# Designing for Stability

## Part 2: Closed-Loop Methods of Compensation

The previous issue of INCREDUCTOR NOTES described some of the factors involved
in the stable design of circuits employing INCREDUCTOR units. Specific circuits using closed-loop methods
of compensation are described in this issue. Each of the following circuits will be
shown in its bellwether configuration, but it should be borne in mind that by
omitting all but the bellwether INCREDUCTOR unit, it becomes a closed-loop circuit.

## Wide-Band Discriminator

Figure 7-1 shows a wide-band discriminator in a bellwether circuit designed to stabilize the operation of an INCREDUCTOR-tuned broadcast band radio. The reference frequency in this circuit is obtained from the local oscillator. With the receiver properly tuned, the local oscillator will be set properly and the discriminator output will be zero. Should the circuit drift from the desired frequency, the rectified discriminator output will add to the control winding current of the INCREDUCTOR units, retuning the receiver to the desired frequency.

Discriminator ($R_1$, $L_1$ and $C_2$) is tuned to 2,150 kc or slightly above the maximum oscillator frequency of 2,105 kc. Maximum discriminator output is obtained at the minimum frequency of the oscillator. A negative DC signal, rectified by $CR_2$, appears across capacitor $C_3$, and its amplitude is inversely proportional to local oscillator frequency.

A high-pass filter, $L_2$ and $C_2$, with cutoff frequency considerably below the minimum oscillator frequency passes the full amplitude of the oscillations, rectifies them through $CR_1$, and applies a positive voltage to capacitor $C_4$.
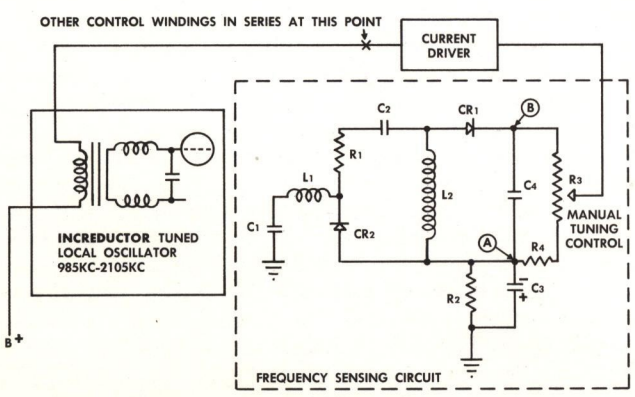


FIGURE 7-1. WIDE BAND DISCRIMINATOR

Thus, point "A" is at a large negative voltage when the oscillator is at minimum frequency, but decreases almost to

zero as the oscillator frequency increases. Point "B" is at a small positive voltage when the oscillator is at minimum frequency, gradually increasing to a large positive voltage as the oscillator frequency reaches maximum.

Potentiometer $R_3$ is the manual tuning control. Some point along the potentiometer is always at zero potential because point "B" is always positive and point "A" always negative. A given zero point on the potentiometer always corresponds with the same oscillator frequency. Should the local oscillator frequency drift, the potentiometer will not be at zero, and this error voltage will then be applied to all the INCREDUCTOR control windings, returning all of them to the correct inductance and frequency.

An advantage of this circuit is that the position of the zero voltage point depends only upon the *relative* voltages between terminals "A" and "B." Any changes in oscillator output amplitude affect both points "A" and "B" together; thus, amplitude variations are cancelled out and the circuit is sensitive only to frequency changes.

## Narrow-Band Discriminator

Where the frequency range of the equipment to be controlled is relatively narrow, a narrow-range discriminator utilizing a Wien bridge can be used. (See Figure 7-2.) In this case, a very precise control of frequency is possible because of the accuracy with which the Wien bridge can be made to operate. The frequency range of the circuit is narrow and the upper limit at which this circuit will operate is limited. In addition to the accuracy of frequency, the circuit has the additional advantage that the null is sharp. The circuit uses easily obtainable commercial components.

