Increductor® Notes #3

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Radio frequency switching with controllable inductors

INCREDUCTOR Controllable Inductors are proving increasingly useful as electronic commutators in radio frequency circuits.

In operation, a controllable inductor is the same as a saturable reactor except that the materials and configuration have been selected to permit operation at high frequencies, e.g., up to 400 mc. Figure 3-1 shows the construction of one type of controllable inductor useful in RF switches in which two ferrite ring cores carry a control winding and a signal (controlled) winding. When a direct current is applied to the control winding, the effective inductance of the controlled winding decreases as the ferrite core becomes saturated. A balanced signal winding and internal shielding reduce capacitive coupling and transformer action between the control and signal windings to a small value.

The elimination of moving parts is important in field use where the requirement for equipment with a long and trouble-free life is dominant.

The switching action of the controllable inductors is rapid and can be controlled by a modest d-c current. This provides maximum flexibility of control and programming in connection with the associated control circuitry. Logic circuitry can be made to control the switching action automatically in response to almost any predetermined set of conditions.

The controllable inductors provide attenuation changes of 40 to 80 db. In most applications, insertion loss of 0.1 db can be achieved at frequencies up to a few megacycles, increasing to 1 - 1.5 db at 400 mc.

INDUCTOR AND CIRCUIT DESIGNS for such a radio frequency switch depend upon:

(1) The frequency and bandwidth of the signal to be switched;

(2) The maximum attenuation required;

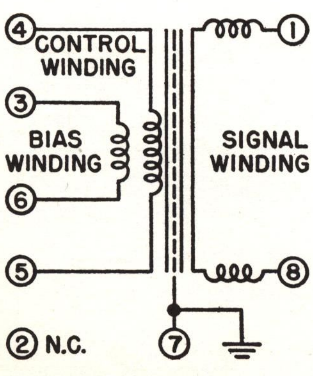
(3) The loss that can be tolerated;

(4) Switching time;

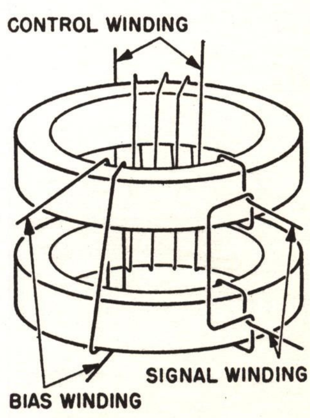
(5) The repetition rate at which the signal is to be switched;

(6) The number of switching elements and combinations required;

(7) Isolation required between the control circuits and the radio frequency circuits being switched.



Circuit Diagram



Core Configuration

Figure 3-1

A SIMPLE CONTROLLABLE INDUCTOR SWITCH arranged only for "on-off" operation is illustrated in Figure 3-2.

R_S indicates the impedance of the source of the radio frequency signal to be switched, and R_L indicates the impedance of the load circuit connected to the switch. L_1 and L_2 represent the inductances of the signal windings of two controllable inductors. A control circuit is arranged so that as the inductance L_1 increases in magnitude, the inductance L_2 decreases and vice versa.

This can be accomplished in a number of ways so that a single control current can simultaneously increase the inductance of one winding and decrease the inductance of the other. For example, one of the inductor cores can be maintained normally in a saturated condition either by a permanent magnet or a separate bias winding carrying a steady d-c bias current. The control winding is connected so that the flux produced by it opposes the bias flux and the control current increases the inductance of the associated signal winding while decreasing the inductance of the other control winding.

When the two units are alike, the insertion loss of the switch is $\frac{L\ min}{L\ max}$ where L min and L max respectively denote the minimum and maximum inductance values of the windings L_1 and L_2. This value is typically about 0.1 db up to a few megacycles, increases to about 0.3 db at 150 megacycles and rises to 1 - 1.5 db at 400 megacycles.

The maximum available attenuation is $\frac{L\ max}{L\ min}$ and an attenuation of 40 db is typical.

