SYNCHRONIZATION OF A VARIABLE FREQUENCY OSCILLATOR

at discrete, stabilized frequencies

with the

E80T

by J. Bruijsten, H. Groendijk and M. R. Mantz[1])

The application of the beam deflection tube E80T as a phase discriminator in an impulse-governed oscillator is most effective. By means of this tube it is possible to generate a large number of discrete frequencies in the V.H.F. range, which are synchronised by a single oscillator equipped with a single crystal. This article deals with the circuit of an impulse-governed oscillator incorporating an E80T.

INTRODUCTION

Communication equipment is often required to operate at various frequencies. Moreover, stringent requirements are imposed on the frequency stability, while the transmission should contain no unwanted frequencies.

Self-oscillating circuits are unable to meet the present requirements imposed on the frequency stability due to the instability of the frequency determining elements and the inaccuracy of tuning mechanisms. The method of frequency multiplication, on the other hand, leads to the generation of undesired frequencies and these are difficult to suppress by simple filtering.

These difficulties have been overcome by the impulse-governed oscillator (I.G.O.) system, which offers the possibility of obtaining a very stable crystal-controlled frequency without undesirable frequencies being generated. This feature is obtained by applying automatic frequency control instead of frequency multiplication. In addition, by using the I.G.O. system, a whole group of frequencies can be synchronized with a single crystal. In this system a phase discriminator is employed which ensures that the frequency of the tunable oscillator is synchronized with the frequency or a whole multiple of the frequency of a crystal-controlled oscillator.

Naturally, during development of the I.G.O. system conventional tubes had to be used, and although satisfactory results were obtained in this way, it proved difficult to achieve synchronization at frequencies exceeding about 100 Mc/s. By using the beam deflection tube E80T as an impulse phase discriminator, the I.G.O. circuit is greatly simplified. Furthermore the E80T offers the possibility of synchronizing a controlled oscillator even in the U.H.F. range. For example it has proved possible to synchronize a butterfly-circuit oscillator tuned to 375 Mc/s directly, by means of this tube, with a crystal-controlled frequency of 5 Mc/s.

The E80T thus paves the way for the construction of transmitters (and receivers), based on the I.G.O. principle, working in the V.H.F. or U.H.F. range.

---

1) Reprinted from Philips Electronic Application Bulletin Vol. 13 No. 11/12, 1952.

PRINCIPLE OF THE I.G.O. SYSTEM

The mechanism of the I.G.O. system, which has already been dealt with in several publications[2]), may be explained as follows.

In general, a phase discriminator is employed to render the frequency of an oscillator exactly equal to (synchronous with) that of a reference signal. This phase discriminator produces a voltage (as a rule a direct voltage of varying value) which depends on the phase relation between the frequency to be controlled and the reference frequency, and this voltage is used for frequency control. It will be clear that since even slight phase deviations will give rise to a variation of the control voltage, the frequencies of the controlled oscillator and the reference circuit can be rendered exactly equal.

Further investigation of the principle revealed that it is also possible to obtain a control voltage which depends on the phase relation if the frequency to be controlled is a whole multiple of the reference frequency. In this case it is necessary, however, to apply the reference frequency to the phase discriminator in the form of impulses, but the duration of these impulses must not exceed that of a half cycle of the highest frequency to be synchronized. In this way it is possible to obtain not only synchronization with an identical frequency, but also a directly stabilized frequency multiplication with multiplication coefficients up to 100.

Still higher multiplication coefficients are usually obtained by means of a more complex system which includes a frequency multiplier circuit having a number of large steps, one of which is also subdivided into a number of smaller steps. By means of such a system hundreds of frequencies can be obtained in a similar way to line selection in a small telephone exchange. Again, it is possible to design the system so that arbitrary frequencies are stabilized; the channels are then no longer linked to a given mutual frequency difference.

All these systems have in common the use of an automatic frequency control system with integral action, in which the control voltage is supplied by a phase discriminator. The impulse phase discriminator is a special type used when the frequencies to be controlled are multiples of the reference frequency.

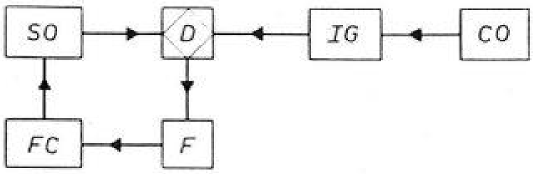

Fig 1. Block diagram of the I.G.O. system. *CO*—crystal-controlled oscillator. *IG*—impulse generator. *SC*—signal oscillator to be controlled. *D*—phase discriminator. *FC*—frequency-control circuit. *F*—low-pass filter.

