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A SIMPLE METHOD OF PRODUCING WIDE-BAND FREQUENCY MODULATION

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ABSTRACT The three-phase R-C tuned radio-frequency oscillator developed by Rakshit and Bhattacharyya (1946) can easily be made to generate frequency-modulated oscillations by varying the tuning resistance of one of the three stages in the oscillator. It has been found that if frequency modulation is produced by shunting any of the three oscillator valves by a triode with the modulating audio voltage on its grid, faithful wide-band modulation can be realised under proper adjustments Frequency stability of the central unmodulated carrier has been attained by incorporating an automatic frequency-control system involving a phase discriminator. The experimental arrangement is fully described in the present paper and a typical set of results with a 1 44-megacycle carrier is presented. The preliminary observations have already given very good results and further studies are in progress.

INTRODUCTION

The R-C tuned oscillator is well known as a very good generator of audio frequency oscillations. Rakshit and Bhattacharya (1946) have pointed out, however, that the conventional circuit of a three-phase system, with components selected for producing audio frequency oscillations, invariably generates radio frequencies by virtue of the unavoidable stray and inter-electrode capacities. In fact, with the simple three phase oscillator it is impossible to generate audio frequencies unless certain modifications are introduced in the circuit. It was further pointed out that the three-phase radio frequency oscillator can easily be made to generate frequency-modulated oscillations by varying the tuning resistance of one of the oscillator stages by the modulating voltage.

In a recent communication by the authors (Rakshit and Sarkar, 1949) it has been reported that if frequency-modulation is produced by shunting any of the three oscillator valves by a triode and applying the modulating audio voltage on the grid of this triode modulator, faithful wide-band modulation can be realised under proper adjustments. The present paper gives the details of the observations.

THEORETICAL CONSIDERATIONS

When the three stages are identical one of which being as shown in Fig. 1, and the anode load of each valve is composed of resistance r_1 shunted

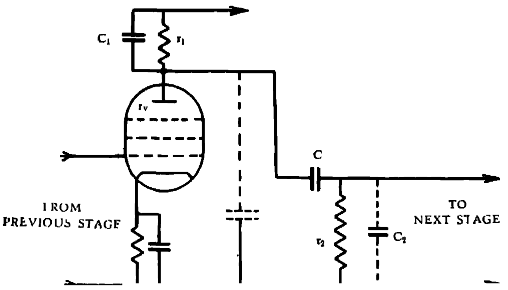

FIG. 1

One of the three stages in oscillator

by capacity C_1 it has been shown that the oscillations produced are of radio frequency given approximately by

$$f = \frac{\sqrt{3}}{2\pi r_1 (C_1 + C_s)}, \qquad \ldots \quad (1)$$

when r_2 as also the anode impedance r_v of valve $>>$ r_1 and $C_2 << C$. The quantity C_s in the above expression denotes the total stray capacity on both sides of the coupling condenser C. In regard to C_1, it will be noted that the performance of the system remains unaltered if it is connected between anode and cathode. In practice the three condensers C_1 of the three stages are replaced by a three-gang condenser between the common H.T. negative line and the three anodes.

Let us consider the case in which the three stages which are otherwise identical in every respect have load resistances r_1 for the two and r for the third stage. If p be the angular frequency of the generated radio frequency oscillations, the phase shift in either of the first two stages having load resistances r_1 is given by

$$\phi_1 = \phi_2 = \tan^{-1} \frac{1 - p^2 r_1 r_2 C (C_1 + C_s)}{p C r_2}$$

when $C >> C_2$ and $r_2 >> r_1$. With further approximation

$$\phi_1 = \phi_2 = \tan^{-1} [-p r_1 (C_1 + C_s)] \qquad \ldots \quad (2)$$

The phase shift produced by the third stage is

$$\phi_3 = \tan^{-1} [-p r (C_1 + C_s)] \qquad \ldots \quad (3)$$

The total phase shift produced by the three stages is

$$\phi = 2 \tan^{-1} [-p r_1 (C_1 + C_s)] + \tan^{-1} [-p r (C_1 + C_s)] \qquad \ldots \quad (4)$$

The gain of a stage with load resistance r_1 is given by

$$\text{gain} = \frac{g r_1 r_2 p C}{\sqrt{[\{1 - p^2 r_1 r_2 C (C_1 + C_s)\}^2 + (pCr_2)^2]}}$$

