THERMAL STABILITY in RECEIVER OSCILLATORS—II

By RALPH R. BATCHER
Consulting Editor, Electronic Industries

A survey of the fundamental causes for oscillator drift by temperature effects, leading to the selection of a suitable compensation device

● In part I, certain conditions were analyzed where the physical assembly of a tuning capacitor affected the frequency drift of the circuit. Another cause for drift is often encountered that may result in even larger changes—that of the dial mechanism. Every set, at least when it is of console dimensions, has its own tuning control design, so it is impossible to bring out universally applicable suggestions here.

In some cases it is a three-way problem: the capacitor rotor, the frequency indicating pointer or dial, and the driving knob each being on different shafts linked together by gears, cords and pulleys or some friction device. These linking mechanisms have expansion stresses with temperature changes which have to be relieved, and it may be found that any one of these three items may change.

Since the control knob rotation usually is geared down to turn the capacitor shaft it is generally the last to shift. On the other hand, the capacitor shaft is free running and moves first. The movement may be either rotational or radial. The latter, to a certain extent, produces warping of the whole condenser structure.

Very few tuning capacitors, designed in the price range necessary for use in receivers, will stand much of this pressure on the shaft, without introducing large and erratic frequency shifts. Although it sometimes happens that these shifts accidentally compensate for other variations, unless the structure is rigid enough to withstand such pressures, the use of friction or pressure discs or cords should be avoided. The temperature/frequency drift rate so introduced is unpredictable and is not repeatable even in a single set.

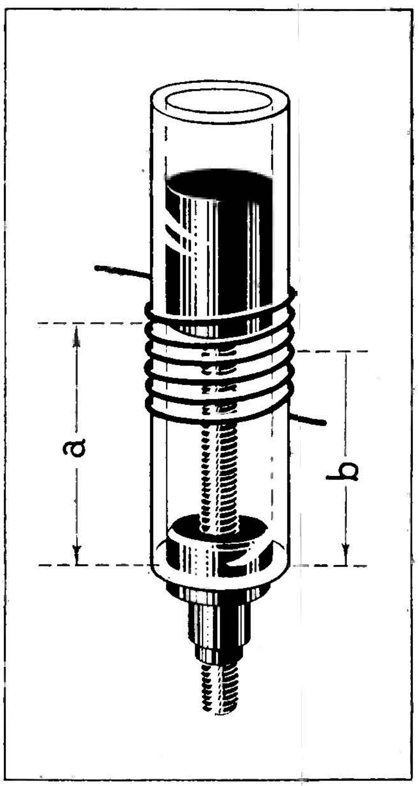


Fig. 1—A typical permeability tuned coil. Different temperature effects can be found if the expansion length of the screw is more or less than the distance along the winding form, to the winding center, although the same total inductance may result in either case

In one case it was found that opposite humidity and temperature drift effects were produced by a simple change of the location of the tension spring in the string of a cord and pulley drive! The shrinking or expansion of the cord due to either factor could thus be made to rotate the condenser shaft either clockwise or counter-clockwise as desired. A study of any proposed drive design for such possibilities should always precede its tooling up to avoid inviting large and uncompensatable drift troubles.

Inductance drift

So far, attention has been called to certain outstanding sources of instability in the tuning capacitor in the circuit. Notwithstanding best intentions, however, a certain amount of drift is inevitable, so that some compensation is always necessary if a low order of drift is to be attained. Before the proper kind and amount of stabilization can be determined it is necessary carefully to analyze the records of the average drift actually found and to discover the "probable" cause. The qualifying word "probable" is used because the thermal drift in some elements follows unusual laws and produces unpredictable curves.

A single layer inductance, wound in a grooved form, may have a variation in length that is controlled by the expansion of the form material, while its diameter may depend on the expansion rate of copper. If the expansion rates of the diameter and length were equal, one would expect that the inductance would change in direct proportion to the change in any one dimension with temperature. Also if the length could be made to increase twice as fast as the diameter, the temperature effect on the inductance would be zero.

