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THE PN JUNCTION AS A VARIABLE REACTANCE DEVICE FOR F.M. PRODUCTION

by

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The PN Junction on a Variable Reactance Device for F.M. Production

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A completely transistorized modulator has been developed for the production of frequency modulation of a 10Mc/s carrier. A frequency deviation of 100kc/s is obtained by a change in the modulating signal of 0·15V and very good frequency modulation results with very little amplitude modulation.

THE small signal equivalent circuit of a pn junction is shown in Fig. 1, R_1 being the resistance across the junction, R_2 the resistance of the bulk p- and n-type material and C_J the capacitance of the junction. When the reverse voltage applied to such a junction is increased, the width of the space-charge region increases, making C_J decrease. The change in capacitance of a germanium pn junction (in which the density of donors in the base region is N_I) with applied voltage V, is found to agree very closely with the theoretical relationship[1]

$$C_J = 3{\cdot}4 \times 10^{-4}\,(N_I/V)^{\frac{1}{2}}\ \text{pF/cm}^2 \quad \ldots\ldots\ldots \quad (1)$$

If such a variable capacitance is placed in parallel with an inductor L and a capacitor C, then if C_J is very much greater than C, the resonant frequency of the tuned circuit changes in a linear fashion with change in the voltage applied to the pn junction.

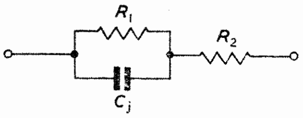

Fig. 1. The small signal equivalent circuit of a pn junction

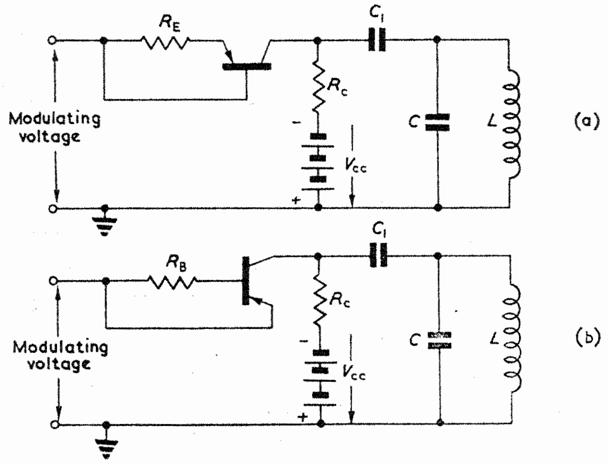

Fig. 2. (a) Grounded base and (b) grounded emitter configuration of the variable reactance transistor

In each case $C_1 \gg C$

A number of references occur in the literature to the use of this property for the production of frequency modulation and for automatic frequency control[2,3]. The change in collector impedance of a transistor as its emitter current is varied has also been used to produce frequency modulation[4]. However, the upper carrier frequency at which such a device can be used is dependent on the maximum frequency at which the transistor can operate. When the work described in this article was being done none of the available junction transistors were capable of operating at 10Mc/s; so the latter method could not be used. Likewise none of the available junction diodes had a sufficientlv large capacitance to make them suitable for use at 10Mc/s Hence it was decided to use the collector capacitance of an audio transistor as the variable reactive element.

D. A. Thomas[4] deliberately used the damping effect on the oscillator tuned circuit of the variable output resistance of the transistor to obtain frequency modulation. The frequency deviation produced by this method is related in a very non-linear fashion to the modulating signal. In order to make the frequency deviation of the oscillator depend purely on the change in capacitance of the pn junction an oscillator is chosen (a transitron) so that the change in shunt resistance has little effect on the oscillator frequency. The operating conditions of the variable reactance transistor are so chosen that the output resistance does not change appreciably as the applied voltage is altered.

