comprising an inductor connected in parallel with a capacitance to define a resonant circuit for detecting electromagnetic radiation at a first predetermined frequency and for responding to said detection by transmitting electromagnetic radiation at a second frequency that is one-half the first frequency, with the circuit being resonant at the second frequency when there is zero voltage across the capacitance, wherein

the capacitance comprises a lamination of an insulation material and a semiconductor material disposed between metal terminals, such that as a voltage applied across the terminals varies, a concentration of charge carriers in a region of the semiconductor material adjacent the insulation material varies to thereby vary the value of said capacitance.

No forward current can flow through such a capacitance because of the layer of insulation material prevents the formation of a p-n rectifying junction.

Also the rate of change of capacitance is orders of magnitude higher than that in presently available varactor diodes, whereby the efficiency of the frequency divider is greatly enhanced.

The frequency divider of the present invention is capable of operating solely in response to the electromagnetic radiation received at the first predetermined frequency; and the preferred embodiment of the frequency divider is both batteryless and portable.

The present invention further provides a presence detection system utilizing a portable, batteryless frequency divider according to the present invention as a transponder tag.

Additional features of the present invention are described in relation to the description of the preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWING

Figure 1 is a schematic circuit diagram of a preferred embodiment of a frequency divider according to the present invention, including a variable capacitance element in a resonant circuit.

Figure 2A is a sectional view of a capacitance element included in the frequency divider of Figure 1, without a voltage being applied across the terminals.

Figure 2B is a sectional view of the capacitance element of Figure 2A, when a voltage is applied across the terminals to deplete the concentration of charge carriers in the region of the semiconductor material adjacent the insulation material and thereby decrease the capacitance.

Figure 2C is a sectional view of a capacitance element of Figure 2A, when a voltage is applied across the terminals to enhance the concentration of charge carriers in the region of the semiconductor material adjacent the insulation material and thereby increase the capacitance.

Figures 2A, 2B and 2C are not drawn to scale.

Figure 3 is a diagram of a presence detection system according to the present invention including a tag including a frequency divider according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to Figure 1, a preferred embodiment of a frequency divider according to the present invention includes an inductance coil L connected in parallel with a variable capacitance C to define a resonant circuit 10. The values of the inductance L and the capacitance C are chosen to define a parallel resonant circuit 10 for detecting electromagnetic radiation at a first predetermined frequency and for responding to said detection by transmitting electromagnetic radiation at a second frequency that is one-half the first frequency, with the circuit 10 being resonant at the second frequency when there is zero voltage across the capacitance C.

Referring to Figure 2A, the capacitance C is a variable capacitance element consisting of a lamination of a dielectric insulation material 12 and a semiconductor material 14 disposed between a first metal terminal 16 and a second metal terminal 18. The semiconductor material 14 comprises a lightly doped epitaxial layer 20 adjacent the insulation material 12 and a heavily doped substrate 22 between the lightly doped layer 20 and the second metal terminal 18. Such doping substantially decreases the series resistance in the semiconductor material 14.

The maximum value of the capacitance C is determined by the area of the first metal terminal 16 and the thickness and dielectric constant of the insulation material 12.

In an embodiment of the capacitance element C in which the semiconductor material 14 is n-type silicon, when a negative voltage is applied to the first metal terminal 16 relative to the second metal terminal 18, charge carriers in the lightly doped epitaxial layer 20 are repelled from the interface of the insulation material and the lightly doped epitaxial layer 20 to deplete the concentration of charge carriers in the lightly doped epitaxial layer 20 in a region 24 adjacent the insulation material 12, as shown in Figure 2B. This depletion of charge carriers exposes silicon ions in the region 24 to thereby establish a second capacitance in series with a first capacitance established by the insulation material layer 12, whereby the overall capacitance of the variable capacitance element C is decreased. As the voltage applied to the first metal terminal 16 becomes more negative, the overall capacitance of the capacitance element C decreases. When a positive voltage is applied to the first metal terminal 16 relative to the second metal terminal 18, charge carriers in the lightly doped epitaxial layer 20 are attracted to the interface of the insulation material and the lightly doped epitaxial layer 20 to enhance the concentration of charge carriers in the lightly doped epitaxial layer 20 in the region 24, as shown in Figure 2C. This enhancement of charge carriers reduces the region of the exposed ions and in-

creases the overall capacitance of the capacitance element C as the voltage applied to the first metal terminal becomes more positive.

