Increductor® Notes #5

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Tuning receivers with controllable inductors / Part 2: Design of control circuits

The previous issue of INCREDUCTOR NOTES described how controllable inductors are used in the RF circuits of electronically tuned receivers. This issue will complete the two-issue series on electronically tuned receivers with a discussion of INCREDUCTOR control circuits.

BASIC CONTROL PRINCIPLES

The current applied to the control winding of the INCREDUCTOR controllable inductor determines the incremental inductance of the unit and hence the resonant frequency of the tuned circuit of which it is a component. It is the function of the control circuits to provide the current required to tune the resonant circuits in the RF head to the desired frequency.

Just as a vacuum tube has an operating point on its E_g-I_p curve, the INCREDUCTOR unit has an operating point on its B-H curve. To set this operating point, a small DC current is sent through a bias winding which has about one third the number of turns as the control winding and less current-carrying capacity. In some controllable inductors, it is possible to set this operating point using a permanent magnet instead of a bias winding; this approach is not generally recommended due to possible adverse aging and temperature effects.

Choosing the operating point: The best operating point of a controllable inductor is determined by the application involved. As mentioned in part I of this series, adjustment of individual operating points is an aid to tracking sets of controllable inductors. Other factors to be considered in selecting the operating point are hysteresis, temperature stability, linearity, and sweep width. These factors are discussed individually in the succeeding paragraphs.

Minimizing hysteresis: Figure 5-1 shows a typical plot of signal winding resonant frequency versus control winding current. It can be seen that selection of an operating point near saturation (region B) will minimize hysteretic effects.

Linearity: Figure 5-1 shows that operation in region A will afford maximum linearity of signal winding frequency with respect to the control current. Linearity also depends on the magnitude of the sweep as well as the power in the signal winding.

Minimizing temperature coefficient: Figure 5-2 is a simplified plot of temperature versus frequency with control current held constant and no bias current. This plot reveals the interesting fact that temperature coefficient is negative at low flux levels and positive at high flux levels. Therefore, greatest temperature stability is obtained by setting the operating point near the region of zero temperature coefficient.

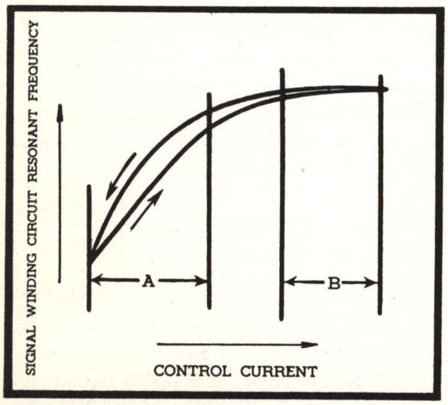


Figure 5-1: *Typical plot of signal winding resonant frequency vs. control current (with no bias current).*

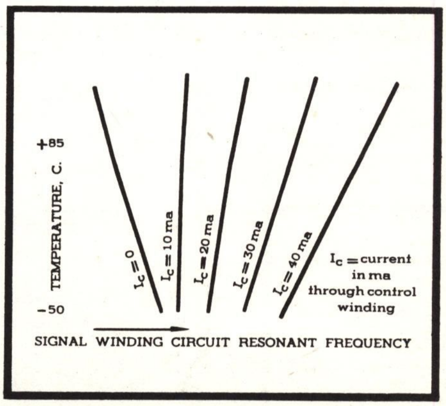


Figure 5-2: *Typical plot of temperature characteristics at different values of control current (with no bias current).*

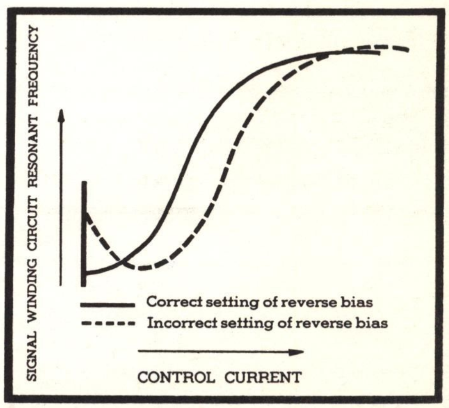


Figure 5-3: *Typical curves of resonant frequency vs. control current for correct reverse bias and too much reverse bias.*

Sweep width: The maximum signal winding inductance, normally attained when the control current sweeps through its minimum value, is reduced by the presence of residual flux in the core. The greater the amount of residual magnetism, the smaller will be the available inductance change ratio for a given unit. Therefore, in applications that require the maximum possible inductance or frequency change ratios, a reverse bias current should be applied to the bias winding to exactly cancel the residual magnetism. Care must be exercised in setting this operating point since too great a reverse bias will cause the maximum signal winding inductance to occur at other than the point of minimum control current. Typical curves illustrating correct and incorrect settings of reverse bias are shown in figure 5-3.