In the symmetrical case it has been shown by Rakshit and Bhattacharyya (1946) that, as a first approximation, $pC_1 r_1 = \sqrt{3}$. Here also, as the variation in frequency is very small, $pC_1 r_1 \simeq \sqrt{3}$ and hence

$$p^2 r_1 r_2 C (C_1 + C_s) = p r_1 (C_1 + C_s) p C r_2 >> 1$$

since

$$r_2 >> r_1.$$

Therefore,

$$\text{gain} \simeq \frac{g r_1 r_2 p C}{\sqrt{[(p r_1 \overline{C_1 + C_s} \times pCr_2)^2 + (pCr_2)^2]}}$$

$$= \frac{g r_1}{\sqrt{[1 + p^2 r_1^2 (C_1 + C_s)^2]}}$$

The overall gain for the three stages

$$= \frac{g^3 r_1^2 r}{[1 + p^2 r_1^2 (C_1 + C_s)^2][1 + p^2 r^2 (C_1 + C_s)^2]^{\frac{1}{2}}} \quad \cdots \quad (5)$$

For maintenance of oscillations we must have

(*i*) $\phi = 2\pi$

and (*ii*) overall gain $\nless 1$.

Condition (*i*) is satisfied if

$$2 \tan^{-1}[-p r_1 (C_1 + C_s)] + \tan^{-1}[-p r (C_1 + C_s)] = 2\pi$$

or

$$\tan^{-1} \left\{ \frac{\dfrac{-2 p r_1 (C_1 + C_s)}{1 - p^2 r_1^2 (C_1 + C_s)^2} - p r (C_1 + C_s)}{1 - \dfrac{2 p^2 r_1 r (C_1 + C_s)^2}{1 - p^2 r_1^2 (C_1 + C_s)^2}} \right\} = 2\pi$$

or

$$\frac{2 p r_1 (C_1 + C_s)}{1 - p^2 r_1^2 (C_1 + C_s)^2} + p r (C_1 + C_s) = 0$$

$$\therefore \qquad p = \frac{1}{r_1 (C_1 + C_s)} \left(1 + \frac{2 r_1}{r}\right)^{\frac{1}{2}} \quad \cdots \quad (6)$$

If, as mentioned in the introduction, the anode load resistance of the third stage is composed of a resistance shunted by the modulator impedance then for a ganged condenser used for C_1 the effective value of C_s for the third stage would be slightly greater, C'_s say, due to the extra capacitances involved. The frequency of the oscillations maintained is then given by

$$p = \frac{1}{r_1 (C_1 + C_s)} \left[1 + \frac{2 r_1 (C_1 + C_s)}{r (C_1 + C'_s)}\right]^{\frac{1}{2}} \quad \cdots \quad (6a)$$

On substitution from (6) expression (5) for the overall gain becomes

$$\frac{g^3 r_1^2 r}{2\left(1+\frac{r_1}{r}\right)\left[1+\frac{r^2}{r_1^2}\left(1+\frac{2r_1}{r}\right)\right]^{\frac{1}{2}}}=\frac{g^3 r_1^2 r}{2\left(1+\frac{r_1}{r}\right)\left(1+\frac{r}{r_1}\right)}=\frac{g^3 r_1^2 r}{2\left(\sqrt{\frac{r}{r_1}}+\sqrt{\frac{r_1}{r}}\right)^2} \quad \cdots (5a)$$

Since $\left(X+\frac{1}{X}\right)$ is always greater than 2 for any positive value of X, it is evident that

$$\text{overall gain} < \frac{g^3 r^2 r}{8}$$

In practice r differs from r_1 by only a small percentage and hence overall gain $\simeq \left[\frac{g r_1}{2}\right]^3$. Condition (ii) for maintenance of oscillations is thus satisfied if

$$g r_1 \nless 2 \quad \cdots (7)$$

The expression (6) for frequency shows that if r is varied the generated frequency will also vary, producing frequency modulation.