If we define the lowest and highest operating frequencies of the switch as those at which there is a 3 db loss caused by L_1 and L_2, and if the load impedance R_L is assumed to be equal to the source impedance R_S, then at the lowest frequency of operation:

$$2\ \omega_1\ L\ max = R_S$$

and at the highest frequency of operation:

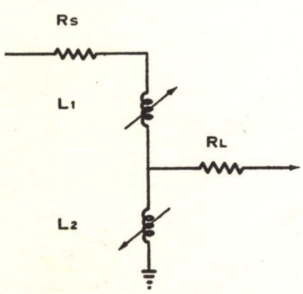


Figure 3-2

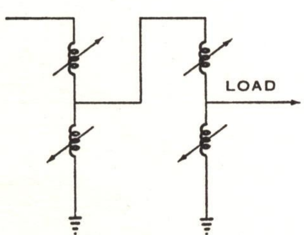


Figure 3-3

$$\omega_2\ L\ min = R_L$$

$$\omega_1 = \frac{R_S}{2\ L\ max} \qquad \omega_2 = \frac{R_S}{L\ min}$$

$$\frac{\omega_2}{\omega_1} = \frac{2\ L\ max}{L\ min}$$

Typically $\frac{L\ max}{L\ min}$ is equal to 100, indicating that a maximum range in frequency of the signal to be switched is about 200:1, and approaches $\left\{\frac{L\ max}{L\ min}\right\}^2$ if L_1 and L_2 are not alike.

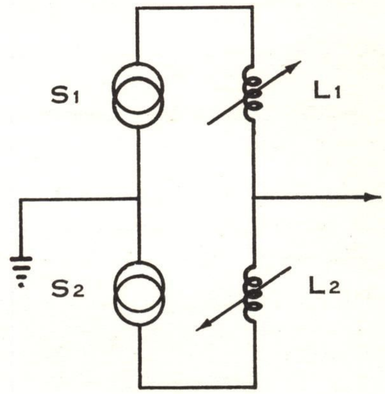


Figure 3-4

The control power required to perform this switching operation is less than 5 milliwatts per square wave cycle per second. The total control power increases rapidly with requirements for increased attenuation or switching rate.

INCREDUCTOR NOTES is published from time to time to keep you informed of the progress in the development and use of high-frequency electrically controllable inductors. The series of INCREDUCTOR NOTES discusses the characteristics of the units themselves and circuitry developed particularly for them. Typical applications of these high frequency saturable reactors in commercial and military equipment will be given.

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When the cores are saturated the Q of the inductances L_1 and L_2 is generally in excess of 100 and is always higher than 50.

Where greater attenuation is necessary, the switching elements can be connected in series as in Figure 3-3.

With the same controllable inductor characteristics as described above, a maximum attenuation of 80 db can be achieved with 0.2 db insertion loss.

Such switches can also be arranged to switch between two sources, as shown in Figure 3-4.

Switches with greater attenuation can be made in the form of filters, as shown in Figure 3-5.

Such a filter switch will provide an attenuation of 12 db/octave/section. The three section filter shown will provide, in typical switching operations, an attenuation of 120 db. Similar switching functions can be performed with high-pass filter configurations.

TO SWITCH BETWEEN A NUMBER OF SEPARATE SOURCES, configurations such as that shown in Figure 3-6 can be used.

The inductances L_1 through L_4 are controlled so that the inductance of any selected one can be reduced to its minimum value, thus providing an instantaneous switching connection between any one of the four sources and the load circuit.

The RF switches described here are used primarily in low power circuits. Higher power switches for transmitting and other applications have been developed.

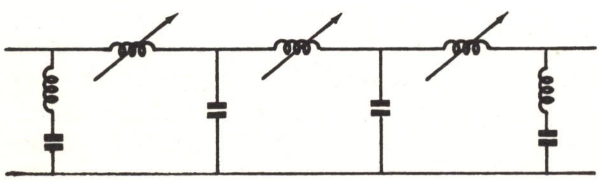


Figure 3-5

The isolation expressed as a voltage ratio between the control voltage and the signal voltage in a typical production controllable inductor is approximately equal to ten times the ratio of control turns to signal turns. By specially balancing the windings, the factor of ten can be increased to 100 or more where such complete isolation is necessary. Increased isolation can be obtained, when the control and signal frequencies are different, by placing a filter in series with the control windings to suppress the undesired frequency components.

