Increductor® Notes #1

Published by TRAK ELECTRONICS COMPANY, Division of CGS Laboratories, Inc., 59 Danbury Road (Route 7), Wilton, Connecticut

DIRECTED TO THE THEORY AND USE OF HIGH FREQUENCY SATURABLE REACTORS

ABOUT INCREDUCTOR NOTES

This is the first issue of INCREDUCTOR NOTES, a report to be 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 will review such factors as temperature characteristics, hysteresis, magnetic bias, frequency range, and Q of the units themselves. There will also be discussions of circuitry developed particularly for use with controllable inductors and typical applications of these devices in commercial and military equipment. Closed-loop circuits for overcoming the effects of hysteresis and temperature changes, circuits for shaping driving currents, sweep generator circuits and many others will be described. We suggest that you collect INCREDUCTOR NOTES in a three-ring loose-leaf binder.

If you would like to receive future issues, please fill out and return the enclosed card. If you know of other engineers who would like to receive INCREDUCTOR NOTES, we shall be glad to add their names to our distribution list.

AN INTRODUCTION TO INCREDUCTOR CONTROLLABLE INDUCTORS

The name INCREDUCTOR is a registered trademark designating controllable inductors manufactured by CGS Laboratories.

Saturable reactors have been known for many years and have been used extensively in low frequency applications. The use of such saturable reactors was limited because they were effective to control alternating currents only at low frequencies, a few thousand cycles at most. Their use was also limited because the inductance of the controlled winding could be changed only over a limited range. A change in inductance of two or three to one was considered good.

In 1948, CGS started experimenting with saturable reactors in an attempt to develop a unit that could be used at radio frequencies and which could provide a much larger range of inductance control. The use of new ferrite materials in the core appeared to provide a possible solution. This development has been carried on unceasingly at CGS since 1948. In present development programs, controllable inductors are able to maintain a useful Q and operate at frequencies as high as 400 megacycles.

These developments have opened scores of new uses and in effect have resulted in a new component available to the electronic engineer.

In order to take full advantage of the useful characteristics of the INCREDUCTOR unit, it was necessary to develop specialized associated circuitry. CGS has pioneered in this and one of the purposes of INCREDUCTOR NOTES is to pass along information that has been acquired and to tell you about new developments as they take place.

CGS is continuing to carry on extensive programs to provide better controllable inductors. INCREDUCTOR NOTES will keep you posted on these new developments as fast as they can be released.

The next issue will cover briefly:

- Hysteresis and Remanent Magnetism.
- Control Circuit Considerations.
- Closed-loop Control Circuits.
- Bellwether Closed-loop Circuits.
- How to Choose The Right INCREDUCTOR Unit.
- General characteristics of the AQ series of INCREDUCTOR Controllable Inductors.

Future issues will discuss the following:

- An INCREDUCTOR Controllable Inductor suitable for Auto Radio application.
- The use of INCREDUCTOR units in delay lines.
- Magnetic switch applications.
- Filters employing INCREDUCTOR Controllable Inductors.
- Amplifier applications for both RF and Audio frequencies.
- General characteristics of other series of INCREDUCTOR Controllable Inductors.
- Details of new INCREDUCTOR units now in the development stage.

INCREDUCTOR* Controllable Inductors

How They Work:

INCREDUCTOR* controllable inductors work like saturable reactors, but they operate at frequencies so much higher than conventional saturable reactors that they may quite properly be considered a new circuit component. The name "controllable inductor" has been adopted to avoid confusion with lower frequency saturable reactors. The high frequency wide-range operation of INCREDUCTOR units is made possible by the use of cores formed at least in part of ferrite materials.

Standard INCREDUCTOR units include a signal winding, a control winding, and a bias winding. The signal winding is the controlled winding whose inductance varies as a function of the current in the control winding. With zero control winding current, the signal winding is at its maximum inductance. As the control current is increased, the permeability of the ferrite core material is progressively reduced, thus reducing the incremental inductance of the signal winding. The bias winding is provided to permit operation at any desired point on the magnetization curve. The signal winding is formed in two counter-connected parts to prevent coupling between the signal and control windings, thus eliminating any transformer action in the unit. To provide further isolation between the signal winding and the control winding, an electrostatic shield is provided between them and is connected to one of the pins on the base of the inductor.