In an alternative embodiment of the capacitance element C in which the semiconductor material 14 is p-type silicon, when a positive voltage is applied to the first metal terminal 16 relative to the second metal terminal 18, charge carriers in the lightly doped epitaxial layer 20 are repelled from the interface of the insulation material and the lightly doped epitaxial layer 20 to deplete the concentration of charge carriers in the lightly doped epitaxial layer 20 in a region 24 adjacent the insulation material 12, as shown in Figure 2B. This depletion of charge carriers exposes silicon ions in the region 24 to thereby establish a second capacitance in series with a first capacitance established by the insulation material layer 12, whereby the overall capacitance of the variable capacitance element C is decreased. As the voltage applied to the first metal terminal 16 becomes more positive, the overall capacitance of the capacitance element C decreases. When a negative voltage is applied to the first metal terminal 16 relative to the second metal terminal 18, charge carriers in the lightly doped epitaxial layer 20 are attracted to the interface of the insulation material and the lightly doped epitaxial layer 20 to enhance the concentration of charge carriers in the lightly doped epitaxial layer 20 in the region 24, as shown in figure 2C. This enhancement of charge carriers reduces the region of the exposed ions and increases the overall capacitance of the capacitance element C as the voltage applied to the first metal terminal becomes more negative.

A frequency divider according to the present invention is utilized in a preferred embodiment of a presence detection system according to the present invention, as shown in Figure 3. Such system includes a transmitter 30, a transponder tag 31 and a detection system 32.

The transmitter 32 transmits an electromagnetic radiation signal 34 of a first predetermined frequency into a surveillance zone 36.

The tag 31 is attached to an article (not shown) to be detected within the surveillance zone 36. The tag 31 includes a batteryless, portable frequency divider in accordance with the present invention.

The detection system 32 detects electromagnetic radiation 38 in the surveillance zone 36 at a second predetermined frequency that is one-half the first predetermined frequency, and thereby detects the presence of the tag in the surveillance zone 36.

Claims

1. A frequency divider, (10), comprising an inductor (L) connected in parallel with a capacitance (C) to define a resonant circuit (10)

for detecting electromagnetic radiation (34) at a first predetermined frequency and for responding to said detection by transmitting electromagnetic radiation (38) at a second frequency that is one-half the first frequency, with the circuit being resonant at the second frequency when there is zero voltage across the capacitance,

wherein the capacitance comprises a lamination of an insulation material (12) a semiconductor material (14) disposed between metal terminals, (16, 18) such that as a voltage applied across the terminals varies, a concentration of charge carriers in a region (24) of the semiconductor material adjacent the insulation material varies to thereby vary the value of said capacitance.

2. A frequency divider according to Claim 1, wherein the semiconductor material (14) comprises a lightly doped epitaxial layer (20) adjacent the insulation material (12) and a heavily doped substrate (22) between the lightly doped epitaxial layer and one of the metal terminals. (18)

3. A frequency divider according to Claim 1 that is both batteryless and portable.

4. A presence detection system, comprising means (30) for transmitting an electromagnetic radiation signal (34) at a first predetermined frequency into a surveillance zone (36);

a tag (31) for attachment to an article to be detected within the surveillance zone (36), comprising a frequency divider (10) and means for fastening the frequency divider to an article to be detected by the presence detection system; wherein the frequency divider comprises