CONDITIONS FOR FAITHFUL MODULATION

The schematic arrangement of the third stage of the three phase oscillator producing frequency modulation is shown in Fig. 2. The effective anode load of the third valve is r'_1 shunted by the anode impedance R_v of the modulating triode. Thus

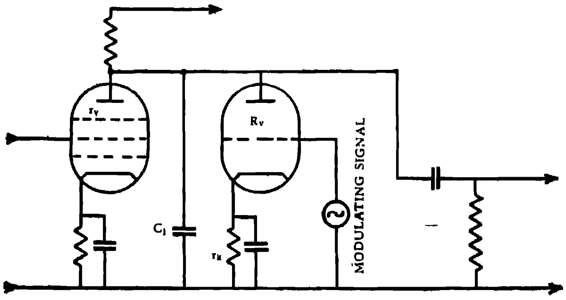

FIG. 2

Modulated stage of oscillator

$$r = \frac{r_1' R_v}{r_1' + R_v}$$

and according to (6) the frequency of the oscillations is

$$f = \frac{1}{2\pi r_1(C_1 + C_s)} \sqrt{\left(1 + \frac{2r_1}{r_1'} + \frac{2r_1}{R_v}\right)}$$

$$= \alpha \sqrt{\left(\beta + \frac{2r_1}{R_v}\right)} \qquad \dots \quad (8)$$

where

$$\left.\begin{aligned} \alpha &= \frac{1}{2\pi r_1(C_1 + C_s)} \\ \beta &= 1 + \frac{2r_1}{r_1'} \end{aligned}\right\} \qquad \dots \quad (9)$$

As shown in Fig. 2, frequency modulation is produced by changing the grid voltage of the modulator. Faithful modulation would, however, require linearity between change in oscillator frequency and amplitude of modulating voltage. Further, there should not be appreciable amplitude modulation introduced in the process.

Linearity of frequency modulation requires that, over a frequency range sufficient for wideband modulation

$$f = K(1 + mV_g) \qquad \dots \quad (10)$$

where K and m are constants of the system which do not change with V_g the modulator grid voltage. Comparing (8) and (10), we find

$$K(1 + mV_g) = \alpha\sqrt{\left(\beta + \frac{2r_1}{R_v}\right)},$$

giving

$$(K^2 - \alpha^2\beta) + 2K^2 m V_g + K^2 m^2 V_g^2 = \frac{2\alpha^2 r_1}{R_v}$$

or

$$R_v = \frac{2\alpha^2 r_1}{(K^2 - \alpha^2\beta) + 2K^2 m V_g + K^2 m^2 V_g^2}$$

$$= \frac{1}{A + BV_g + CV_g^2}, \text{ say} \qquad \dots \quad (11)$$

where

$$\left.\begin{aligned} A &= \frac{K^2 - \alpha^2\beta}{2\alpha^2 r_1} \\ B &= \frac{K^2 m}{\alpha^2 r_1} \\ C &= \frac{K^2 m^2}{2\alpha^2 r_1} \end{aligned}\right\} \qquad \dots \quad (12)$$

$$\text{giving } B/C = 2/m \qquad \dots \quad (13)$$

It has been found possible to have, under proper working conditions, R_v varying very closely according to (11), at least over a range of V_g sufficient for wideband modulation,

OBSERVATIONS ON FREQUENCY STABILITY

To make a quantitative study of the variation of carrier frequency with change of voltage on modulator grid it is essential that the R-C oscillator has a good degree of inherent frequency stability. It is therefore desirable to discuss this question in detail and make an experimental study of the stability before we attempt to study the nature of frequency modulation capable of being produced by this system.

When all the three stages are identical, disregarding the presence of the modulator for the present, the radio frequency of the R-C oscillator is given by

$$f=\frac{\sqrt{3}}{2\pi r_1(C_1+C_s)}$$

It has already been pointed out that in arriving at this approximate value, the impedance r_v of the oscillator valves has been neglected as being $\gg r_1$, since r_v is actually in shunt across r_1.

One of the causes of variation of oscillation frequency is the variation of r_v of the oscillator valves due to fluctuation of supply voltages. Taking r_v into account we have $f=\dfrac{\sqrt{3}}{2\pi(C_1+C_s)}\times\dfrac{1}{R_1}$

where $1/R_1=1/r_1+1/r_v$.