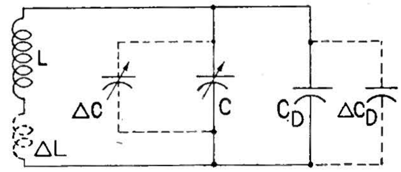
However, it is necessary that the wire be wound with enough tension so that it remains tight at all temperatures to be encountered. In this case the temperature coefficient depends entirely on the expansion rate of the form material, since diameter and length are both affected at the same rate, and little can be done practically to utilize this method of securing a low coefficient.

In circuits using multilayer coils (as for example the diamond weave or self-sustained type) other effects are to be noted. Here the diameter of the first few layers may be influenced by the expansion of the form, but the rest of the layers depend on the expansion rate of copper. The length of the winding may follow one of several variation laws, since the wires have a tendency to spread out or contract sideways to equalize strains in any direction, like an accordion.

If impregnated with wax, the length depends upon the expansion of the wax, while the diameter depends largely on the expansion of copper. It is even possible to use a wax that gives a negative coefficient of inductance drift with temperature, if it expands enough! Proper impregnation is the most important factor in coil design as far as low drift rate is concerned, but the correct wax for one coil shape ratio may be the wrong type for another.

The thoroughness of waxing is a deciding factor and the expansion rate changes enormously if a heavy dip in melted wax is replaced by a light dip, or if the impregnation is accomplished by evaporation with the use of waxes dissolved in a solvent. In passing, attention is also directed to the ever-present shift in the distributed capacitance of a coil, as the impregnating compound is changed. Waxes have large temperature coefficients in their dielectric constant characteristics, so that even if all other effects are accounted for, this factor may complicate the correction curve. Luckily this variation is of the type that is accurately handled by negative coefficient ceramic trimmers or bimetallic capacitors of other types.

Fig. 2—Basic tuning circuit of an oscillator or amplifier. C represents the adjustable portion of circuit capacitance; the elements with triangle prefixes are increments (either positive or negative) produced by temperature, etc.



It is possible to measure the drift of the distributed capacitance coefficient quite easily by considering the multilayer impregnated coil as a capacitor and connecting it in shunt with another coil with a much lower inductance value, and making measurements at a frequency a couple of decades higher up the range.

All plastics have a large coefficient of expansion, compared with metals. At times this can be utilized in producing a negative inductance variation coefficient. For example, a layer wound rf coil on a bakelite or polystyrene tube normally will be considered to have a positive coefficient, so that the inductance goes up with temperature. In the usual mounting arrangement with permeability tuning, the core slug will move relative to the coil, by an amount depending on the relative expansion rates of the coil form and the screw mounting of the slug. If this expansion pushes the two together at increased temperatures, a positive coefficient will result. If they move apart, a negative coefficient is found. In Fig. 1, the tuning slug moves in accordance with the expansion rate of brass, but the winding moves at a greater rate, that of polystyrene.

If desired, the slug can be moved even greater distances by the movement of a thermostatic bimetallic strip. Study of the curves in Fig. 3 will show the compensating trends of a variable inductance compared with a capacitor type and indicate which is preferable for a given circuit. It has been shown* that a typical coil wound on a polystyrene tube may have either a positive or a negative coefficient depending on whether the tube thickness is greater or less than ⅛ in.

Compensation

There are two general methods of approach to the frequency stability problem: improvement in the operating stability of each component, or the application of corrective means for neutralizing the overall shift that is found in a well-designed setup. Corrective measures will be effective only when they follow up the original shift at the same rate, considering both temperature and frequency.

Consider a simple basic resonant circuit, Fig. 2. Here C_D is assumed to include all capacitance in the circuit when the tuning capacitor is entirely unmeshed. As mentioned in Part I the resonant frequencies at two temperatures are:

$$f = K/\sqrt{L(C + C_D)} \qquad (1)$$

$$f' = K/\sqrt{(L+\Delta L)(C+\Delta C + C_D+\Delta C_D)} \qquad (2)$$

$$(f/f')^2 = (1+\Delta L/L)[1+(\Delta C+\Delta C_D)/(C+C_D)] \qquad (3)$$

$$= (1 + A)(1 + B + D) \qquad (4)$$

where

$$A = \Delta L/L; \quad B = \Delta C/(C+C_D); \text{ and } D = \Delta C_D/(C+C_D) \qquad (5)$$

$$(f/f_1)^2 - 1 = R^2 - 1 = A + B + D \qquad (6)$$

In the above the Δ factors represent the increments in the values of the respective factors caused by some operating change. They may be either positive or negative. In obtaining eq. (6) from (4) the second order effects AB and AD can be ignored.