In operation, the output of the oscillator is applied through transformer $T_1$ across the Wien bridge. The Wien bridge is tuned to have a null at the frequency at which the oscillator is to be tuned. The output of the Wien bridge and a sample of the oscillator frequency are applied to the phase detector. If the output of the Wien bridge is zero, the phase detector is balanced and equal and opposing currents flow in its upper and lower branches producing a minimum output.
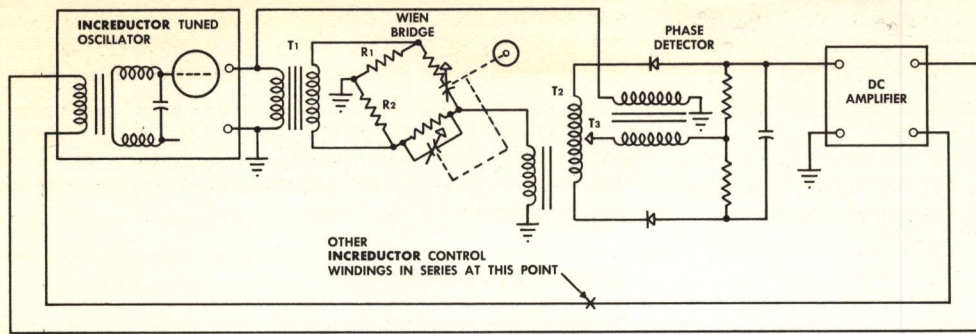
FIGURE 7-2. NARROW-BAND DISCRIMINATOR

Should the oscillator drift off frequency, the Wien bridge output will unbalance the detector, and it will produce a DC output whose polarity depends upon the direction or error. The amplified error voltage is applied to the control windings of all the INCREDUCTOR units, adjusting them to the proper frequency.

The capacitors in the Wien bridge are shown as adjustable components. This can be for alignment purposes. The circuit will perform quite well even though the oscillator is set for a fixed frequency. Drift in the DC amplifier is not a problem, because the feedback action of the circuit automatically corrects for drifts, too.

Note that the oscillator does not have to operate at the same frequency as the other INCREDUCTOR-tuned circuits. The basic requirements are: (1) that the oscillator be INCREDUCTOR-tuned and (2) that the INCREDUCTOR unit used to tune it be constructed of the same core material as the other INCREDUCTOR units being controlled. In practical circuit work, the oscillator INCREDUCTOR unit and the other INCREDUCTOR units would be tracked sets.

In the circuit as described, the oscillator serves only the function of providing a reference frequency for the bellwether circuit. However, it is also possible to select an oscillator that is being used as part of the circuit being controlled — for example, the local oscillator in a receiver. It would then be necessary to change the null frequency of the Wien bridge in step with the oscillator. This could be done by substituting vacuum-tube amplifiers for Wien bridge resistors $R_1$ and $R_2$ causing the impedance of one to rise as the other is lowered.

In another variation of this circuit it is possible to eliminate the DC amplifier by raising the level of the signals fed into the phase detector. This can be done by adding an AC amplifier just before transformer $T_2$ and another just before transformer $T_3$.

## Self-Tuned Discriminator

Tuning a discriminator circuit increases the precision of control — that is, it increases the sharpness of the null. At the same time, the tuned discriminator is effective over a very limited range. As the input frequency changes, the discriminator output voltage increases rapidly; however, the output voltage decreases rapidly to zero if the input frequency deviates more than a given amount. Therefore, in a control system using such a tuned discriminator, when the frequency drifts off center so far that the discriminator output is reduced nearly to zero, the stabilization circuits lose all control.

The self-tuned discriminator circuit overcomes this objection — the signal winding of an INCREDUCTOR unit forms part of the discriminator tuning circuit so that the center frequency of the discriminator is always the same as the frequency to which the oscillator is to be held.