The variation δf in frequency, due to variation δr_v in r_v

is
$$\delta f=-\frac{\sqrt{3}\,\delta r_v}{2\pi(C_1+C_s)r_v^2}$$

or
$$\frac{\delta f}{f}=-\frac{R_1\delta r_v}{r_v^2}=-\frac{r_1}{r_1+r_v}\cdot\frac{\delta r_v}{r_v}.$$

So far as variation in r_v is concerned, it is obvious that for a high degree of frequency stability $\frac{\delta f}{f}$, r_v should be as large and r_1 as small as possible. A large value of r_v necessitates the use of r. f. pentodes and a small value of r_1 necessitates the use of high-mu pentodes, since oscillations are maintained when $gr_1 \not< 2$. For a typical case in which $r_1=2\times 10^3$ and $r_v=10^6$ ohms,

$$\frac{\delta f}{f}=-2\times 10^{-3}\,\frac{\delta r_v}{r_v}.$$

For one per cent variation in r_v, there would be 2×10^{-3} per cent variation of the frequency of the oscillations. For a one megacycle carrier the frequency variation due to one per cent increase in r_v will in this case be minus 20 cycles. Stabilisation of the voltages to the different electrodes is therefore essential to minimise this variation. In actual practice, the anode and screen voltages were derived from a stabilised source as shown in Fig. 3 and the heaters of the valves were fed from a voltage regulation transformer.

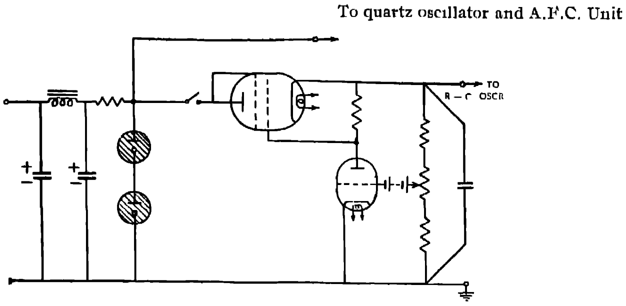

FIG. 3
Stabilized H T supply

Another important cause of frequency instability is the variation of the load resistance r_1 with change in temperature. To minimise the frequency variation due to change in r_1 caused by temperature change, the resistances r_1 must be wound with wires having low temperature coefficient. Proceeding as above, we get, for variation of r_1

$$\frac{\delta f}{f} = -\frac{R_1}{r_1^2}\,\delta r_1 = -\frac{r_p}{r_1 + r_p}\cdot\frac{\delta r_1}{r_1} \simeq -\frac{\delta r_1}{r_1},$$

since $r_p >> r_1$.

The resistances r_1 were actually wound on thin mica cards with manganin wires which have an average temperature coefficient of 10^{-5} per degree Centigrade. For a temperature rise of 1°C of the resistances r_1, there will thus be a frequency change of minus 10 cycles on a one-megacycle carrier.

Frequency instability is also caused by changes in C_1 due to variations in temperature. Assuming an average temperature coefficient of capacity to be 2×10^{-5}, for small change in temperature, the change in frequency caused by change in capacity due to increase of temperature by 1°C is, for a one-megacycle carrier, minus 20 cycles.

From a consideration of the frequency change due to change in working temperature it is desirable to place both r_1 and C_1 in thermostatically controlled chambers.

The degree of stability attained in this way was checked by comparing with a quartz-controlled oscillator. In the absence of a direct frequency measuring equipment of high accuracy, the R-C oscillator was heterodyned with a quartz-controlled oscillator to produce a 1,000 cycle beat note. The R-C and quartz-controlled oscillators were both separated by buffer amplifiers before applying to the mixer, as shown in Fig. 4. The beat note produced

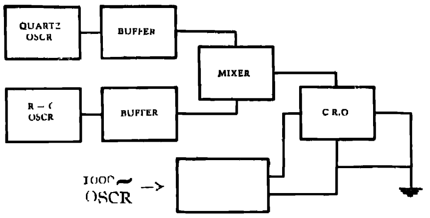

FIG. 4

Checking stability of R-C oscillator

was in turn compared with a valve-maintained tuning fork (1,000 cycle) oscillator. The observed stability was found to be sufficiently good for making quantitative studies in frequency modulation.

VARIATION OF OSCILLATOR FREQUENCY WITH MODULATOR GRID VOLTAGE

One of the oscillator valves was now shunted by a triode modulator as explained before and shown in Fig 2. The load resistance of this valve was increased from r_1 to r'_1 so that under average grid bias on modulator the equivalent resistance formed by r'_1 and modulator anode impedance R_a in parallel is equal to r_1. The beat frequency produced by heterodyning the R-C and quartz-controlled oscillators was then measured by comparison with a beat frequency audio oscillator of good frequency stability.