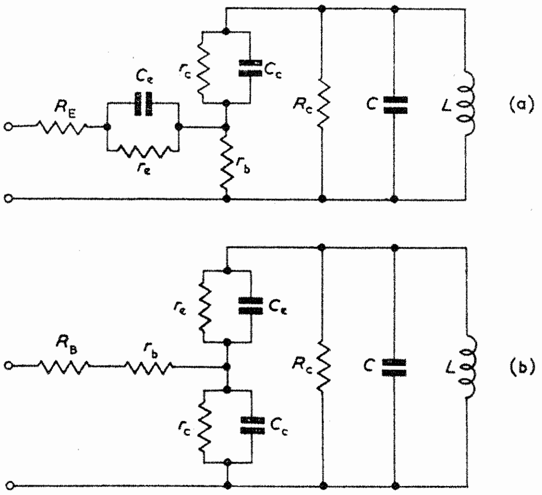

Fig. 3. The equivalent circuits of (a) the grounded base and (b) the grounded emitter configuration of the variable reactance transistor

As $C_1 \gg C$ *it is neglected and* r_b, r_c, r_e, C_c *and* C_e *have their usual meaning*

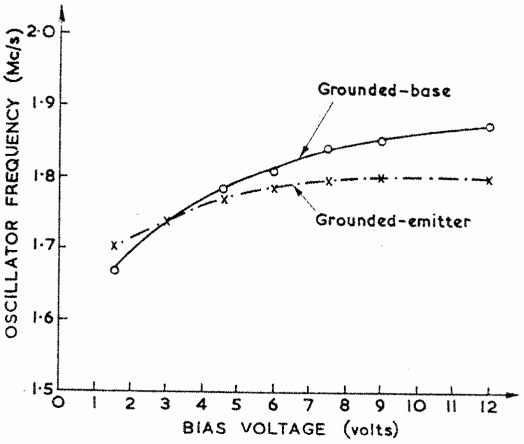

Fig. 4. Variation in frequency with bias voltage for the grounded emitter using an OC70

Bias voltage = voltage applied between collector and base

Two possible means of using a transistor in this fashion are shown in Fig. 2 and the equivalent circuits in Fig. 3. When a voltage is applied to the grounded base configuration the percentage change in capacitance is greater than that of the grounded emitter configuration. This is illustrated in Fig. 4 which gives the change in frequency of an oscillator on applying a signal to a transistor in both the grounded base and grounded emitter configuration, the transistor being in parallel with the oscillator tuned circuit. The

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* *The College of Aer*[illegible] † [illegible]

This is part of the [illegible] *oma of the College of Aerona*[illegible] temperature stability of the grounded base configuration is also inherently better than that of the grounded emitter configuration. For these reasons the grounded base configuration is chosen for use in the modulator.

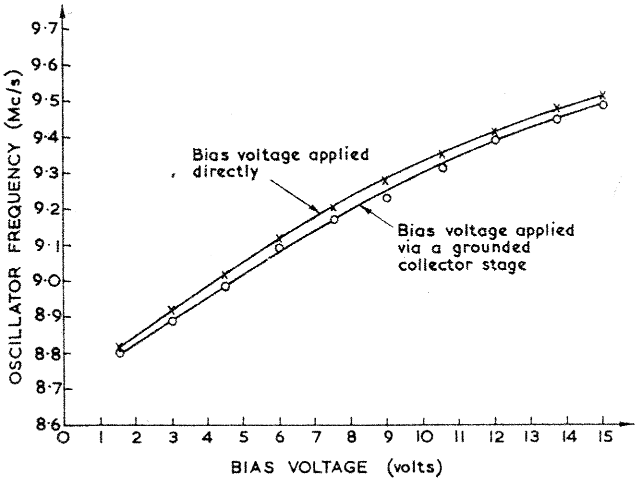


Fig. 5. Variation in frequency variation of bias voltage for a V10/50 (a) via a grounded collector stage and (b) directly

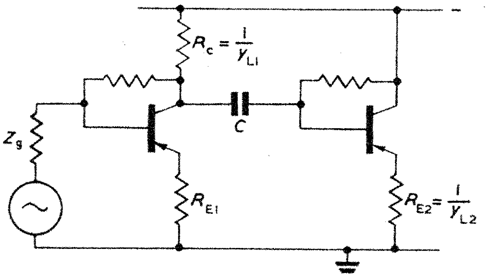
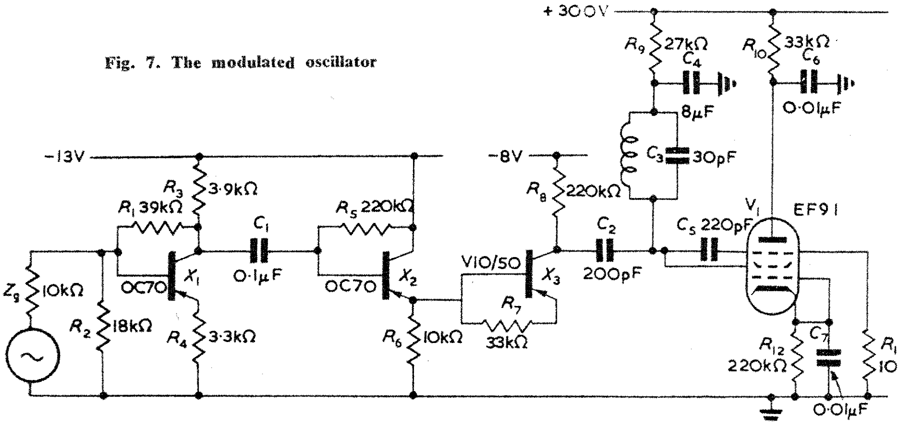