SUCH SWITCHES ARE FINDING USE also in applications where a continuously smooth transition between "off" and "on" conditions is necessary, as, for example, in automatic gain control circuits. In such uses, they have the advantages of wide control range (40 to 80 db), introduce no cross modulation, and they do not cause any change in plate current of the tubes and therefore no change in the B+ voltage even with poorly regulated supplies. A single diode will in most cases handle the necessary control power.

In some switching applications, production INCREDUCTOR units can be used, but it is usually necessary to modify the inductors or to design new ones with the best characteristics for the intended use. The control circuitry for the switches must be closely coordinated with the inductor design and for that reason, we usually suggest that CGS Laboratories provide the complete switch package including the control circuits. CGS engineers have had many years of concentrated experience in the design of controllable inductors and in control circuit systems for use with them.

CONTROLLABLE INDUCTOR SWITCHES ARE NEW and no one can say to what extent they will be adopted for various uses. The switches so far constructed by CGS engineers exhibit characteristics that appear likely to make them desirable for a variety of applications. In installations where the switching action is to be controlled remotely, the use of controllable inductors offers obvious advantages.

THE DEVELOPMENT OF BETTER controllable inductor switches is being aided by improvements in the controllable inductors. Recent CGS developments have markedly reduced the control power required to saturate the ferrite. This permits the design of switches requiring substantially less reactive power in the control circuits than was possible previously. More information about these new controllable inductors will be presented in future issues of INCREDUCTOR NOTES.

IF YOU HAVE A PROBLEM that you think might be solved by the use of controllable inductors, why not ask us about it? We would like to hear from you.

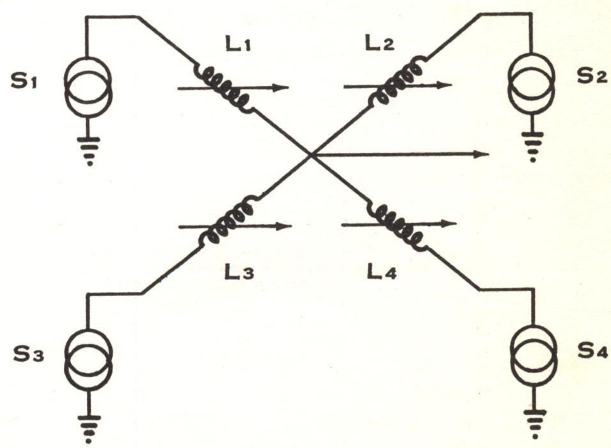


Figure 3-6

SERIES AB

The three INCREDUCTOR units in this series are characterized by the high Q of the signal winding; the Q remains nearly constant throughout the operating range.

The three units of this series cover starting frequencies from 100 kilocycles to 2.5 megacycles.

The core is formed entirely of ferrite and consists of two rings as shown in the sketch. The control and bias windings encompass both rings and the balanced signal winding is in two parts, each on one of the core rings.

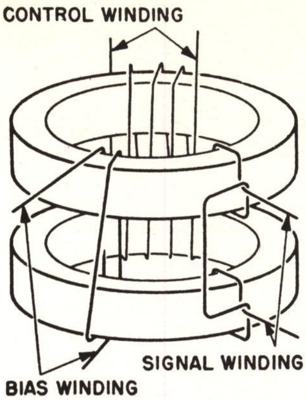
The construction is such that the inductance of the control winding varies in the same manner as the signal winding, a feature which is of importance when it is desired to sweep the inductance rapidly over the operating range with minimum driving power.

THE SIGNAL WINDING	63AB1	63AB2	53AB1
Maximum Inductance (μh)	100	500	2500
Inductance Change Ratio	14:1	14:1	14:1
Starting Frequency Range (mc)	0.7–2.5	0.3–1.0	0.10–0.35
Capacity to Electrostatic Shield (μμf)	15	30	60

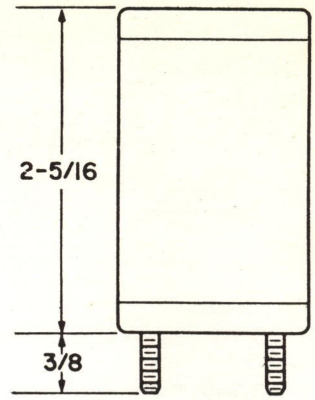
The Control Winding—The control winding has a nominal inductance of 6 henries and a d-c resistance of 1000 ohms. The peak current should not exceed 50 ma and the maximum R.M.S. current should not exceed 30 ma.