Fig. 1 shows the block diagram of the I.G.O. system. The reference frequency is supplied by the crystal-controlled oscillator CO. The impulse generator IG produces impulses, the repetition frequency of which is identical to the frequency of the signal produced by the oscillator CO. These impulses and a signal derived from the tunable signal oscillator SO, which is to be controlled, are then applied to the impulse phase discriminator D in which the two signals are compared. The control voltage produced in this phase discriminator is now applied to the frequency-control circuit FC via the low-pass filter F, and synchronizes the oscillator SO so that its frequency is stabilized.

2) H. B. R. Boosman and E. H. Hugenholtz, Frequency Control in Transmitters, Philips Communication News IX, p. 21, 1947 (No. 1).
E. H. Hugenholtz, The Application of Impulse-Governed Oscillators in Aircraft Transmitters, Philips Communication News XI, p. 13, 1950 (No. 1).
E. H. Hugenholtz, Impulse-Governed Oscillator, A System for Frequency Stabilization, Philips Techn. Review 14, No. 5, 1952/53.

TYPES OF IMPULSE GENERATOR

Ringing Circuit

In recent years several fairly simple circuits have been designed to produce impulses of short duration by exciting an LC circuit tuned to a high frequency, the oscillation thus initiated being rapidly damped after half a cycle, by means of a diode. The difficulty, however, consists in applying the impulses thus obtained to the control electrode of the tube which performs the function of phase discriminator. In practice the unavoidable stray capacitance of the wiring and the input capacitance of the phase discriminator tube attenuate the high frequencies of the spectrum of the original impulse, so that its duration increases, while its amplitude decreases.

This is why it is difficult to synchronize an oscillator directly in the V.H.F. and U.H.F. ranges.

Impulse Phase Discriminator E80T

The difficulty mentioned above has been overcome by using the beam deflection tube E80T, the simplified cross section of which is shown in fig. 2.

The electrons emitted by the cathode k are focused by the two interconnected electrodes g_1 and the slotted electrodes g_2 and g_3, so that a ribbon shaped electron beam[3]) of rectangular cross section is obtained. The electrodes, g_1, moreover, control the current flowing through the tube, whilst the electrode g_2 also serves for suppressing the electron beam (gating) when necessary.

The slotted electrode g_4 intercepts the beam when a deflection voltage is applied to the plates D and D'. The tube also incorporates a suppressor grid g_5, which prevents electrons that impinge on the anode a from returning to the screen grid g_4.

When the electron beam is swept swiftly along the slot of the electrode g_4, current is passed during very short instants only. The number of electrons passed, moreover, depends on the intensity of the beam at the instant it passes through this slot, that is, on the instantaneous value of the beam current determined by the voltage at g_1.

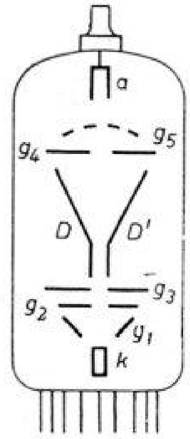

Fig. 2. Simplified cross section of the beam deflection tube *E80T*. grids g_3 and g_4 are interconnected, whilst the suppressor grid g_5 is internally connected to the cathode *k*.

The mechanism of the impulse phase discriminator is, in fact, analogous to that of a stroboscope. When the reference frequency is applied to the deflection plates D and D' the beam will sweep twice per cycle across the slot of g_4, namely when $V_D = V_{D'}$. During the forward (or backward) travel, however, a gating voltage is applied to g_2, so that the beam will reach the anode during a very short period, which occurs only once in every cycle.

Further, by applying to g_1 a voltage the frequency of which is a whole multiple of the reference frequency, the instant during which current passes will always coincide with the same instantaneous value of the beam current. *Since the voltage applied to* g_1 *is sinusoidal as a function of time, the instant during which current passes may coincide with either a large or a small value of the beam current, depending on the phase relation between the signal applied to* g_1 *and that applied to* D *and* D'. In other words, the amplitude of the anode current impulse

3) See J. L. H. Jonker, Valves with a Ribbon-Shaped Electron Beam, Philips Research Reports, 5, 1, p. 6, 1950.

is a measure of the phase relation. The control voltage is obtained by integration of these pulses, as will be shown later.