To start with, a preliminary investigation was made to find out the range of modulator grid bias, if any, over which the variation of frequency was approximately linear. This study revealed that for grid bias greater than 1 volts the variation was more or less linear The cathode bias developed across r_k (figure 2) was accordingly set for 4 volts and the measurements of frequency for different values of grid voltage were made with all possible accuracy.

With 4.30 volts grids bias (negative) on the modulator the three ganged tuning condenser of the R-C oscillator was carefully adjusted to give a beat note of say 500 cycles/second with R-C oscillator-frequency below that of the quartz controlled one. From a knowledge of the quartz oscillator frequency, that of the R-C oscillator was thus ascertained. This setting of the tuning condenser was kept undisturbed. The modulator grid bias was then slightly increased with consequent decrease of the R-C oscillator frequency. The audio beat frequency accordingly increased and the grid bias carefully adjusted to make this exactly 1000 c/s. This grid bias was recorded and the process repeated for higher and higher beat frequencies A typical set of results is shown in Table I and also plotted in Fig. 5.

TABLE I

Modulator grid voltage V_g (volts, negative)	Oscillator frequency f (kc/s)	Modulator grid voltage V_g (volts, negative)	Oscillator frequency f (kc/s)
4.30	999.5	5.35	995.5
4.47	999.0	5.45	995.0
4.60	998.5	5.60	994.5
4.75	998.0	5.70	994.0
4.87	997.5	5.82	993.5
5.00	997.0	5.95	993.0
5.10	996.5	6.05	992.5
5.20	996.0	6.15	992.0

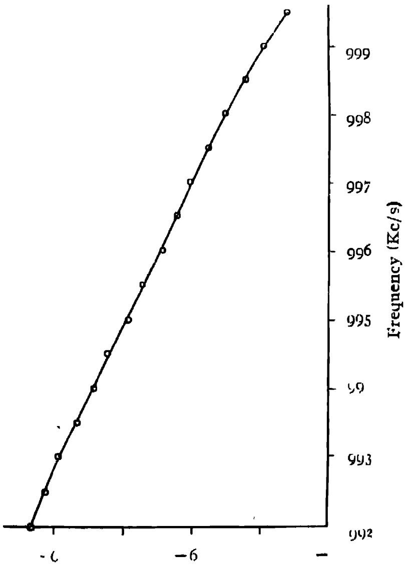

FIG. 5

Frequency—modulator grid voltage

From the plot in Fig. 5 it is obvious that R-C oscillator frequency is practically a linear function of modulator grid bias over the range $V_g = -4.75$ to $V_g = -6.0$ volts. Within this range the variation in frequency is 5.25 kc/s. It will be noted that the standard practice of wide-band frequency modulation is to have a frequency variation of ±75 kc/s over an average carrier of, say, 50 Mc/s. This would require a frequency deviation of ±1.5 kc/s over a one-megacycle carrier. In the plot of Fig. 5 there is a total deviation of 5.25 kc/s over the linear regime and hence if the modulator is worked with a static bias of -5.4 volts we can easily get faithful frequency modulation suitable for wide-band system. The modulating audio-frequency voltage is to be inserted in series with the D-C. grid bias and the resulting variation in R_0 of modulator will produce a deviation of carrier frequency proportional to the amplitude of the modulating voltage.

Within the linear portion the variation of f with V_g may be represented by the equation

$$f = K(1 + mV_g) \tag{10}$$

In the particular plot under consideration,

$$\left.\begin{aligned} K &= 1.024\; 10^{6} \\ m &= 4.18\; 10^{-1} \end{aligned}\right\} \quad \ldots \quad (11)$$

AMPLITUDE MODULATION ASSOCIATED WITH FREQUENCY MODULATION

Frequency modulation being produced by varying the effective anode load of one of the oscillator valves will automatically involve amplitude modulation It must be remembered however, that the percentage change in frequency is very small. For example, wide-band frequency modulation requiring a deviation of ±75 kc/s over an average carrier frequency of 50 Mc/s involves a frequency change of 0.0015%. This would require a very much smaller percentage change in *r* and hence the degree of amplitude modulation will also be negligibly small. A typical set of data is shown in Table II and plotted in Fig. 6.