From the foregoing, one can see that several of the factors involved in choosing an operating point are sometimes contradictory. The design engineer must first decide which factors are most pertinent to the particular application and then see what compromises can be made.

Driving requirements: A controllable inductor is a current-controlled rather than a voltage-controlled device. It should be driven from a constant-current source of control power.

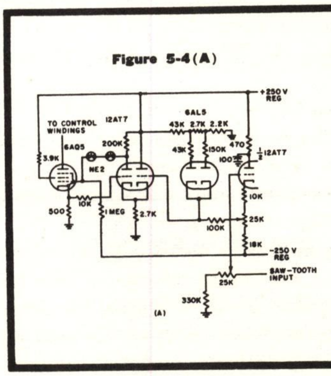
When a varying control current is applied to the control winding of an INCREDUCTOR unit, a back EMF is generated by the inductive component of the control winding impedance. By opposing any change in control current, this back EMF causes a lag in the response of the controllable inductor. However, when the unit is driven from a constant-current source, the inductive load of the control winding receives the applied control current regardless of the back EMF generated. It should be added that a constant-current source also minimizes the effects of any changes of control winding resistance due to temperature variation.

The most readily designed constant-current source is a pentode driver with the INCREDUCTOR control winding in its plate circuit. An alternate arrangement would employ an amplifier circuit with high inverse feedback. A cathode follower is *not* recommended because of its low driving impedance. In semiconductor equipment, the controllable inductor is placed in the collector circuit of a transistor driver.

Control circuits for optimizing operation: The setting of the operating point is not the only method the designer has available for improving linearity and minimizing the effects of hysteresis and temperature variation. Other approaches involve diode shaping of the control current and use of a closed-loop control circuit.

Diode shaping: Sweep linearity in a panoramic receiver can be improved by employing diode current shaping of the sawtooth sweep waveform. It is desired to shape the control current sweep waveform into a mirror image (2, figure 5-4B) of the frequency-control current curve (1, figure 5-4B). The combination of the two curves will produce a linear sweep with respect to the voltage input to the current driver. A diode shaper approximates the desired current waveshape by straight-line segments (3, figure 5-4B). A typical circuit, shown in figure 5-4A, operates as follows:

The desired waveform is obtained by the operation of two successively biased shunt diodes on the sawtooth waveform. The diodes are positively biased; thus, the amplitude of the early portion of the sawtooth input will be less than the bias of the diodes and they will conduct. The conducting diodes shunt the lower portion of the input voltage divider, thus reducing the slope of the sawtooth voltage at the diode cathode. As the sawtooth rises, it approaches the bias point of one of the diodes, eventually exceeds the bias point of this diode, and cuts it off. The lower portion of the input voltage divider is now shunted by only one of the diodes, hence the slope of the voltage at the diode cathode increases. As the sawtooth voltage rises higher still, the second diode stops conducting, producing a still sharper slope of the voltage at the cathode. Thus, the output voltage (and the output current) is divided into three straight-line segments.



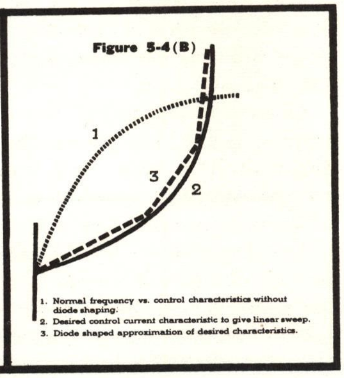


Figure 5-4(A): *Linearizing circuit.*

Figure 5-4(B): *Control characteristics as function of frequency.*

Note: For additional information on diode shaping, refer to the article Transfer Functions of Diode Networks *by A. Schlang and A. B. Jacobs that appeared on page 66 in the February 1956 issue of Tele-Tech & Electronic Industries magazine.*

Bellwether closed-loop circuits: When the control windings of a group of controllable inductors are placed in series, and are subjected to the same conditions of temperature and hysteresis, the entire string of units will behave in like fashion. Therefore, one of these units — called the bellwether — can be placed in a closed-loop circuit and all the remaining INCREDUCTOR units will follow it.