To utilize this relation the value of R must be obtained at several frequencies by direct measurement.

In this analysis the value of C is assumed to be the incremental capacitance of the variable capacitor since its "zero" capacitance has been lumped in C_D. Then ΔC represents the shift due to normal rotational movements of the rotor.

The relation in (6) shows that shifts of equal per cent magnitude in any one of the three components will produce equal changes in frequency. Over the complete frequency range, a straight line law does not exist, however, because of the change in C and ΔC as the tuning is changed, a square law difference between f and C being found. It will be found, however, that it is impossible to accurately apply eq. (6) to interpret experimental data so as to determine the importance of A, B or D, even by making complete temperature-frequency runs at numerous points within the operating range.

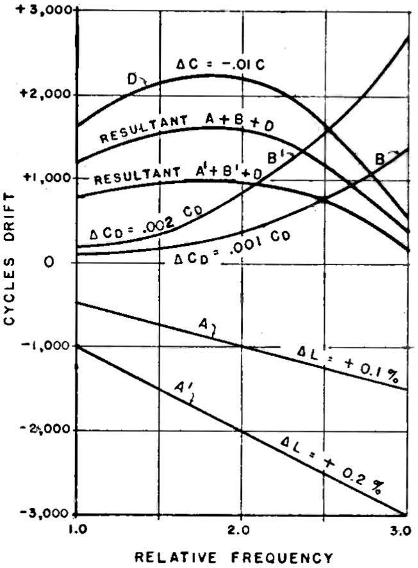


Fig. 3—Typical frequency drift trends from various circuit components

There are several analytic expedients that will prove of value if another assumption is made: that the value of L and ΔL (or A) does not change with frequency, at least within a narrow frequency range of say 2:1. It is possible to eliminate the effect of the variable capacitor (that is item B) by the simple process of turning it so that the plates are entirely unmeshed and making a temperature run in this condition. In this case (6) reduces to $R^2 - 1 = A + D$.

It can be assumed, following the above definition of D, that its value does not change with frequency, although its effect is dependent on a "cube law" relation.

This is an important relation, since means for obtaining temperature compensation by the use of ceramic capacitors with large temperature coefficients (either negative or positive, as the case requires) provides a correction that follows this rule.

This cube rule is an approximation but is essentially correct when $C' >> \Delta C$ and $C' < C$. Here ΔC is a capacitance increment that may occur at any point in the tuning range, and C' is the capacitance at the highest frequency point (f') of the range, and C is some other

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*"Polystyrene Applied to Radio Apparatus," RCA Review, Oct., 1939, page 203.

capacitance at a lower frequency (f) in the range. The rule states that the relative frequency increment caused by ΔC is very nearly proportional to $(f'/f)^3$. For example, if the useful tuning range is 2.8:1, a capacitance shift of 1 mmf will cause $2.8^3 = 21.95$ times as much frequency shift at the high frequency end of the range as at the other end. Using the common relations between f and C, it can be shown that:

$$\Delta f/\Delta f^{1} = \frac{K/\sqrt{C} - K/\sqrt{C + \Delta C}}{K/\sqrt{n^2 C} - K/\sqrt{n^2 C + \Delta C}} \qquad (7)$$

$$\text{where } n = f^{1}/f \qquad (8)$$

$$\Delta f/\Delta f^{1} = \frac{n(\sqrt{C + \Delta C} - \sqrt{C})(\sqrt{n^2 C + \Delta C})}{(\sqrt{n^2 C + \Delta C} - n\sqrt{C})(\sqrt{C + \Delta C})} \qquad (9)$$