As pointed out above, the duration of the pulses produced in the E80T should not exceed that of half a cycle of the highest frequency to be synchronized. This condition determines the value of the deflection voltage which is to be applied to the electrodes D and D′; the higher the deflection voltage, the shorter will be the intervals during which the tube passes current.

CIRCUIT DETAILS

Gating

It has already been mentioned that the beam is intercepted once per cycle of the reference frequency. This is necessary because, owing to unavoidable asymmetry, the spacing of the subsequent pulses would not be exactly half a cycle. When alternate pulses are suppressed the intervals between the remaining pulses will be exactly one cycle.

A further advantage of suppressing the beam during the time when it is not required is that it does not impinge unnecessarily on the deflection plates, and thus does not impose an undue load on the circuit by which these plates are fed.

Fig. 3 shows a gating circuit. The deflection plates are connected to the

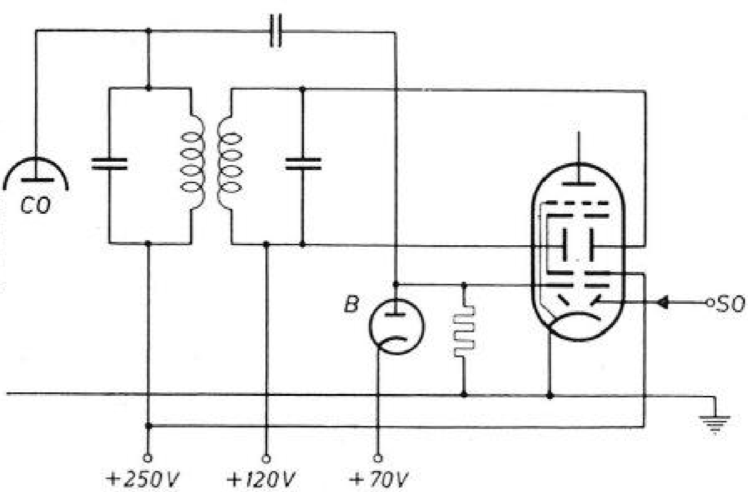

Fig. 3. Gating circuit. The signal applied to g_2 is in quadrature with the signals applied to the deflection plates D and D'. The positive peak voltage at g_2 is limited by the diode B.

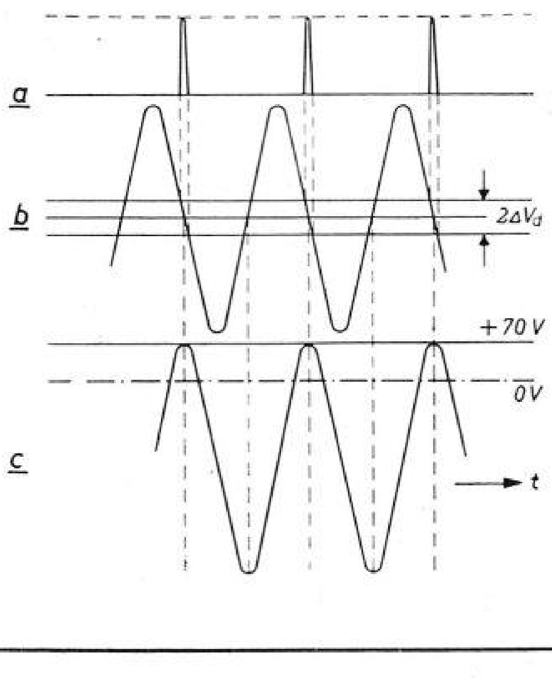

Fig. 4. Oscillogram showing the voltages applied to g_2 (c) and to the deflection plates (b), and the resulting anode current impulses (a). The dash-dot line indicates the cathode potential which coincides with the cut-off level of g_2.

secondary of a band-pass filter incorporated in the anode circuit of the crystal-controlled oscillator CO. As a result of the band-pass filter nature of the interstage coupling, the voltages applied to the deflection plates are in quadrature with the gating voltage applied to g_2, and this phase difference ensures that current is passed once per cycle only (see fig. 4).