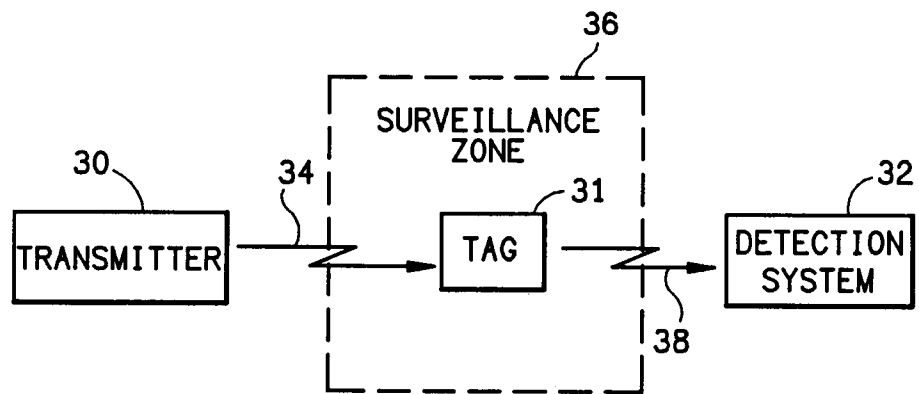
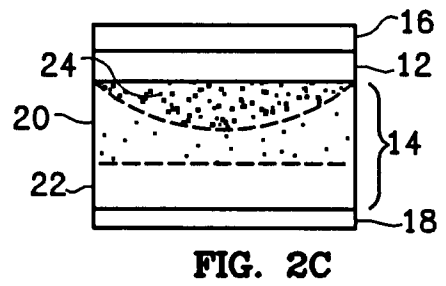
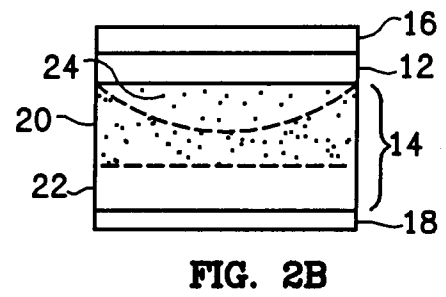
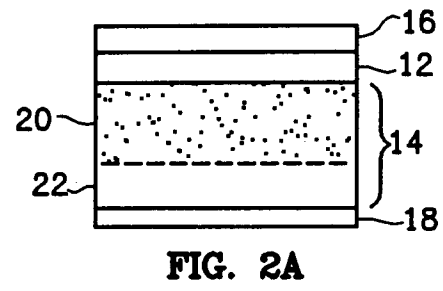
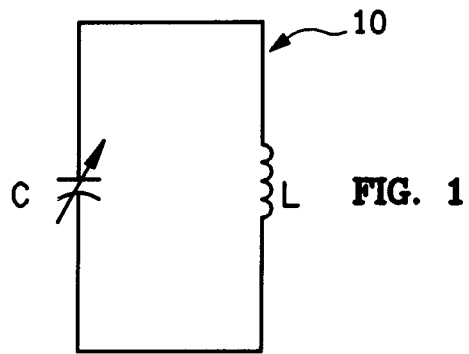
an inductor (L) connected in parallel with a capacitance (C) to define a resonant circuit for detecting electromagnetic radiation (34) at the first predetermined frequency and for responding to said detection by transmitting electromagnetic radiation (38) at a second frequency that is one-half the first frequency, with the circuit being resonant at the second frequency when there is zero voltage across the capacitance,

wherein the capacitance comprises a lamination of an insulation material (12) and a semiconductor material (14) disposed between metal terminals (16, 18), such that as a voltage applied across the terminals varies, a concentration of charge carriers in a region (24) of the semiconductor material adjacent the insulation material varies to thereby vary the value of said capacitance;

means (32) for detecting electromagnetic radiation (38) at the second frequency in the surveillance zone.

5. A system according to Claim 4, wherein the semiconductor material (14) comprises a lightly doped epitaxial layer (20) adjacent the insulation material (12) and a heavily doped substrate (22) between the lightly doped epitaxial layer and one of the metal terminals (18).

6. A system according to Claim 4, wherein the frequency divider is both batteryless and portable.





European Patent
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EUROPEAN SEARCH REPORT

Application Number

EP 93 30 1827

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
D,Y	US-A-4 670 740 (HERMAN ET AL.) * the whole document *	1-6	G08B13/24
Y	US-A-3 860 945 (DAWSON) * claims *	1-6	
A	US-A-3 634 738 (LEITH) * the whole document *	1	
A	EP-A-0 216 584 (SECURITY TAG SYSTEMS)		
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			G08B
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 02 JULY 1993	Examiner REEKMANS M.V.
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p>			

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