Assuming that C>>ΔC, which is correct in practical cases, as when ΔC is the capacitance variation due to thermal expansion effects only, then

$$\overline{\;C} = \sqrt{C} + \frac{\Delta C}{2\sqrt{C}} + \frac{\Delta C^2}{4C} \qquad (10)$$

and

$$\sqrt{n^2 C + \Delta C} = n\sqrt{C} + \frac{\Delta C}{2n\sqrt{C}} + \frac{\Delta C^2}{4n^2 C} \qquad (11)$$

Substituting (10) and (11) in (9) and omitting terms containing $(\Delta C)^2$.

$$\Delta f/\Delta f^{1} = n\left(\frac{2n^2 C + \Delta C}{2C + \Delta C}\right) \qquad (12)$$

$$= \frac{2n^3 C + n\Delta C}{2C + \Delta C} \qquad (13)$$

This relation (13) becomes an important factor in the application of temperature compensation of the capacitive type. Since the important term is the first term in the numerator, it means that at two frequencies anywhere in the operating range (f) and (f'), the respective frequency - increments (Δf) and (Δf') have values inversely proportional to the cube of the ratio between f' and f. Thus, if a 10 mmf compensating capacitor having a characteristic giving 750 parts per million change per degree follows a 20 degree temperature shift (0.15 mmf absolute change) and causes a frequency change of 5,000 cycles at one megacycle, it would cause a change of 40,000 cycles at the two megacycle point on the dial if the only difference between the settings is the position of the tuning capacitor rotor.