The operation of the bellwether is compared against a known standard, and an error signal is derived. This error signal can then be used to correct any discrepancy in controllable inductor operation. (A simple bellwether closed-loop circuit is shown on page 7 of INCREDUCTOR NOTES No. 2.) Since the bellwether closed-loop circuit is self-correcting, it can virtually eliminate the effects of hysteresis and temperature variation. Because of their importance to the circuit designer, closed-loop circuits will be considered in detail in a future issue of INCREDUCTOR NOTES.

PRACTICAL APPLICATIONS OF CONTROL CIRCUITS

The remainder of this issue of INCREDUCTOR NOTES will discuss the control circuits in the CGS Laboratories TRAK® Type 2917 RF Head System. The 2917 is a complete receiver front end, electronically tuned, and capable of either a panoramic or a listening mode of operation. The system consists of three chassis — an INCREDUCTOR-tuned RF unit, a tracking control unit, and a tuning control unit. The 2917 possesses the following characteristics:

Please send INCREDUCTOR NOTES to me at this address.
This is a new ☐ corrected ☐ address.
(Maximum five lines, please.)

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Electrical characteristics:

	Model A	Model B
Nominal RF tuning range	*50-90 mc*	*90-160 mc*
Intermediate frequency	*23 mc*	*27 mc*

Overall gain .... *30 db ± 3 db*	Voltage input ....
Dynamic range .. *60 db over 1 uv*	*— 150 VDC, + 150 VDC,*
Noise figure .... *Less than 8 db*	*+ 300 VDC, 6.3 VAC*

Mechanical dimensions: RF unit .... *14½" x 4½" x 4½"*
Tracking control unit *8"x4½"x4½"* Tuning control unit *8"x4½"x5"*

Panoramic system: In the panoramic mode, the system consists of the tuning control unit and the INCREDUCTOR-tuned RF unit. (See figure 5-5.)

The control waveform in the panoramic mode is a shaped sawtooth current. When applied to the control windings, this sawtooth current will cause the INCREDUCTOR inductance to sweep through its range and hence will cause the tuned circuits in the RF unit to sweep through the frequency range.

An externally generated linear sawtooth voltage is applied to the tuning control unit. Since the frequency-control current curve (figure 5-4B) reveals a non-linear relationship, some reshaping of the sawtooth sweep waveform is needed to produce a frequency sweep which is linear with time. (Two-point shaping is used.)

The shaped sawtooth is next applied to a current driver which converts the voltage waveform to a current waveform suitable for the controllable inductors. High negative feedback around this stage provides the high output impedance necessary to drive the inductor control windings. The inductor control windings are series-connected and the string of windings constitutes the plate load of the driver stage. The driver output sweeps the tuned circuits across the band.

Sweeps from 1 to 40 cps can be obtained in the 2917 system with linearity within 3% of the external sawtooth voltage.

Listening system: In this mode of operation, the system consists of the tuning control unit, the tracking control unit, and the RF unit. (See figure 5-6.)

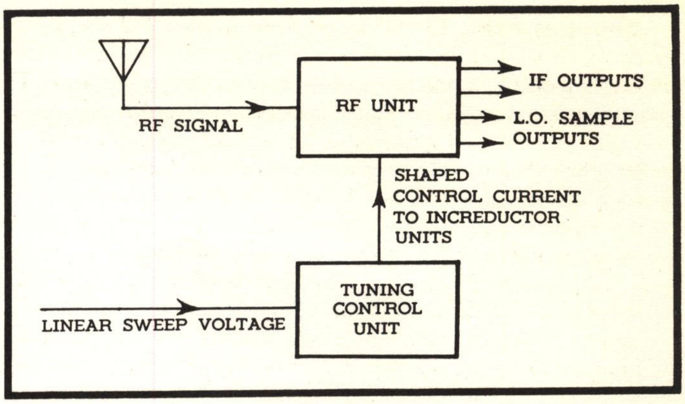


Figure 5-5: *Block diagram of TRAK Type 2917 panoramic mode system.*

An external, manually-tuned local oscillator is the primary source of control voltages in this mode. The external oscillator applies both a coarse-tuning DC voltage to the tracking control unit and an RF signal to the RF unit. (The coarse DC voltage is used to keep the initial mistuning within the range of "pull-in" from the discriminator in the tracking control unit.)