Inductance Change Ratio:

The inductance change ratio is the ratio of maximum to minimum inductance of the signal winding. Ordinarily, wide ranges of inductance variation are possible with controllable inductors. Larger change ratios are possible at the lower frequencies with gradually decreasing range available at the higher frequencies. At the lower frequencies, inductance ranges of 400 to 1 or even more can be attained.

In some INCREDUCTOR units the inductance of the control winding changes in the same manner as the inductance of the signal winding. In other inductors (for example, those in which the core is formed partly of iron), there may be only a small change in the inductance of the control winding over the operating range. In inductors of the latter type, the change of inductance of the control winding may be no more than 2 to 1 over the full operating range.

Because the characteristics of the signal winding are usually of dominant importance, careful production control of them is maintained. As a result, however, considerable variation in the values of the control windings is to be expected.

The Signal Winding Q:

Because INCREDUCTOR units are used widely in tuned circuits, as, for example, where the signal winding is connected in parallel with a low-loss capacitor, the Q of the signal winding is of importance. Usually, as the control current is increased from zero value, the Q rises, reaches a peak at some relatively low value of control current, and then generally levels off and may have either a negative or positive slope at the upper end of the frequency range.

In the design of controllable inductors, Q and range are to a large extent interchangeable; that is, in units where Q requirements are not critical, wider tuning ranges can be attained; whereas maximum Q's are available in units designed to cover a smaller range. Our continued research on special ferrites promises even higher Q's and greater operating range in the future.

In general, peak Q's of between 40 and several hundred can be attained at frequencies up to 50 mc. At higher frequencies, the Q generally is less, varying between 10 and 80 at frequencies from 50 to 200 mc.

In circuit applications, it is frequently possible to increase the Q of the signal winding circuit by connecting in parallel with it a low-loss fixed inductor,

although this modification will decrease the inductance range.

The Temperature Coefficient:

The temperature coefficient of an INCREDUCTOR unit depends upon the characteristics and configuration of the core. Most controllable inductors have larger temperature coefficients than linear components. A typical temperature coefficient curve is shown in Figure 1. At low values, the temperature coefficient of inductance is positive, passing through zero at a relatively low value of control current, and becoming negative at higher values. It is sometimes

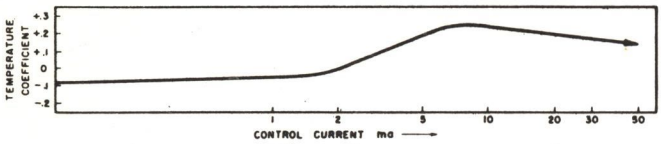


Figure 1

possible in cases where temperature effects are important to arrange to operate in the area of zero temperature coefficient. The values of temperature coefficients may range from 0.02% to 0.6% per degree C. In applications where temperature considerations are important, closed-loop circuits such as those described below can be used to eliminate the effects of temperature changes.

Frequency of Operation:

Controllable inductors can be used to control circuits operating from the low audio frequencies up to and above 200 megacycles. Below 10 megacycles, inductance change ratios of 100 and more are readily attainable. At frequencies between 10 and 50 mc, inductance change ratios in the order of 30 to 100 can be attained. At higher frequencies, the tuning range may have to be reduced to 2 to 1 or less in order to maintain satisfactory Q's.