The graph of Figure 7-3A shows the discriminator step function, the diagonal portion of the curve representing the stable operating range. High Q circuits give large outputs in the vicinity of resonance but fall off at applied frequencies far from the resonant point of the circuit. A low-Q circuit on the other hand more closely approximates the desired step

function but shows smaller amplitudes and hence less sensitivity. It may be seen that for the purposes of this control loop any output is acceptable which has a steep characteristic near the crossover point and, where not in the vicinity of resonance, produces a greater voltage than the minimum necessary to actuate the feedback loop. This minimum will depend, of course, on the effective gain of the DC amplifier.
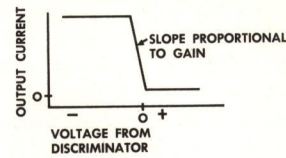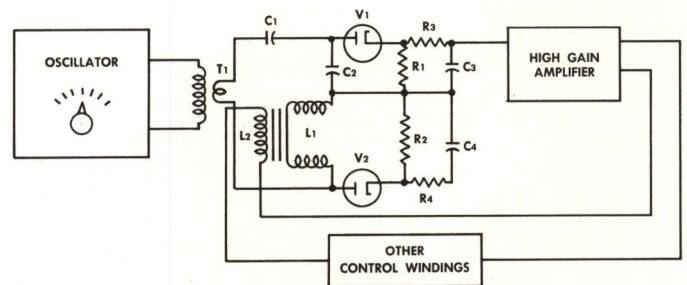


FIGURE 7-3A



FIGURE 7-3B.

FIGURE 7-3 SELF-TUNED DISCRIMINATOR

The circuit operates in the following manner. (See Figure 7-3B) If the applied frequency is equal to the center frequency to which the discriminator is tuned, the voltage across $C_1$ will equal that across $L_1$ (the signal winding of the INCREDUCTOR unit), the two will be 180° out of phase, and the net output voltage will be zero. At frequencies above resonance, the inductance will predominate and a negative output will be produced. At frequencies below resonance, the capacitance will have the larger voltage developed across it and a positive output will be developed. Rectified and amplified, the signal is then fed back to the receiver control windings and the control winding of the INCREDUCTOR unit in the discriminator. This error signal acts to bring the discriminator back to the center frequency of the oscillator, and also to reset the receiver control windings so that the receiver tuned circuits are properly set.

When operating at relatively high frequencies, the signal winding does not present a pure inductance to the circuit but has significant associated capacitance effects. Accordingly, the frequency at which the maximum voltage is developed across the inductor $L_1$ does not coincide with the exact frequency at which the inductive reactance is equal to the capacitive reactance of the inductor. For this reason, the capacitive portion of the network is formed by the series connection of capacitors $C_1$ and $C_2$ and only the voltage appearing across capacitor $C_2$ is used to develop the DC voltage across capacitor $C_3$. The relative values to be selected for these two capacitors will depend upon the frequency of operation and upon the amount of capacitance associated with the signal winding $L_1$.

In constructing this circuit for high-frequency use, the oscillator is completely shielded from the discriminator section and the desired coupling is achieved through a Faraday shield. The Faraday shield is necessary to eliminate capacitive coupling from the oscillator section of the discriminator. The secondary of coupling transformer $T_1$ consists of a single turn

of heavy copper strap. Care must be taken to have the inductance of this turn as low as possible since any inductive voltage appearing across this coil is not measured by the diodes but acts as a voltage divider to decrease the output of the circuit and hence to decrease the overall gain.

In an apparatus designed for operation between 50 and 100 megacycles, capacitor $C_4$ had a value of about 800 micromicrofarads. It was formed by a mica sheet interposed between the brass plate which supported the discriminator and the metal chassis which formed the common ground circuit.

## Remote-Control Bellwether

A virtue of the controllable inductor is that its inductance can be controlled from a distant location. The bellwether circuit shown in Figure 7-4 utilizes a remotely-located tuned discriminator in which the manually varied inductance serves as the tuning control for the equipment. Use of crystal diodes in lieu of filament-operated stages allows use of a remotely controlled stage with no power requirements.

With signal source and discriminator set for the same center frequency, the error voltage output from the discriminator is zero. If the tuning control is then manually varied, an error voltage will be generated that will be amplified and fed to the control windings of the INCREDUCTOR units, including the one that controls the inductance of the signal source resonant circuit. The signal source is then returned to the center frequency of the discriminator and the error voltage drops to zero as the system stabilizes. Should hysteretic effects or temperature changes cause frequency drift, the error voltage produced will again initiate a sequence of operation that will retune the signal source to the discriminator center frequency.

