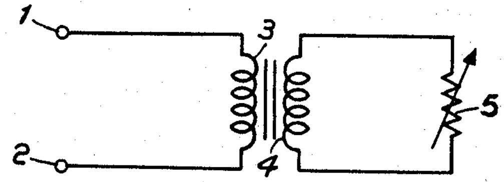
Dec. 10, 1968 L. M. VALLESE 3,416,105

VARIABLE REACTANCE ELEMENT

Filed April 21, 1966 2 Sheets-Sheet 1

Fig. 1a



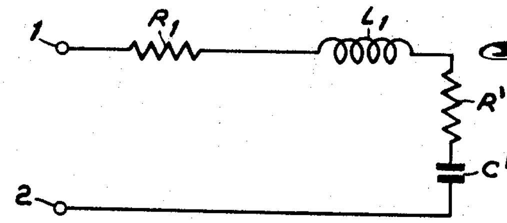


Fig. 1b

Fig. 2

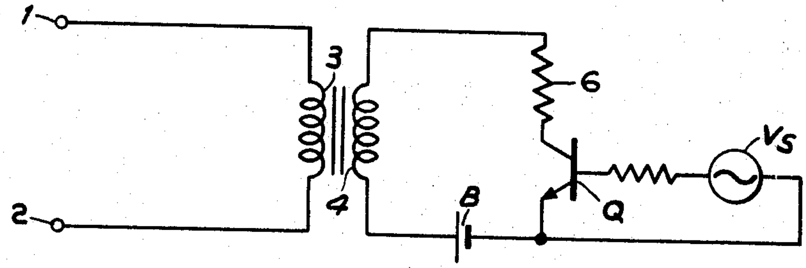


Fig. 4

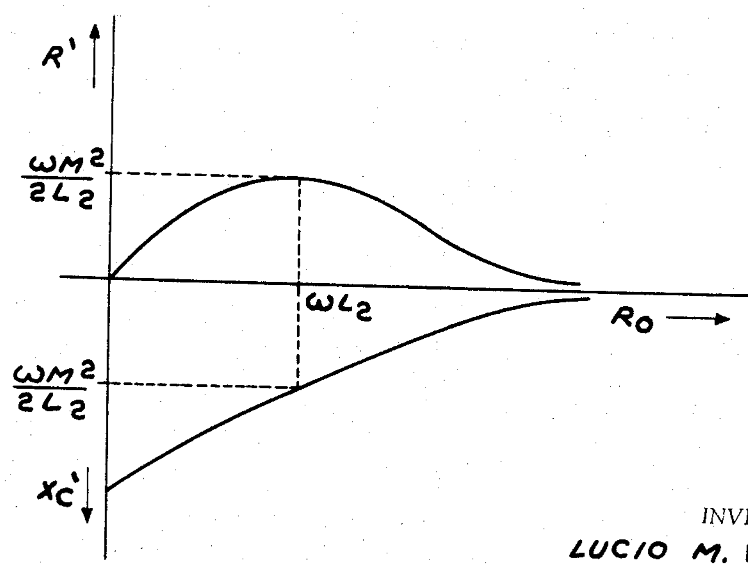


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Fig. 3a

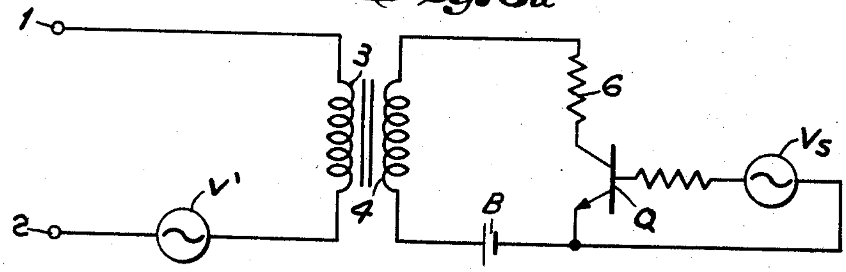


Fig. 3b

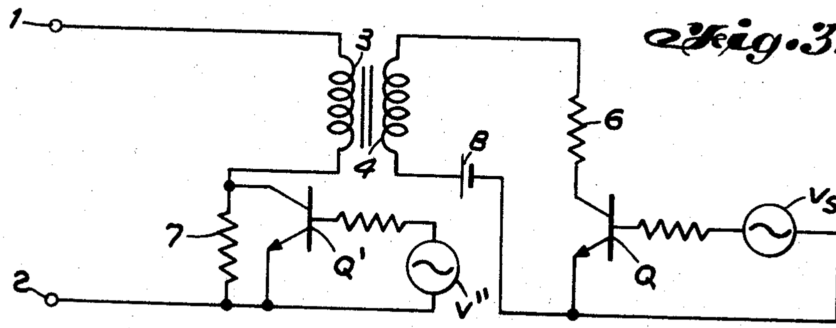


Fig. 3c

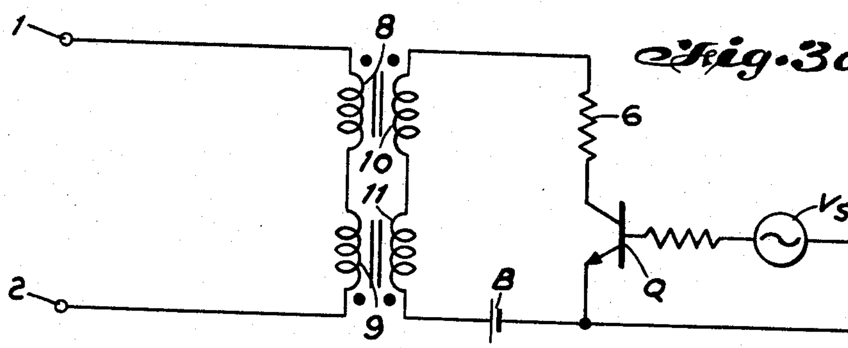
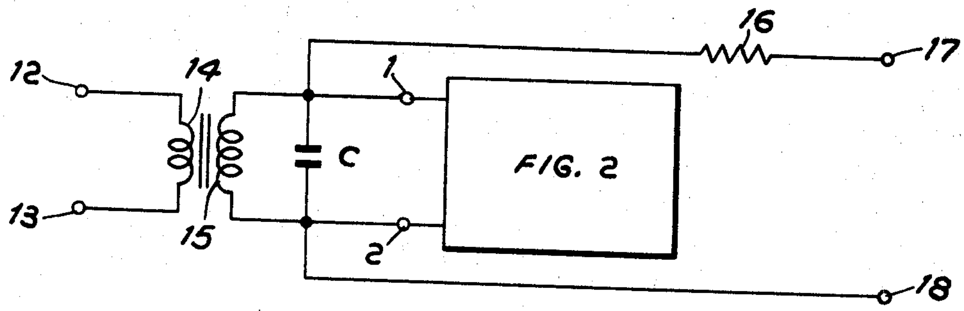


Fig. 5



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VARIABLE REACTANCE ELEMENT

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ABSTRACT OF THE DISCLOSURE

This is a nonlinear reactance element having a variable resistance element in series with the secondary of a transformer whereby variations in the resistance element produces variations of inductive reactance at the primary terminals of the transformer. Negative resistance means are electrically coupled to the primary winding in order to reduce the effective reflected resistance from the secondary to the primary terminals.

This invention relates to variable reactance circuit elements and more particularly to an improved electrically variable inductive reactance circuit element.

Electrically controllable inductive reactance circuit elements are widely utilized in frequency modulation transmission equipment, parametric amplifiers, tunable filters and parametron logic devices. These elements have heretofore been realized by electromechanical means, reactance tube techniques and ferrite devices.

Electromechanical techniques have been employed to change the mechanical parameters associated with an inductor in response to suitable electrical control signals. Such techniques have been limited to low frequency applications and been relatively unreliable, requiring relatively large amounts of power and occupying considerable space and weight.

Reactance tube techniques, while widely used in frequency modulators, require frequency sensitive phase shift networks to insure that the voltage and current applied to the reactance tube element remain 90° out of phase throughout the range of frequencies over which the device is to operate, and are thus unsuitable for broadband applications.

Ferrite inductors utilize the nonlinear B–H characteristic of the ferrite material to obtain a variation of incremental inductance as the bias current through the inductor surrounding the ferrite is varied. Such ferrite inductors are useful at only relatively low frequencies (a few megacycles) and are subject to inherent saturation effects.