Power Handling Capabilities:

Standard INCREDUCTOR units are designed to handle only small amounts of power. Usually, there is no difficulty controlling several watts of RF power. The power requirements for the control winding are

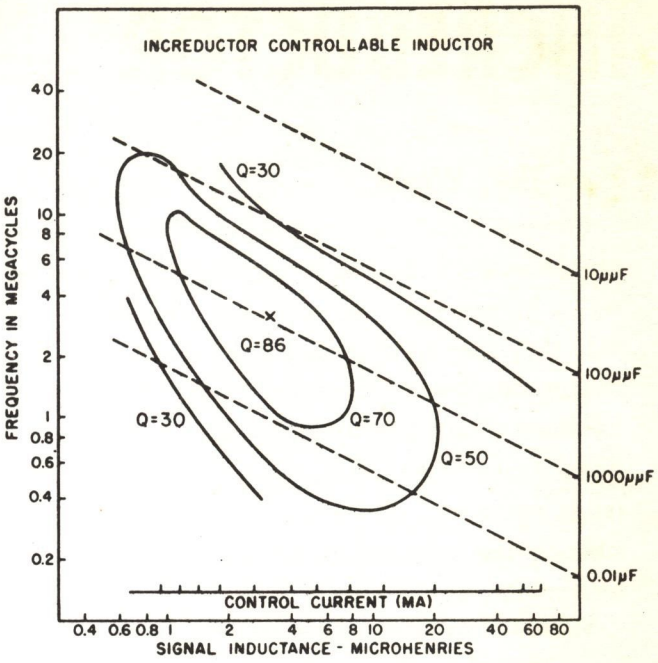


Figure 2

correspondingly modest, and the control winding usually does not dissipate more than one watt of control energy. Higher power units are available on special order. For example, INCREDUCTOR units capable of handling several hundred watts at frequencies between 50 and 100 mc have been constructed.

The Q Map:

Much of the information needed by an engineer using controllable inductors can be presented on a single chart called a Q map, as shown in Figure 2. The frequency of operation is plotted vertically and the inductance of the signal winding and the corresponding control current are plotted horizontally. The chart itself is obtained by measuring the Q of the signal winding at various frequencies throughout the operating range of the unit. The points on the chart having equal Q's are then joined to form constant Q contours. A number of parallel oblique broken lines indicate the fixed capacity connected in parallel with the signal winding. Thus, from the single map, the frequency range and Q can be determined readily and the correct size of shunt capacitor to obtain this operation can be selected. The readings taken from the chart, however, represent operation only at one particular temperature.

SERIES DB

These units are especially suitable where wide ranges of inductance change are required. An inductance change of 350 to 1 is readily obtained. The units are recommended for starting frequencies between 200 cycles and 200 kilocycles.

The core configuration is the same as that shown for the AB series, and consists of two ferrite ring cores with the control and bias windings encompassing both cores and the balanced signal winding being in two parts each around one of the cores. These units are characterized by an extensive range of linear relation between the control current and change in frequency of the controlled circuit. A linear range of five to one in frequency is readily obtained.

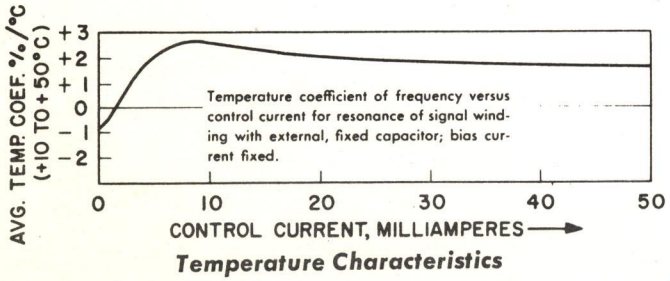
The inductance of the control winding varies in the same manner as the inductance of the signal winding giving an advantageous control characteristic where higher sweep rates are required.

THE SIGNAL WINDING	38DB1	48DB2	48DB3	58DB1	58DB2
Nominal Maximum Inductance (mh)	3000	500	100	20	4
Inductance Change Ratio	350:1	350:1	350:1	350:1	350:1
Maximum Q	60	80	100	110	130
Starting Frequency Range (kc)	0.2–5	1–20	2–40	4–100	10–200
Capacity to Electrostatic Shield (μμf)	85	85	75	65	60

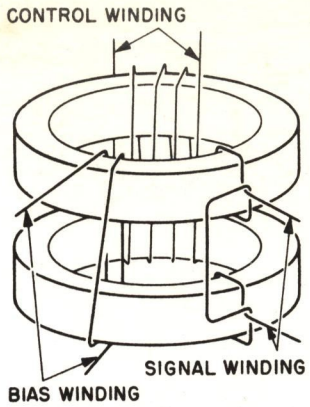
The Control Winding—The control winding of each unit has a nominal inductance of 50 henries and a d-c resistance of 750 ohms. The peak control current should not exceed 130 ma and the average current should not exceed 70 ma.