Both the AC signal from the oscillator and the DC discriminator output travel over the same shielded cable. Impedance at the discriminator end of the cable is always low since the series resonant circuit has low impedance near the center frequency. Hence stray or shunt capacity appearing between the connecting cable and the common ground circuit will have negligible effect on the operating frequency of the system.

This is a narrow-band discriminator. It always operates on the most sensitive portion of its range so that relatively large signals are produced by small deviations between the frequency of the signal source and the resonant frequency of the discriminator network. Sensitivity of the tuning circuit increases as the L/C ratio of the discriminator network is made larger in comparison with the source resistance at the discriminator end of the cable. In practical tuning circuits, the discriminator network is made to have a relatively high
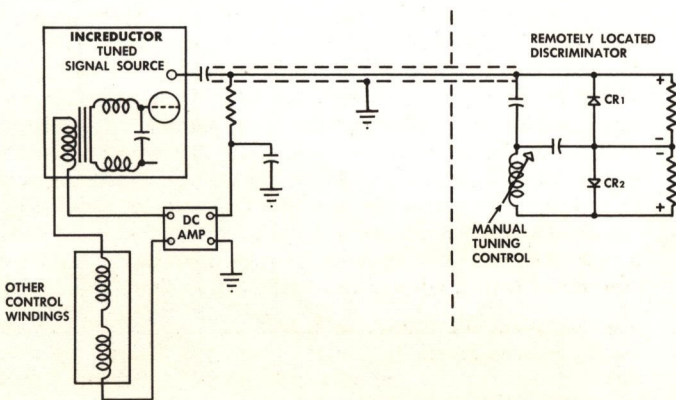
"Q" which causes the voltage appearing across the inductor and capacitor to be large when the applied frequencies are near the resonant frequency of the network. Thus a relatively large control voltage is produced at the cable input by relatively small changes in the frequency of the signal source with respect to the resonant frequency of the discriminator. With this large output, a DC amplifier of less gain and hence greater stability can be used.

## Linear Closed-Loop

All the closed-loop control circuits previously considered have been designed primarily to reduce the effects of hysteresis and temperature variations so that the frequency of the tuned circuits would remain constant. In doing this, the control circuit incidentally reduced non-linearity. In the circuit shown in Figure 7-5, however, reducing non-linearity is the principal consideration. The basic requirement is that INCREDUCTOR-tuned oscillator $V_3$ generate a frequency that is linear with the voltage applied to the input. $L_1$, the inductive portion of the tuned circuit is the signal winding of an INCREDUCTOR unit. $C_1$ completes the resonant circuit. $L_2$, the bias winding,
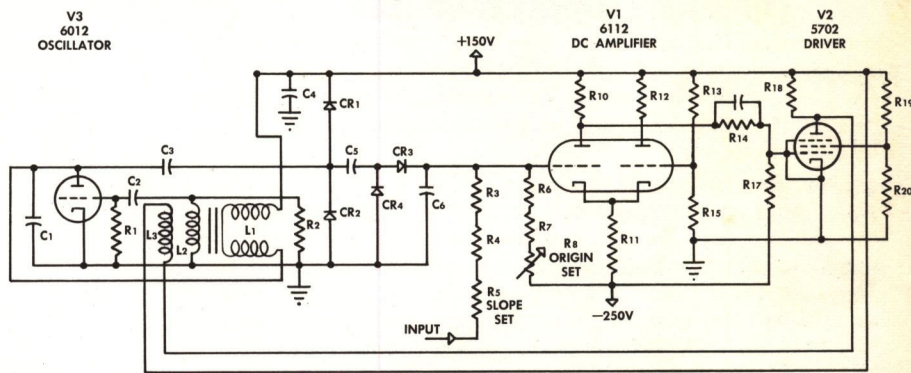


FIGURE 7-5. LINEAR CLOSED-LOOP CIRCUIT

is placed in the grid leak circuit and establishes the proper operating point for the INCREDUCTOR unit.