The diode B in the circuit shown in fig. 3 limits the positive peak voltage at g_2 to + 70 V, which is the voltage required for optimum focusing. In view of the high value of the alternating voltage applied to g_2 (several hundreds of volts) the tube is to all intents and purposes cut off during the greater part of the cycle, the beam current being less than $50\mu A$ at $V_{g2} = 0$ V.

Derivation of the Control Voltage

The amplitude of the current impulses in the anode circuit determines the magnitude of the ultimate control voltage V_r. For application to the frequency control circuit (for example the control grid of a reactance tube), this voltage should as a rule have a value of several volts with respect to earth. It may be obtained by means of one of the following circuits.

(1) In the circuit of fig. 5 a blocking capacitor C isolates the frequency control circuit from the direct anode voltage of the E80T, but passes the impulses. These are subsequently rectified by a double diode, so that the required direct control voltage V_r with respect to earth is obtained.

(2) An alternative solution is shown in fig. 6, in which the anode of the E80T is fed with an alternating voltage of the reference frequency instead of with a direct voltage. The control voltage is now derived by connecting an RC network in series with the supply circuit, rectification being obtained in the E80T itself. It is possible to feed the E80T with an alternating voltage, because this tube is operative only during the instants at which impulses are produced. The required anode voltage of about hundred volts can very well be derived from the primary of the preceding band-pass filter, the voltage across this circuit being just at its maximum at these instants.

(3) For practical reasons, however, it will usually be necessary to incorporate an additional amplifying stage. This is of particular importance at high multiplication coefficients, where the content of the anode current impulse becomes very small and the control voltage is apt to assume a low value.
In the circuit shown in fig. 7, one of the harmonics of the anode voltage impulses of the E80T is amplified by means of pentode A before being rectified. The coupling elements consist of single LC-circuits tuned to a harmonic of the impulse frequency. Tuning to the fundamental frequency would, in fact, require special precautions in view of the unavoidable parasitic coupling with the deflection circuit, which carries a high voltage of this frequency. It is true that in designing the E80T special care has been taken to minimize the capacitance of the deflection plates to the anode, but it will nevertheless be advisable to tune the interstage circuits to the second harmonic $2f_d$ of the reference frequency, for example, so that less care need be paid to screening.
The amplifier should pass relatively high frequencies in the vicinity of $2f_d$ to ensure that synchronization is obtained. This can easily be achieved with a single stage of amplification comprising two tuned circuits, provided their quality factors are not made too high. This is explained in the following section.

Low-Pass Filter in the Control Circuit

It is necessary to include a low-pass filter F in the control circuit. This filter serves the following purposes.

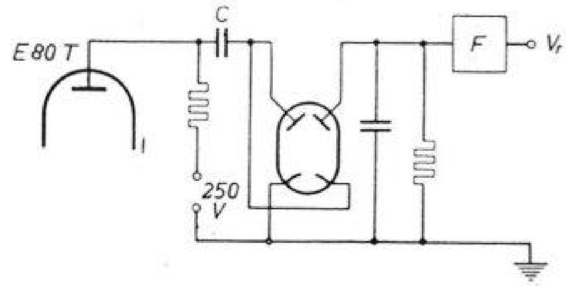

Fig. 5. Method of obtaining the control voltage by rectification of the anode voltage impulses. The direct anode voltage of the E80T is blocked by the capacitor C.

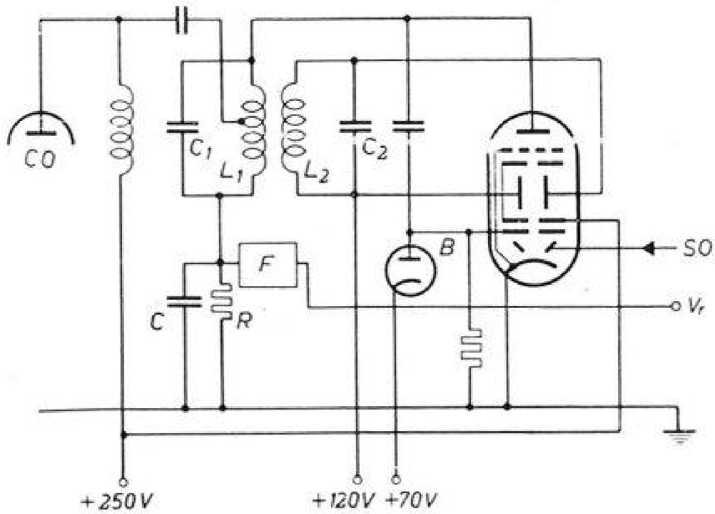

Fig. 6. The anode of the E80T is A.C. fed by the voltage across the preceding band-pass filter, the control voltage being obtained from the *RC* circuit included in the supply lead.