The Bias Winding—The bias winding has a nominal inductance of 2.5 henries and a d-c resistance of 500 ohms. A maximum bias current of 25 ma is recommended.

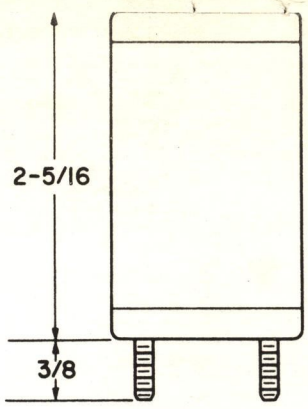
Where it is desired to track a number of INCREDUCTOR units, it is recommended that special precision units be ordered as a group. Such units are specified by adding the suffix "P" to the above designations.



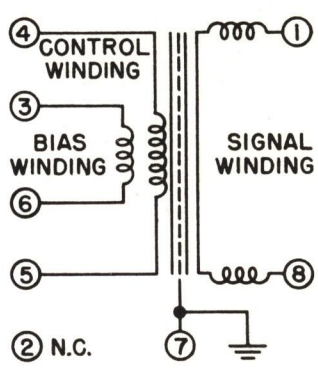
Temperature Characteristics



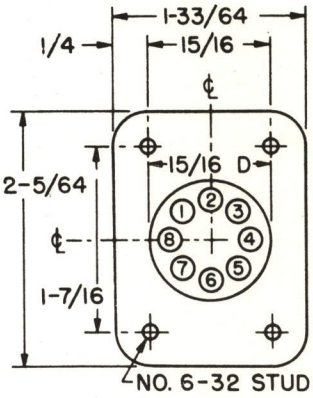
Core Configuration



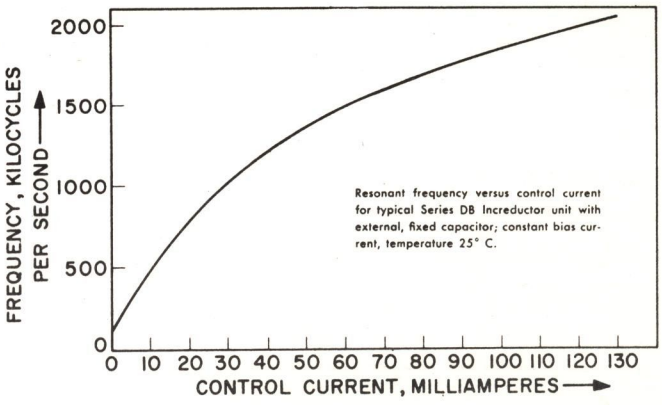
Exterior Dimensions



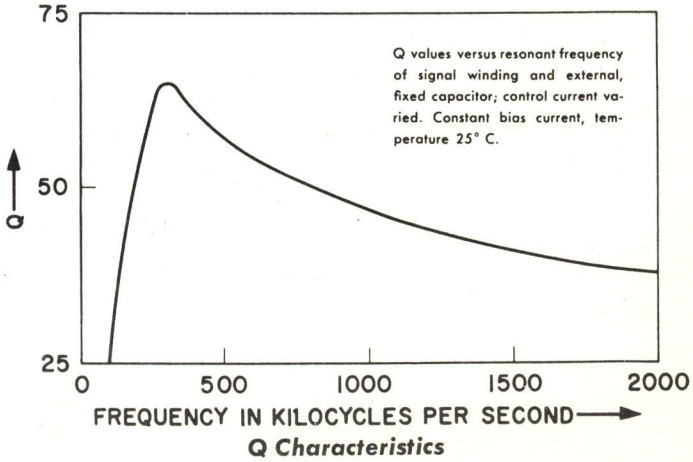
Circuit Diagram



Base Diagram



Control Characteristics



Q Characteristics