Fig. 6. The modulator amplifier

Fig. 7. The modulated oscillator



The Modulator

Fig. 5 shows the variation of the frequency of a transitron oscillator as the applied voltage is varied. The departure from linearity is quite small for applied voltages (or bias), between three and nine volts. The variable reactance transistor is therefore operated at a quiescent bias of six volts. In order to increase the low frequency response of the modulator amplifier d.c. coupling is used between the variable reactance transistor and the previous stage, and as a high input impedance is required to this stage, a grounded collector configuration is chosen. To obtain a quiescent operating bias of six volts (i.e. a base-collector voltage of six volts), as the voltage drop across the emitter load of the grounded collector stage is two volts, eight volts is chosen for the collector voltage supply on the variable reactance transistor.

Using such a method of injecting a bias voltage into the variable reactance transistor proves to be very efficient. This is shown in Fig. 5 which compares the frequency shift or an oscillator as the bias is applied directly from a battery and from a battery via the grounded collector stage.

As a frequency deviation of 100kc/s is desired when the signal input has an amplitude of 0·15V, an amplifying stage is required before the grounded collector stage having a voltage gain of about ten times. The modulating signal source has an impedance of 10kΩ; therefore the input impedance of the amplifier stage must be larger than 10kΩ. A grounded emitter configuration was chosen, with degeneration introduced by means of an emitter resistor, to both increase the input impedance and improve the stability factor*. The modulator amplifier circuit is shown in Fig. 6.

The input impedance of the grounded collector stage, Z_{in}, using the hybrid matrix parameters is given by

$$Z_{in} = \frac{1 + h_{11}y_{L2}}{h_{22} + y_{L2}(1 + h_{21})} \quad \ldots\ldots\ldots (2)$$

Hence for a transistor where y_{L2} is 10^{-4}mho, h_{11} is 70Ω, h_{22} is 7×10^{-7}mho, h_{21} is $-0{\cdot}97$ and h_{12} is 7×10^{-4} the input impedance Z_{in} is approximately 330kΩ. A 0·1μF coupling capacitor is therefore quite large enough to obtain a good low frequency response from the modulator amplifier. The input impedance of the grounded collector stage is so high that it can be ignored in the analysis of the grounded emitter stage.

The grounded emitter stage has an input impedance Z_{in}' given by

$$Z_{in}' \frac{h_{11}h_{22} - h_{12}h_{21} + h_{11}y_{L1}}{h_{22} + y_{L1}(1 + h_{21})} \quad \ldots\ldots\ldots\ldots (3)$$

In this special case where degeneration is introduced by means of an emitter resistor R_E the input impedance becomes

$$Z_{in}' = \frac{(h_{11} + R_E)(h_{22} + y_{L1}) - h_{12}h_{21}}{h_{22} + y_{L1}(1 + h_{21})} \quad \ldots\ldots (4)$$

when R_E is 3·3kΩ and y_{L1} is $2{\cdot}5 \times 10^{-4}$mho, Z_{in}' is approximately equal to 60kΩ, which is large compared to the source impedance. An additional stabilizing network is employed in the grounded emitter stage which results in a stability factor of 3·2.

The circuit diagram of the modulated oscillator is shown in Fig. 7, it is found to be very reliable, producing good quality frequency modulation with hardly any amplitude modulation. A frequency of 100Mc/s is by no means the upper limit at which this technique could be used, and employing some of the new r.f. transistors now available it should be possible to produce frequency modulation at hundreds of megacycles per second.

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* *Stability factor is defined as* ($\partial I_c/\partial I_{co}$), I_c *being the collector current and* I_{co} *the collector current when the emitter current is zero.*

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