The feedback loop is closed through stages $V_1$ and $V_2$. A DC input voltage is applied to the grid of the left section of $V_1$ through several precision resistors. Bias for $V_1$ is established through the action of resistors $R_6$ through $R_8$. Now consider the action of the discriminator circuit. A sample of the output frequency is taken from the junction of $L_1$ and $C_1$. These oscillations are then clipped both top and bottom by the action of $CR_1$ and $CR_2$. The square wave so produced is applied to a counting discriminator consisting of $CR_3$, $CR_4$ and $C_6$. This is an extremely linear form of discriminator with the current produced through $C_6$ proportional to the number of pulses received in unit time. That is to say, it is proportional to frequency. This error current is combined at the junction of $R_6$ and $R_9$ with two other currents — the input current and the bias current. The combined currents produce the voltage at the input to $V_1$ which is amplified and used to drive $L_3$, the INCREDUCTOR control winding so the oscillator is at the desired frequency.

This is a wide-range discriminator type of closed-loop circuit which can be designed to operate to 4 or 5 megacycles. The upper limitation is determined by the capacity of $C_6$ in the counting discriminator. The linearity of the circuit depends upon the flatness of the clipped signal and the precision of the resistors which bias DC amplifier $V_1$ and attenuate the input signal. Resistors $R_3$, $R_4$, $R_6$, and $R_7$ should be metal film resistors. Potentiometers $R_5$ and $R_8$ should be wire-wound types.

The circuit features excellent speed of response in use with a 500 kc oscillator. As far as possible, only resistive components are used in stages $V_1$ and $V_2$ so that speed of response will not suffer. The principal factor determining the speed of the circuit is $R_{18}$, which shunts the INCREDUCTOR control winding.



FIGURE 7-4. REMOTE CONTROL BELLWETHER

# 81AM1 INCREDUCTOR® CONTROLLABLE INDUCTOR

**Miniature Size** **UHF-VHF** **Hi-Q**

The Type 81AM1 INCREDUCTOR Controllable Inductor is designed for electronic tuning applications in the VHF-UHF frequency region. The unit features reduced size and improved electrical performance. It is epoxy encapsulated, with the exception of the signal winding which is impregnated to eliminate the effects of humidity.

81AM1 units are normally furnished with a 4-40 NC 2A chassis mounting stud and both pierced and pin lug terminations for the control and bias windings. The pierced lugs are for use with conventional wiring, and the pin lugs are for use in printed or wire wrap circuits.

Units meeting military specifications are available on special order.

## TYPICAL CHARACTERISTICS

### Signal Winding:

| | |
|---|---|
| Suggested operating frequency | 50-400 mc |
| Frequency change ratio (with less than ¼″ leads) | 2:1 |
| Nominal maximum inductance | 0.2 $\mu$h |
| Maximum Q | 70 |
| Maximum hysteresis effects | 2.7% of frequency |

### Control Winding:

| | |
|---|---|
| Current for 2:1 frequency range | 70 ma max |
| Inductance | 410 mh |
| Resistance | 245 ohms |