Automatic frequency control in the listening mode is provided by the tracking control unit which forms a bellwether closed loop. The frequency-sensitive portion of the tracking control unit is an INCREDUCTOR-tuned oscillator with its control winding in series with those of the controllable inductors in the RF unit. If either hysteresis or temperature effects have caused the RF unit tuned circuits to shift frequency, the tracking control oscillator will likewise shift frequency by the same amount. The tracking control discriminator senses the error between the tracking control oscillator and the external manually tuned local oscillator and sends an error signal to the tuning control unit which alters the control current to correct the discrepancy.

If electronic tuning appears inviting in an application you might have, please let us know about it. We might well have a standard TRAK system that will do the job for you. In any event, we would be glad to determine feasibility and offer helpful suggestions.

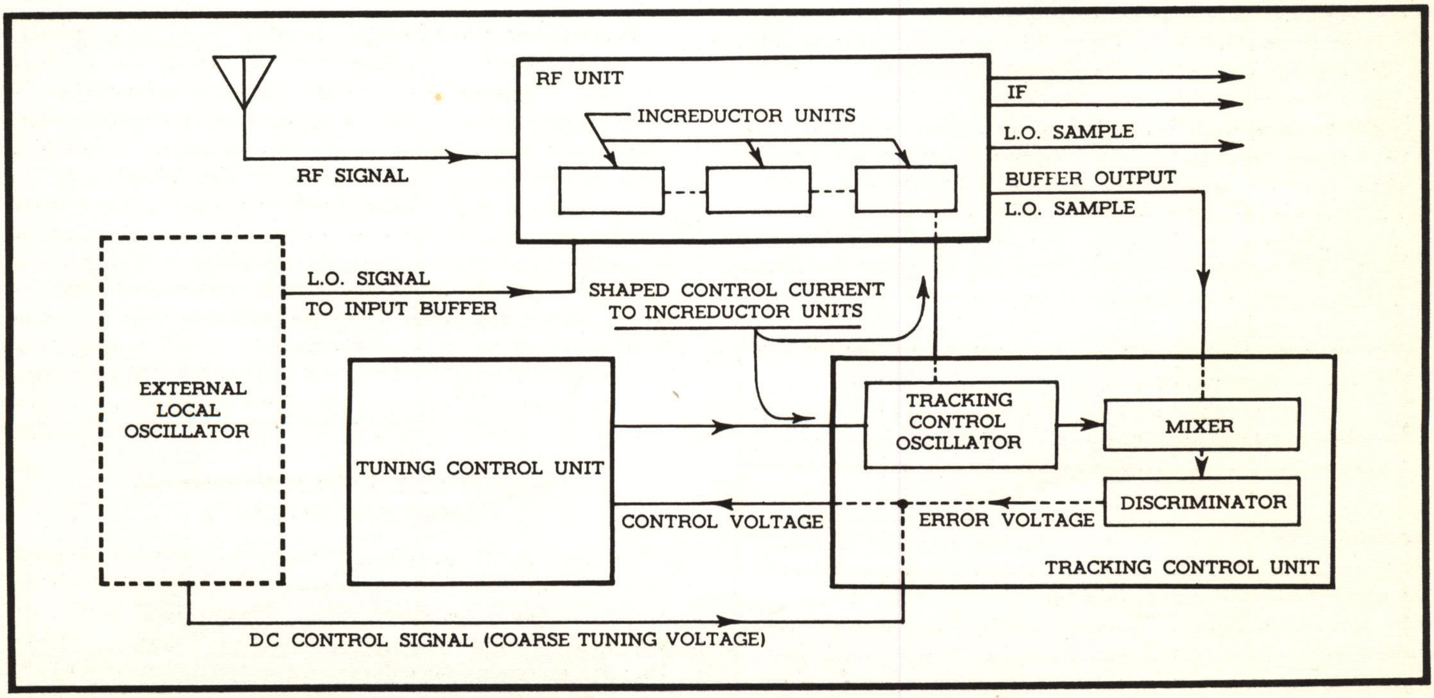


Figure 5-6: *Block diagram of TRAK Type 2917 listening mode system.*

PRELIMINARY SPECIFICATIONS

HIGH FREQUENCY TEMPERATURE STABILITY HIGH Q

SERIES AP

The units of this series are particularly useful in the higher frequency ranges between approximately 25 and 260 mc.