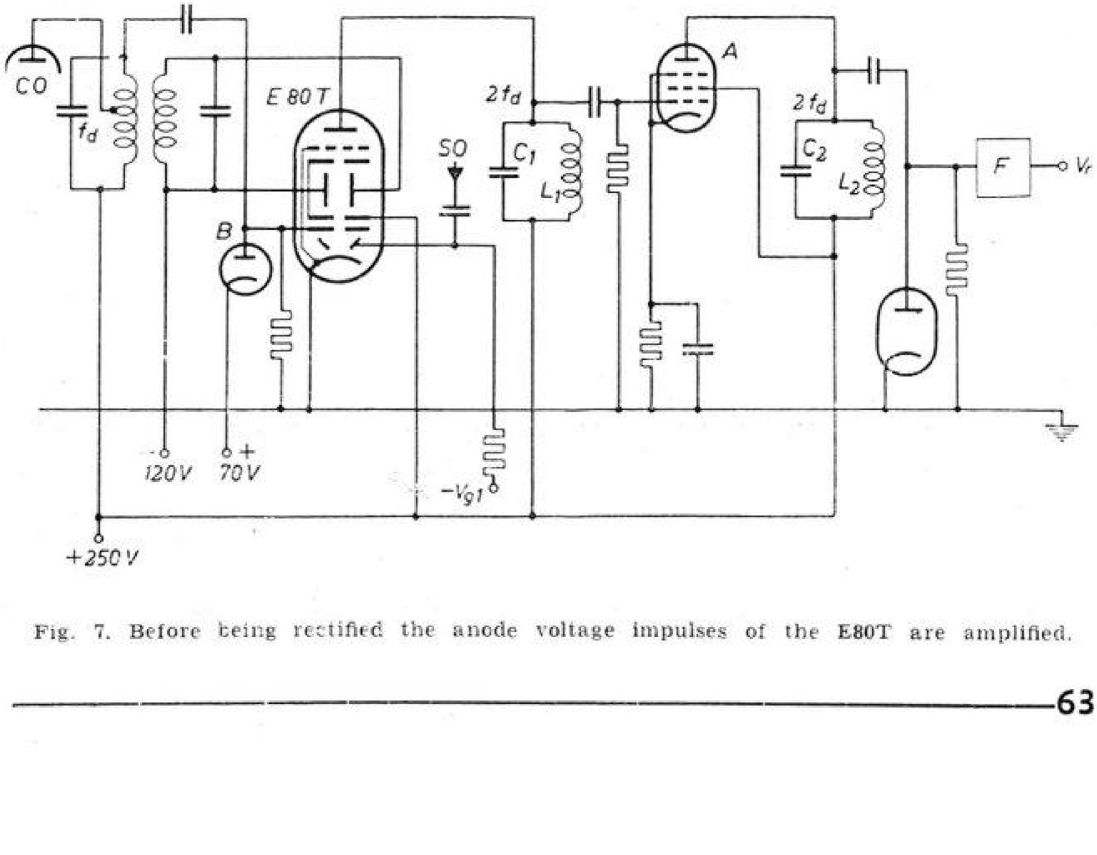

Fig. 7. Before being rectified the anode voltage impulses of the E80T are amplified.

(1) The impulse frequency and its harmonics should be prevented from penetrating into the signal oscillator. This would give rise to undesirable frequency modulation of the I.G.O. A low-pass filter should, therefore, be incorporated for this purpose.
(2) Another factor which must be taken into account is stability. The entire I.G.O. circuit obviously behaves as a feedback amplifier, which becomes unstable when at a particular frequency the phase shift between input and output voltage is 180°. It should be recognised that, due to the character of the integral action of the frequency control, a phase shift of 90° occurs in the phase discriminator, so that an additional phase shift of 90° will immediately lead to instability if the critical frequency is not sufficiently attenuated in the filter.

A disadvantage of the filter is that the collecting zone[4]) is reduced. This may be explained as follows.

During synchronization the control voltage is constant, and assumes the exact value required for keeping the oscillator synchronized. To maintain synchronism in the holding zone, it therefore suffices for the filter to pass the direct voltage. Before synchronization is reached, however, the situation is different.