Accordingly, an object of the present invention is to provide a variable inductive reactance circuit element which is capable of operating over a broad frequency band.

Another object of the invention is to provide an inductive reactance circuit element capable of operating at relatively high frequency and relatively insensitive to saturation effects.

These and other objects which will become apparent by reference to the following detailed description, the appended claims, and the accompanying drawings are realized by varying the resistive load in the secondary of a transformer in such a manner that the inductive reactance seen looking into the transformer primary varies in synchronism with the load resistance variation.

The invention will be more readily understood by reference to the following detailed description taken in conjunction with the accompanying drawing in which:

FIGS. 1*a* and 1*b* show the general principle of operation of an inductive reactance circuit element according to the invention.

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FIG. 2 shows a particular embodiment of a circuit element according to the invention.

FIGS. 3*a*, 3*b* and 3*c* show improved embodiments of inductive reactance circuit elements according to the invention.

FIG. 4 shows a diagram useful for purposes of explaining the invention.

FIG. 5 shows a parametron logic element incorporating an inductive reactance circuit element according to the invention.

FIG. 1*a* shows a transformer of the linear (i.e., having a linear B–H characteristic core) type consisting of first and second inductance elements **3** and **4** which have mutual inductance therebetween. A variable resistance element **5** is connected to the secondary inductance element **4**. The equivalent circuit for the network of FIG. 1*a* is shown in FIG. 1*b*, where R_1 and L_1 represent the resistance and reactive components of first inductance element **3**, and R′ and C′ represent the resistive and reactive components of driving point impedance (i.e., impedance seen looking into terminals **1** and **2**) reflected into the primary circuit by mutual coupling between the inductances. It may be readily shown that

$$R'=\frac{\omega^2M^2R_0}{R_0^2+\omega^2L_2^2};\ X_{c'}=-\frac{j\omega^3M^2L_2}{R_0^2+\omega^2L_2^2} \qquad (1)$$

where

ω equals the operating angular frequency.

M=the mutual inductance between the inductance elements.

R_0=the loop resistance in the transformer secondary circuit, i.e., the sum of the variable resistance **5** and the resistance of inductance element **4**.

L_2= the self-inductance of the inductance element **4**.

X_c'=the (capacitive) reactance reflected into the primary circuit.

By differentiating the expression for R′ with respect to R_0, it may be shown that when R_0 is equal to ωL_2

$$\left.\frac{\partial R'}{\partial R_0}\right|_{R_0=\omega L_2}=0 \qquad (2)$$

And also that

$$R'|_{R_0=\omega L_2}=X_{c'}|_{R_0=\omega L_2}=\frac{\omega M^2}{2L_2} \qquad (3)$$

Therefore if a value of the variable resistance element **5** is chosen such that the total secondary loop resistance is equal to the self-reactance of inductance element **4**, small variations of the resistance element **5** from this value will result in corresponding variation of the reflected capacitive reactance $X_{c'}$, while having substantially no effect on the reflected resistance R′. It may be readily shown that the capacitive reactance $X_{c'}$ is always less than the self-reactance of inductance element **3**, so that the reactive component of the driving point impedance seen looking into terminals **1** and **2** is always inductive.

Since under the foregoing conditions R′ is substantially equal to $X_{c'}$ the quality factor of the variable inductive reactance circuit of FIG. 1*a* will be quite low, although sufficiently high for many practical applications. This quality factor may be improved by provision of a suitable negative resistance to effectively cancel the reflected resistive component R′ or by suitable modification of the transformer windings **3** and **4** to effect such cancellation.

FIG. 2 shows an inductive reactance circuit element according to the invention. The transistor Q serves as the variable resistance element, and is controlled by the voltage source V_s. The resistor **6** is preferably chosen so that the transistor Q effects variation of the secondary loop resistance about a mean value substantially equal to the self-inductance of inductance element **4**. The battery B supplies proper bias for the transistor Q and should be chosen such that the current bias applied to inductance element **4** does not produce excessive heating or undesired nonlinearity effects. It is evident from the foregoing discussion that if the voltage V_s is varied at a frequency ω the inductive reactance seen looking into terminals **1** and **2** will vary accordingly, while the apparent resistance seen looking into these terminals will be substantially constant.