This series features an open type of construction to minimize stray capacitance. The core configuration, illustrated in the sketch, consists of a U-shaped, ferromagnetic yoke carrying the control and bias windings. A slotted ferrite bar bridges the open end of the yoke and carries a balanced signal winding. The control winding is wound on two bobbins, thus reducing distributed capacity in the control winding, and raising the self-resonant frequency of the winding to approximately 15 kc. This makes possible a higher sweep frequency.

The units are vacuum varnish-impregnated to eliminate the effects of humidity. An improved ferrite used in the signal structure offers high Q and great temperature stability. A maximum Q of 120 is obtainable. Maximum temperature coefficient of frequency drift is on the order of 0.02% per degree Centigrade or less.

Signal winding: The table below shows the suggested operating frequency range for each unit in the AP series. These measurements were made with a 15 uuf capacitor across the signal winding and with ¼-inch total signal winding lead length.

Type	*Suggested operating frequency*	*Frequency change ratio from: Demag.*	*Resid.*
81AP1	88-192 mc	2.8	2.3
81AP2	48-122 mc	3.2	2.7
81AP3	88-192 mc	2.8	2.3
81AP4	130-260 mc	2.6	2.4

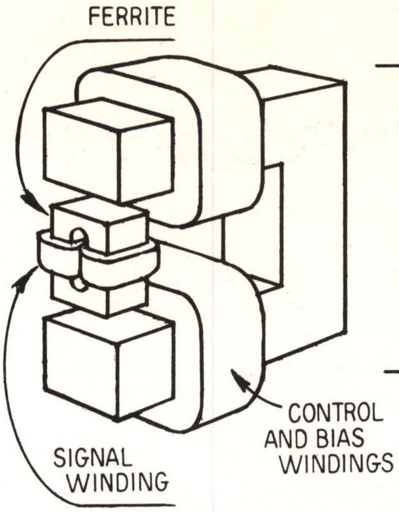
Control winding: Average control winding current should not exceed I_c value given below. Peak current should not be greater than 30% above average value.

Type	*I_c, ma*	*L, hy*	*R, ohms*
81AP1	70	1.5	225
81AP2	140	0.58	100
81AP3	140	0.58	100
81AP4	140	0.64	88

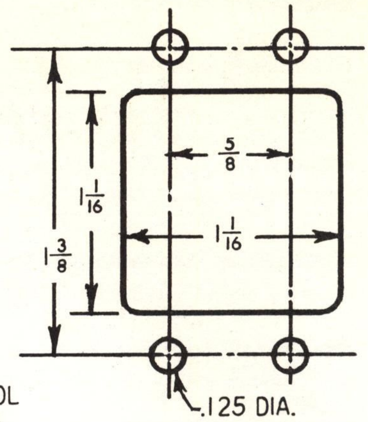
Bias winding: Average bias current should not exceed I_b value given below.

Type	*I_b, ma*	*L, hy*	*R, ohms*
81AP1	15	1.1	900
81AP2	20	2.1	750
81AP3	20	2.1	750
81AP4	20	2.3	700

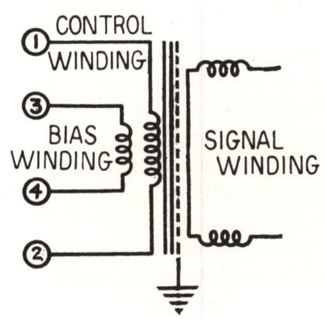
Tracked sets: Where it is desired to track a number of INCREDUCTOR units, it is recommended that special precision units be ordered as a group. Such units are specified by adding the suffix "P" to the above designations. When purchased in tracked sets, each unit comes supplied with data on control current versus frequency, taken at a specified capacitance and bias current. The Q at the starting frequencies are also given.



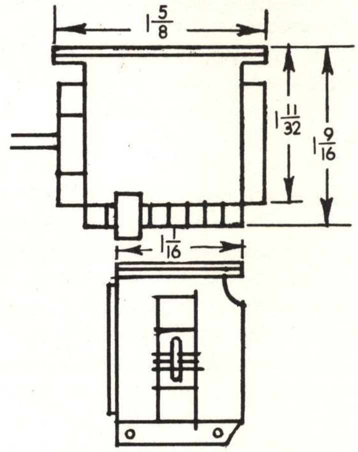
Core configuration



Chassis mounting



Schematic



Exterior dimensions