TABLE II

f (kc/s)	992	993	994	995	996	997	998
Output (volts)	1.400	1.390	1.383	1.380	1.370	1.365	1.360

VARIATION OF R_v WITH V_g OF MODULATOR

From the linearity of modulation it is obvious that over the range of grid voltage between −4·75 and −6·0 volts, the anode impedance of the modulator follows the relation (11). It was therfore considered desirable to make an experimental study of the variation of R_v with V_g. Table III gives the results of a typical set of observations and the plot is shown in Fig. 7.

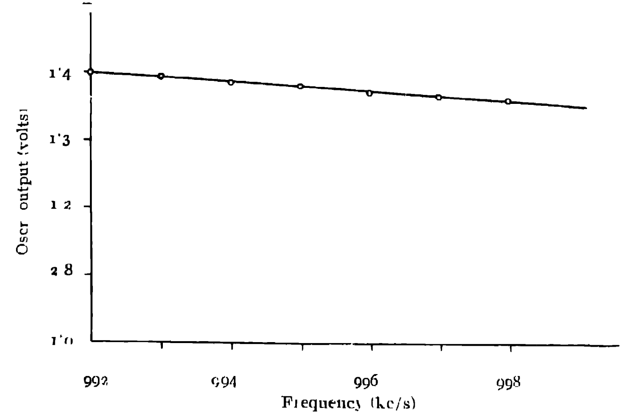

Fig. 6

Oscillator output—Frequency

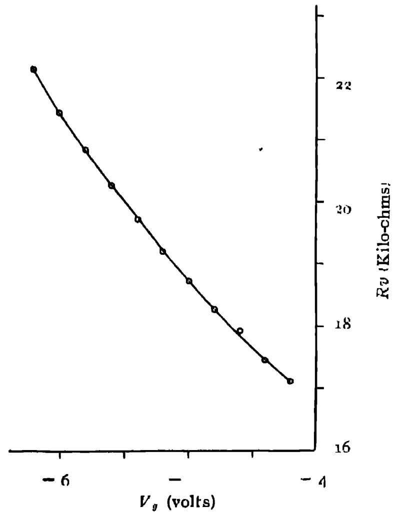

Fig. 7

Modulator impedence—Grid voltage

TABLE III

V_g (volts,-ve)	4.2	4.4	4.6	4.8	5.0	5.2	5.4	5.6	5.8	6.0	6.2
R_i (kilo-ohms)	17.10	17.45	17.85	18.25	18.69	19.18	19.69	20.23	20.80	21.40	22.1

Assuming R_g to vary according to (11), the constants A, B and C are found to be

$$\left.\begin{aligned} A &= 8.8\times10^{-2} \\ B &= 7.0\times10^{-3} \\ C &= 2.5\times10^{-5} \end{aligned}\right\} \quad \cdots \quad (15)$$

within the grid voltage range from -5 to -6 volts. From the values in (15) it will be noted that

$$B/C = 280 \quad \cdots \quad (16)$$

According to equation (13), $B/C = 2/m$. But this experimental value of B/C is not very close to the value of $2/m$ as obtained from (14). In this connection, it must be remembered that since the quantity C is very small, a slight error in measuring R_i may cause large changes in the value of C, making it even negative. The agreement between the observed values of B/C and $2/m$ is, therefore, sufficiently good for all practical purposes.

It may be noted that from the point of view of frequency stability it is better to work on that part of R_i vs. V_g characteristic (provided it satisfies the condition of fidelity), or with such valves, for which R_r changes slowly with V_g. In that case, slight changes in V_g will not appreciably alter the generated frequency.

STABILITY OF CENTRAL CARRIER FREQUENCY

It has been pointed out before that with proper regulation of the voltage to the different electrodes of the oscillator valves, the frequency stability obtained is sufficiently good for making quantitative observations on frequency modulation. If, however, we remember that to get the final radiation frequency of the order of 50 megacycles/sec , the R-C oscillator frequency is to be multiplied many times it is obvious that the stability of the R-C oscillator must be of a very high order.

In a previous communication by Rakshit and Bhattacharyya (1946) it was pointed out that the three-phase R-C oscillator can easily be controlled by a quartz crystal used as a connecting link between the anode of any one stage and the grid of the succeeding one. This method is quite simple but is applicable only when quartz-controlled oscillations at a fixed frequency are needed. It is not suitable for the present case where frequency modulation is wanted. A method very similar to the automatic frequency control system in superheterodyne reception has, however, been found to work satisfactorily.