FIG. 4 plots the reflected resistive and reactance components as a function of the secondary loop resistance R_0. It can be seen that at the point where $R_0=\omega L_2$ the slope of the R′ curve is substantially zero while the $X_{c'}$ curve has substantial slope and is approximately linear in this region.

FIG. 3*a* shows the circuit of FIG. 2 with added provision of a voltage source V′ in the primary circuit. If V′ is synchronized with V_s, the relative phase of V′ may be chosen so as to effect cancellation of the reflected resistance R′; when utilized in this manner, the source V′ acts essentially as a negative resistance element equal and opposite to the reflected resistance R′.

FIG. 3*b* shows an alternative negative resistance element consisting of the transistor Q′, the resistor **7** and the voltage source V″. The voltage V″ could be obtained by coupling a suitable phase shift network between the secondary voltage source V_s and the base of the transistor Q′.

FIG. 3*c* shows an alternative technique for compensating the reflected resistance R′. In this approach, each of the inductance elements **3** and **4** is divided into two operating portions **8** and **9** and **10** and **11** respectively. The sign of the mutual inductance between portions **8** and **10** is opposite to that of the mutual inductance between portions **9** and **11**. The circuit parameters are selected so that the real components of the reflected impedances cancel while the imaginary components add.

FIG. 5 shows a parametron logic component employing the inductive reactance circuit element of the invention. The transformer consisting of windings **14** and **15** serves to couple the driving signal applied to terminals **12** and **13** to the inductive reactance element terminals **1** and **2**. The capacitor C serves to resonate the inductive reactance circuit element at a frequency equal to one half the drive frequency. This subharmonic of the drive frequency is coupled to other parametron components in the logic network via output terminals **17** and **18** through isolating resistor **16**. The inductance of the inductive reactance circuit element (FIG. 2) is varied at a frequency equal to the driving frequency. The inductive reactance element thus serves to produce the desired subharmonic by parametric coupling of the drive signal, the subharmonic phase being synchronized with the phase of the drive signal. The manner in which parametrons are utilized in logic networks is well known in the art, the operation of the circuit of FIG. 5 as viewed at terminals **1** and **2** being similar to parametron circuitry employing other types of variable inductive reactance elements.

While the principles of the invention have been described above in connection with specific embodiments, and particular modifications thereof, it is to be clearly understood that this description is made only by way of example and not as a limitation on the scope of the invention.

What is claimed is:

1. A variable reactance circuit element comprising: first and second inductance elements having mutual inductance therebetween;

a variable resistance element electrically coupled to said second inductance element, said resistance element together with said second inductance element providing an impedance having a resistive and inductive component which is reflected from said second inductance element and is exhibited across the terminals of said first inductance element so that a variation in said resistance element causes a change in said inductance component of said reflected impedance across the terminals of said first inductance element; and

negative resistance means electrically coupled to said first inductance element causing said resistive component of said reflected impedance to be reduced.

2. A circuit element according to claim **1** wherein the resistance of said resistance element is varied about a mean value substantially equal to the magnitude of the self-reactance of said second inductance element.

3. A circuit element according to claim **2**, wherein the variation of said resistance is small in comparison with said mean value.

4. A circuit element according to claim **1**, wherein said resistance element includes:

a semiconductor device having input and output terminals; and

drive means operatively connected to said input terminals for varying the current through said output terminals,

said current being substantially in phase with the voltage across said output terminals.

5. A circuit arrangement according to claim **4**, wherein said negative resistance means includes a source of voltage synchronized with said drive means of said resistance element.

6. A circuit element according to claim **4**, wherein each of said inductance elements comprises a plurality of operating portions, each operating portion of said first inductance element being inductively coupled to a corresponding operating portion of said second inductance element, said operating portions being arranged so as to reduce said resistive component.

7. A circuit element according to claim **4**, wherein said negative resistance means includes a transistor having a base, emitter and collector, a source of voltage coupled to said base, and a resistor connected across said collector and emitter, said resistor being connected in series with said first inductance element.

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U.S. Cl. X.R.

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