When the controlled oscillator is out of synchronism, the phase discriminator supplies a signal with a beat note frequency to the control circuit, and this gives rise to frequency modulation of the oscillator. As a result, when the oscillator is being tuned, synchronism is reached prior to the point at which the synchronous frequency would be passed if no frequency control were applied. Since the synchronous frequency can be approached from two directions, there are thus two points at which synchronization comes into action, the frequency difference between these points being called the collecting zone. This zone becomes smaller as the attenuation of the higher frequencies in the control circuit is increased. It will be clear that a narrow pass band of the filter results in a small collecting zone, which imposes high requirements on the accuracy of adjustment of the tuning device.

Frequency Control Circuit

In the experimental design use was made of a circuit developed by Hugenholtz, which—in contrast to conventional circuits with a reactance tube—still operates satisfactorily within the range from 100 Mc/s to 400 Mc/s.

Fig. 8. Frequency control circuit in which two germanium diodes G are used instead of the conventional reactance tube. The control voltage from the filter F is applied to an amplifying tube A. The alternating voltage at point p is fed to g_1 of the E80T.

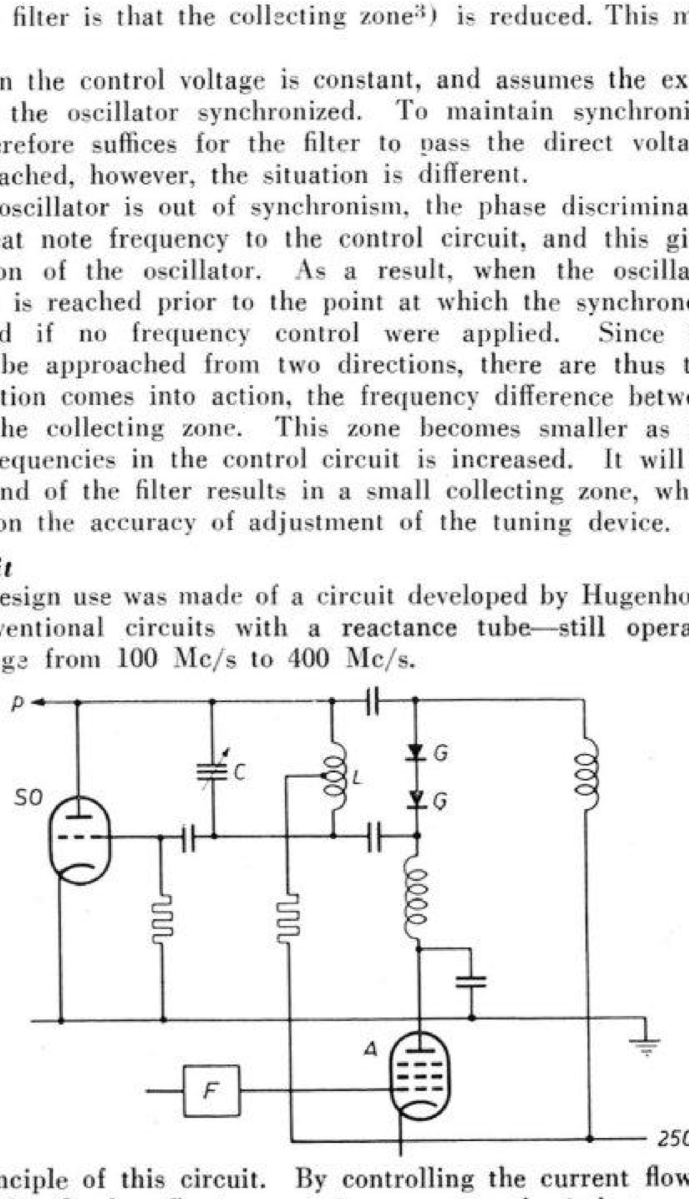

Fig. 8 shows the principle of this circuit. By controlling the current flowing through the germanium diodes G, the effective capacitance across the inductance L is varied, so that the LC circuit is detuned to the required extent. The control voltage supplied by the low-pass filter F is amplified by an additional tube before being applied to this circuit.

4) Cf. J. M. van Hofweegen. A Transmitter and Receiver for a Radio Link in a Carrier Telephone System, Philips Electronic Appl. Bull. 11, No. 5, 1950, in particular p. 92.