The Bias Winding—The bias winding has a nominal inductance of 175 millihenries and a d-c resistance of 200 ohms. A maximum bias current of 10 ma is recommended.

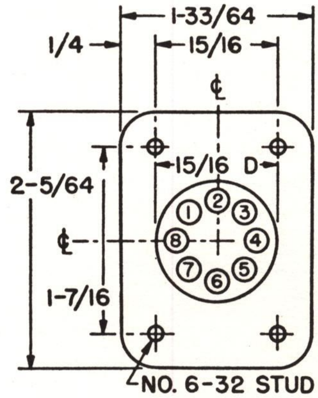
Where it is desired to track a number of INCREDUCTOR units, it is recommended that special precision units be ordered as a group. Such units are specified by adding the suffix "P" to the above designations.



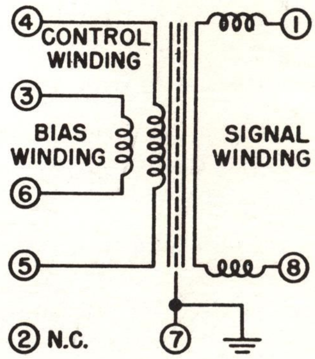
Core Configuration



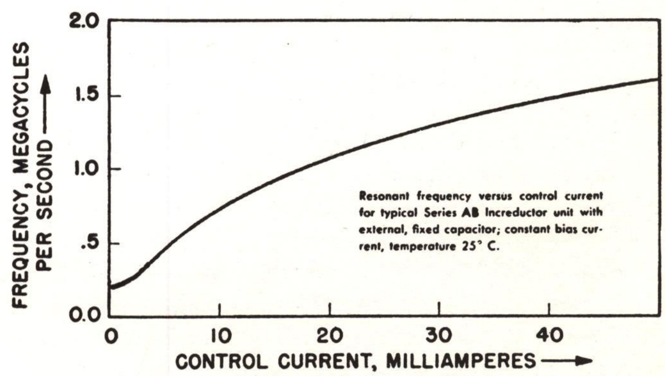
Exterior Dimensions



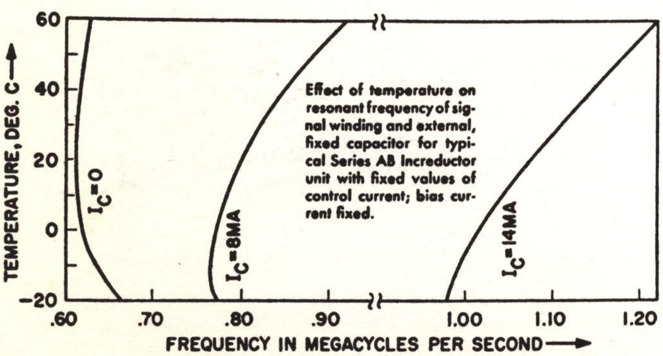
Base Diagram



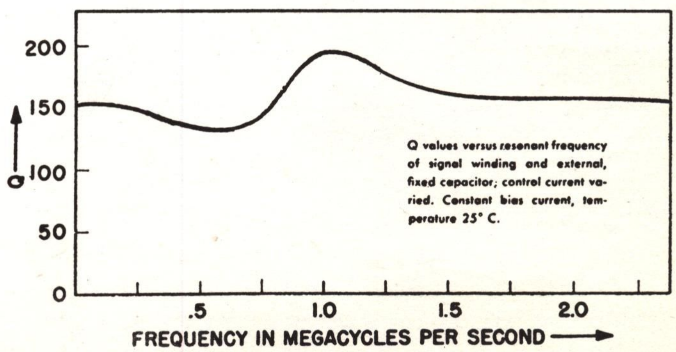
Circuit Diagram



Control Characteristics



Temperature Characteristics



Q Characteristics