### Bias Winding:

| | |
|---|---|
| Typical current | 5 ma |
| Inductance | 110 mh |
| Resistance | 330 ohms |
| Approximate sensitivity | ½ that of the control winding. |
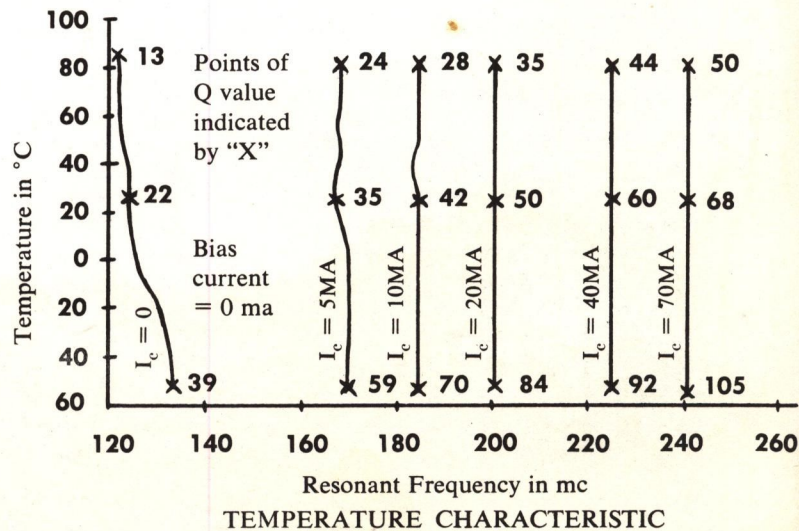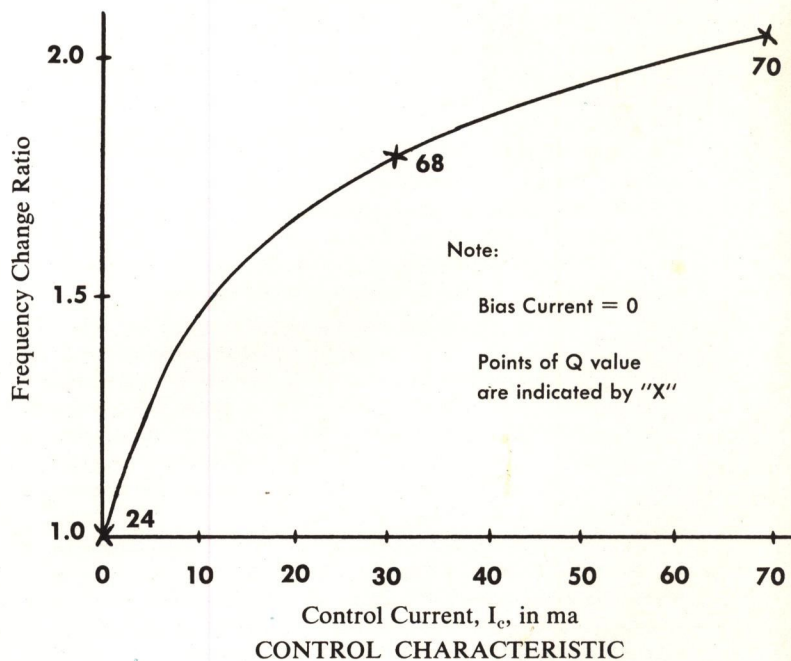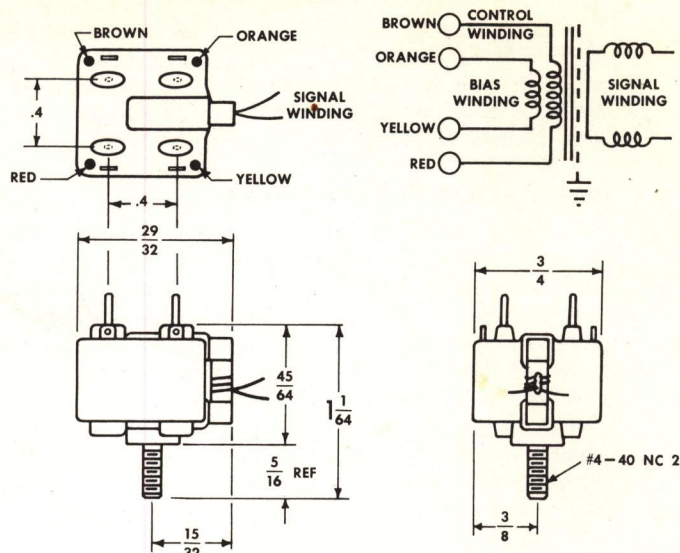
MAGNETIC COMPONENTS DEPT.

## TRAK ELECTRONICS COMPANY
*Division of CGS Laboratories Inc.*

**59 DANBURY ROAD (ROUTE 7) WILTON, CONNECTICUT**

*Telephone POrter 2-5521*

CONTROL CHARACTERISTIC

Note:

Bias Current = 0

Points of Q value are indicated by "X"

TEMPERATURE CHARACTERISTIC