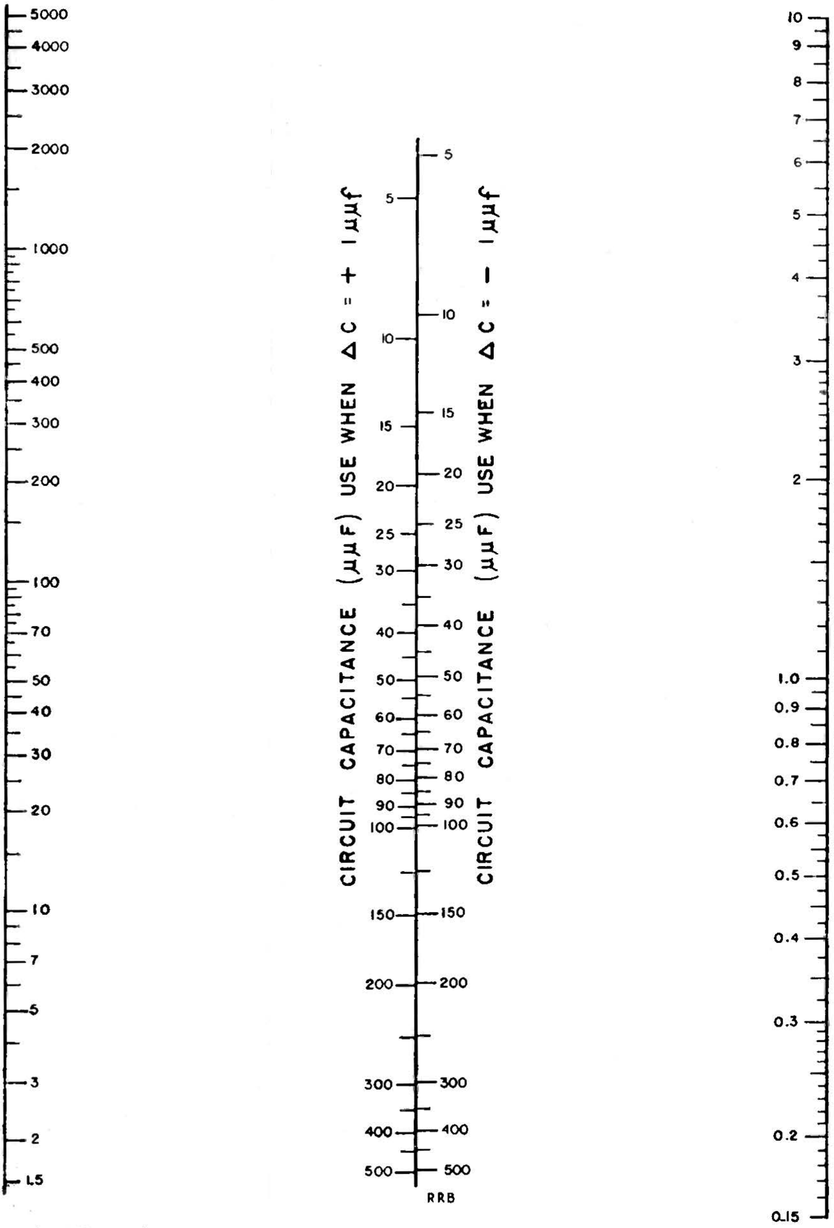

Fig. 4—Effect of 1 μμf incremental capacitance on frequency shift under various circuit parameters

A chart, Fig. 4, may be found of interest in determining the frequency shift caused by a small capacitance increment under various circuit conditions. Knowing the actual frequency shift at any point in the range, it is possible to determine the required corrective capacitance to compensate for this shift. Application of this cube rule will show the resulting change at other frequencies in the range.

It is desirable that a plot be made of the data obtained in any frequency run, as the resultant curve in Fig. 3. From these data, it is often possible to estimate the probable cause for any shift discovered and to estimate the best procedure—whether inductive compensation or capacitive compensation should be used. To improve the resultant curve A + B' + D in Fig. 3 still more, it would be necessary to increase ΔL/L to about 0.25 per cent (that is—actually to make the coil "worse") and to add more

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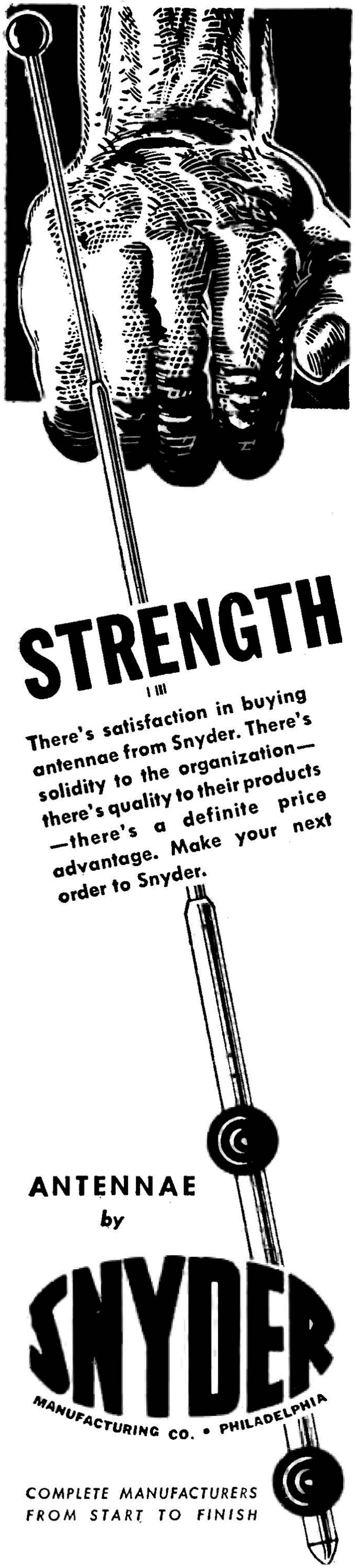
Relative frequency	$C + C_D$	C when ($C_D = 36$)	$\frac{\Delta C}{C} = .01$ (assumed)	Relative effectiveness of C. (cube rule)	Δf (relative)
3	40	4	$\Delta C =$ .04	27.	1.08
2.5	57.6	21.6	.216	15.62	3.37
2.0	90.0	54	.54	8.00	4.32
1.5	160.	124	1.24	3.37	4.18
1.0	360.	324	3.24	1.00	3.24



THERMAL STABILITY

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negative-coefficient capacitance as well, to about 0.0025.

The effect of a certain percentage change in inductance is a linear shift, that is proportional to the frequency, as indicated in curve ΔL in Fig. 3. Percentage changes in the value of C, however, follow an entirely different variation law, as indicated in the curve ΔC in this figure. Also, as will be shown, changes in ΔC_D follow a different law, the above cube rule. A combination of all three circuit parameters produces a wide variety of drift relations, as might be seen by looking at the resultant curve Δf obtained by adding together the three individual curves that are shown in Fig. 3.