EXPERIMENTAL ARRANGEMENT

The schematic arrangement of the control system is shown in Fig. 8. The R-C oscillator output, via buffer amplifier, is applied to the signal grid of the mixer valve and the crystal oscillator output similarly applied to the oscillator grid. The two tuned circuits on the anode of the mixer are separately tuned to a pre-determined frequency f_1 and are sufficiently loosely coupled so that the tuning of one does not appreciably affect the other. The crystal oscillator has a frequency of 1,000 kc/s and the R-C oscillator adjusted to 1440 kc/s ($f_1 = 440$ kc/s) so that the difference frequency f_1 is applied to the phase discriminator as shown The function of the discriminator is to distinguish between signals which are (i) above and (ii) below the proper frequency. When the R-C oscillator frequency is exactly 1440 kc/s, i e. the difference frequency is the same as the resonant frequency of the two tuned circuits, there is no D-C. voltage across the points marked *ME*. With zero voltage across *ME* the grid bias on modulator is such that R-C oscillator frequency is exactly 1440 kc/s and under this condition the discriminator circuit has no effect upon the oscillator If, however, the R-C oscillator frequency drifts from 1440 kc/s the difference frequency accordingly changes and a D-C. voltage is developed across *ME* having its polarity dependent upon the nature of the drift. It is so arranged that with decrease of R-C oscillator frequency the voltage of *M* becomes positive with respect to *E* so that

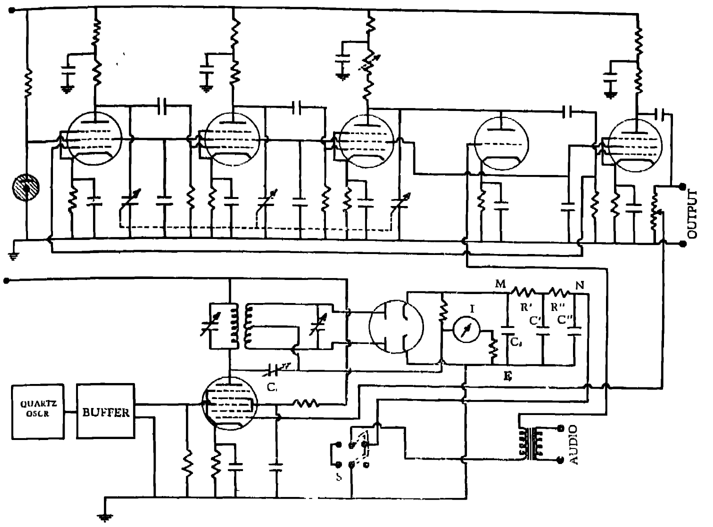

FIG. 8

Complete oscillator with stabilised central carrier

R_v of modulator decreases and thereby tends to increase, and hence stabilise, the R-C oscillator frequency. Similarly, for increase of R-C oscillator frequency above the present value (1440 kc/s).

To start with, both the R-C and the quartz oscillators were disconnected and only a signal generator set for 440 kc/s applied to the signal grid of the mixer. The coupling condenser C_c was also disconnected and the two tuned circuits on the mixer anode were separately tuned to 440 kc/s, the resonance condition being indicated by the microammeter I. A sensitive D.C. valve voltmeter was connected across M E and suitable adjustments was made to see that under resonant condition no difference of potential existed between M and E. The coupling condenser C_c was then connected and the tuning of primary readjusted to restore resonance. On changing the signal generator frequency above and below 440 kc/s, the voltmeter across M E indicated voltages of opposite polarity and with proper adjustment these voltages were equal in magnitude for equal frequency deviations above and below 440 kc/s. As explained before, M has to be positive with respect to E for decrease of R-C frequency and vice versa. If instead of this it is found that for any particular set of connections M becomes negative with repect to E, E is to be connected to the modulator and M is to be earthed. With variation of C_c and the mutual inductance between the primary and the secondary the sensitivity of the arrangement could also be controlled.