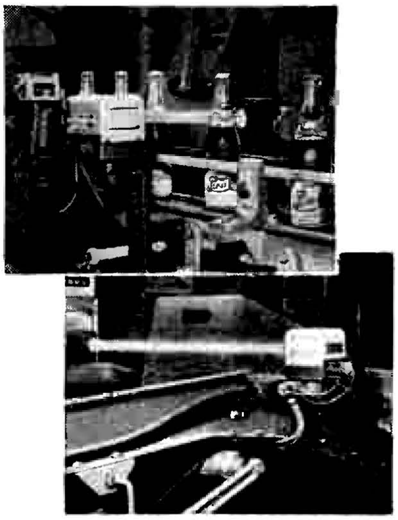
The curve for $\Delta C/c = .01$, Fig. 3, is obtained from the table on page 95. Although all values are assumed, they are of a magnitude that can possibly occur in practice. In other words, if the tuning capacitor can be assumed to have a fixed thermal coefficient so that $\Delta C/C$ is a constant, the frequency shift would follow a curve plotted from the data in the last column.

The previous analysis has been concerned with the frequency drift in oscillators caused by thermal variations. In the first place, the setting of the oscillator may not be the only factor that determines the frequency that will be received. Also, tube voltage parameters can cause substantial changes in frequency, but this latter is largely a design factor, involving mainly the location of the tap on the oscillator coil. This problem will not be considered here.

Drift compensation

If the oscillator frequency is higher than the incoming frequency, its thermal drift is sometimes assumed to be compensated partially by the drift of the if stages. The extent to which this takes place depends upon the relative frequencies of the oscillator and the if. An .001 per cent change in frequency in a 55 megacycle oscillator is equivalent to a .005 per cent change in the if (11 megacycle) stages of the receiver. In the latter case, however, there is a fixed frequency shift at any temperature variation, while in a variable frequency oscillator the drift is rarely constant over the range. Although keeping the oscillator frequency higher than the input frequency will only produce a partial correction, it still should be considered in any design since it is well to have all factors work toward improving conditions rather than making them worse.

It is hoped that this review of some of the common causes of fre-



quency drift will point out possible corrective methods when a given circuit must be improved. There is nothing that is so bothersome as to have to readjust the tuning of an FM or television receiver after each 5 or 10 minutes operation during the first half hour's operation, to keep the signal tuned in.

From tests at several points in the tuning range, it is usually possible to discover whether improvements should be made in certain components or whether a ceramic compensator with a definite drift rate can be used, or whether a bimetallic strip is applied to alter the inductance (as by shifting the permeability tuning slug) of either the oscillator coil, or the if transformer coils.

RADAR SYSTEM

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across the gap will prevent energy from being transferred to the output cavity and consequently damaging the receiver.

Some antenna arrays suitable for radar use are stacked dipoles with an untuned reflector; a radiator with tuned reflectors; and the dipole with parabolic reflector. In the case of the parabolic reflector very narrow rf beams can be produced where the diameter of the reflector is large in comparison to the wavelength. In the microwave region where wave guides are practical, the antenna may take the form of horns, or other impedance matching wave launcher.

Radar receivers

Since radar frequencies are high it is difficult to obtain sufficient amplification. The superheterodyne principle may be used and components of high stability and sensitivity are required. A block diagram of such a receiver is shown in Fig. 10. In general the power rf signal is fed directly to the mixer tube. The mixer and local oscillator are located close to the T junction of the transmission line in order that the received rf energy may be converted to a lower frequency before being passed on to the remaining elements of the receiver. Such a receiver is typical of UHF practice. The mixer is a non-linear element such as a diode, or mineral crystal. The frequency conversion elements must be located close to the transmission lines to minimize rf losses. Multiple frequency conversion is essential to high gain if amplifiers.

The output of a conventional second detector is fed into a wide band amplifier typical in many respects to the video amplifier in television receivers. The output of this amplifier is connected to the cathode ray indicator system. *(Turn page)*