The signal generator was now disconnected and the R-C and quartz oscillators connected as shown. The tuning condenser of the R-C oscillator was carefully adjusted, with modulator grid bias set for −5.4 volts as required for faithful modulation, so that the generated frequency was exactly 1440 kc/s as shown by zero reading of the D.C. voltmeter across ME. The R-C and quartz oscillator voltages as applied to the mixer were next adjusted to get the desired sensitivity in D C. voltage output across M E for deviations of R-C oscillator frequency from 1440 kc/s

To check the improvement in frequency stability attained with the incorporation of the discriminator, the points M and E were connected to the modulator through a double-throw switch S as shown in Fig. 8. When S was thrown to the left the discriminator output was not applied to the modulator and the D. C. voltmeter across ME occasionally showed perceptible fluctuations indicating variations of R C oscillator frequency. When S was thrown to the right, there was absolutely no fluctuation in the reading of the voltmeter indicating greater frequency stability. The functions of the combinations $R'C'$ and $R''C''$ in the discriminator output circuit are to allow only the D. C. voltage output of discriminator to be applied to modulator.

From the nature of the arrangement shown in Fig. 8 it will be realised that the system maintains a stable central carrier and there is no change in voltage across N E even when modutating audiofrequency voltage is applied to the modulator. The discriminator is effective in eliminating frequency drifts or scintillations of long periods and the normal desirable modulations are not in any way affected. The stabilising system with discriminator cannot obviously be used for making observations on variation of oscillator frequency with modulator D.C grid bias as depicted in Fig. 5.

DISTORTION PRODUCED IN THE SYSTEM

It has been pointed out in a previous communication by Rakshit and Bhattacharyya (1946) on the three-phase R-C oscillator that harmonic distortion of the unmodulated carrier can be kept low by maintaining three-phase symmetry. For introducing frequency modulation asymmetry has been deliberately adopted with resulting increase in harmonic distortion. But by adjusting the anode load resistance of the modulated stage in the three-phase system, the symmetry for the unmodulated condition can be maintained and hence harmonic distortion kept low. In any case, if the overall gain is the minimum required for maintenance of stable oscillations, the harmonic distortion is quite small although there might be slight asymmetry.

The presence of the modulator introduces other sources of distortion which are of interest The modulator valve is essentially a non-linear element, its anode impedance varying with H.T. voltage used. Since the oscillator voltage is applied across the modulator, its impedance will vary over one period of the radio frequency oscillation and this is likely to produce some distortion. If the r f. voltage on the modulator be not large, the distortion due to this cause will be very low.

It should also be noted that the modulating voltage on the grid of modulator will naturally be present on its anode and hence the frequency modulated output will have the modulating voltage superimposed upon it. This can easily be removed by using a high-pass filter of suitable design.

The frequency deviation required for wide-band modulation on a 1440 kc/s carrier being about ± 2.2 kc/s it is obvious that if the discriminator has a pull-in width of about 6 kc/s and the capacity C_d across the diode load (Fig. 8) has a value suitable for usual second detection, there will be audio output across C_d when the R-C oscillator will be frequency modulated by means of an audio signal. For sinusoidal modulating voltage, faithful modulation would give—assuming ideal discriminator characteristics—sinusoidal audio voltage across C_d. Preliminary observations have already been made with good results and further waveform studies are in progress.

Observations on frequency deviations resulting from modulation are also in progress.

CONCLUSION

The method of producing wide-band frequency modulation as described in this paper is very simple and the preliminary results, as reported, are quite encouraging. The stability of the central carrier is no doubt dependent upon that of the phase discrimination assembly but is practically the same as the stability of the associated quartz-controlled oscillator. The overall stability attained is quite satisfactory for all practical purposes.

It must be pointed out that a large degree of frequency multiplication would be necessary to get the usual carrier of about 45 Mc/s starting from, say, a 1.5 Mc/s carrier. It was reported earlier (Rakshit and Bhattacharyya, 1946) that a carrier frequency as high as 9 Mc/s can be obtained by using 6SK7 valves as oscillators with 1,500 ohm load resistances and having no external C_1's across them. The inter-electrode and stray capacitances alone then control the frequency and the stability is poor. To attain a high carrier frequency with good stability, it is desirable to have external tuning capacitances much greater than the inter-electrode and stray capacitances and to use high-mu pentodes requiring small anode load resistances for the maintenance of oscillations. Quantitative observations along this line and also on the different aspects of producing faithful frequency modulation are in progress.

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