The DC90 as an Additive Mixer

With increasing demands for quality and performance in FM radio receivers, developers have had to solve the mixer problem for VHF in a different manner than used for conventional bands (short, medium, and long wave).

While multiplicative mixing has been and continues to be viewed as the best option for conventional bands, additive mixing has to a large degree replaced the initial use of multiplicative mixing for FM. Multiplicative mixing is particularly important in applications with a wide tuning range. For FM, a tuning range of only 10% is needed; therefore some of the general disadvantages of additive mixing are not noticeable, while on the other hand, its advantages can be fully exploited.

The most important advantages of additive mixing are the following:

a.) The equivalent noise resistance is substantially lower for additive mixing than for multiplicative. An important component of the noise in tubes is due to current distribution noise. However, this noise is fully eliminated for triode mixers, and largely eliminated for pentode mixers, as opposed to the case for hexode converters with dual control grids.

  Example: For type ECH81, the equivalent multiplicative noise impedance for short, medium, and long wave is R_e = 70-74 K ohms and for FM, R_e = 35 K ohms. In a triode configuration, the ECH81 has R_e = 7 K ohms.

b.) The input impedance of an additive mixer is larger than that of a multiplicative mixer. This can be seen by the following: To a first approximation, the input impedance is inversely proportional to the current flowing past the control grid. Without going into further detail, this can be understood by the following example: If current in a tube is cut off by large negative bias, the loading, which is controlled by the electron transit time and the cathode inductance, is reduced.

For a hexode, the current flow past the first control grid is practically constant, with no dependence on the phase of the oscillator voltage. In contrast, in an additive mixer, the current flows only during part of the positive half cycle of the oscillator voltage (see Figure 1). For this reason, the current is lower, when averaged over the whole cycle, and therefore the input loading is lower.

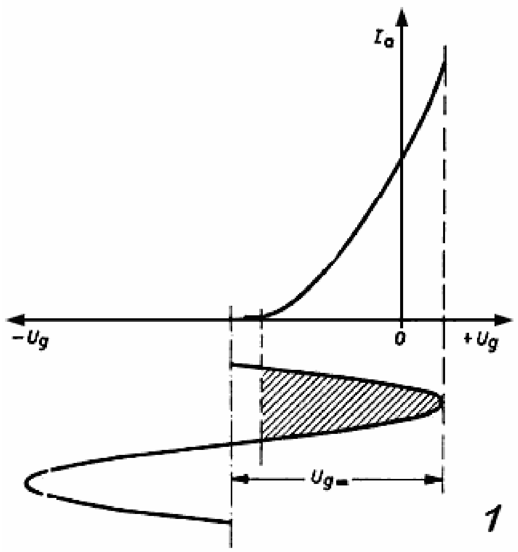

Fig. 1: For explanation of the input impedance. The zero line of the AC oscillator voltage lies beyond the foot of the Ia (anode current) – Ug (grid voltage) curve; therefore current flows only during a restricted part of the positive half cycle of the AC voltage.

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c.) In an additive self-oscillating mixer, a lower oscillator amplitude is needed compared to a multiplicative mixer. The reason for this is because the current control capability of the third grid is lower than that of the first grid in a multiplicative mixer. Operating the oscillator at lower amplitude can be valuable for minimizing radiation of the oscillator signal and its harmonics.

d.) Additive mixing allows the use of simpler tube designs (triode or pentode) than multiplicative (hexode or heptode). This facilitates the reduction of tube element spacing, which increases transconductance. This is one reason why tubes used for additive mixing have higher mixer transconductance than those used for multiplicative mixing.

ECH42 (multiplicative)	S_c	0.7 mA/V
ECH81 (triode, additive)	S_c	1 mA/V
EC92 (additive)	S_c	1.9 mA/V

e.) The frequency drift of the oscillator during the first 30 minutes of use is considerably lower for an additive mixer than for a multiplicative mixer (higher heat capacity of the overall system). In the case of an ECH42 multiplicative mixer, the drift is 100-200 kHz. For an EC92 additive mixer, it is not difficult to achieve a drift of 5-20 kHz. This substantial difference is due both to the circuit and the tube characteristics.

f.) Since the tuning range for FM is relatively small, it is easy to achieve the necessary uniformity of the oscillator voltage over the tuning range. This makes it possible to combine the oscillator and mixer in a single tube (a self-oscillating triode or pentode mixer stage). Instead of the two elements required for a multiplicative mixer, both functions can be performed in a single tube element.

To provide for these advantages in a battery operated set, the DC90 tube was developed. The DC90 was introduced as a Pico 7 tube in 1953, with data published in *Radio Mentor* volume 1, page 10.

A comparison of the DC90 triode with the EC92, which was intended for line powered applications, shows that for the battery operated tube, there is a much lower transconductance, since the requirements for battery operation include the lowest possible operating current – both for filament and anode current). At low current, however, only a significantly reduced transconductance is possible. Because of this situation, the use of the EC90 as a mixer needs to take into account the low transconductance. In addition, it must also be noted that although the anode and filament voltages are nominally constant, due to battery drainage the voltages can vary significantly. With new batteries, the upper limits of anode voltage is 90 V and 1.5 V for the filament. When the battery is nearly drained, the voltages may sink to 40 V and 1.1 V respectively. If attention is given to the relatively low transconductance of 1 mA/V and the aforementioned supply voltage variation, a three-point circuit must be used when working in the 100 MHz range instead of one with inductive feedback. At the same time, in the event no RF stage is used before the mixer, the circuit must be designed so that radiation of the oscillator signal stays below the allowed limit, and must provide for cancellation of the internal impedance of the mixer triode, which is in parallel with the first IF transformer, so that an optimal value for the selectivity and amplification can be achieved, and the circuit can function practically the same as a pentode.

These goals are met in the circuit shown in Fig. 2.

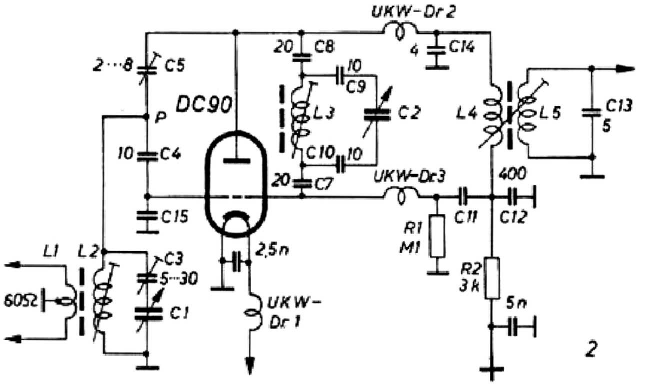

Fig. 2: Additive mixer circuit for the DC90

Three-point oscillator circuit

First of all, the three-point circuit of the oscillator will be described in more detail. The right side of the of the circuit is isolated from the oscillator frequency by virtue of the two VHF chokes Dr2 and Dr3, so that the circuit elements beyond these chokes have no influence on the grid and anode, and therefore are unable to load the oscillator circuit in any way.

The resonant circuit for the oscillator frequency is between the grid and anode. The feedback necessary to induce oscillation is achieved via a capacitive divider acting on the signal.

In Fig. 3, all of the essential components for the RF part of the circuit are shown. The components L_3; C_9, C_2, C_{10}; C_8, C_{ga}, C_7; C_4, C_5; C_{15}, C_{gk}, C_{ak} form the oscillator circuit. The degree of feedback is determined by the capacitance ratio $(C_{15} + C_{gk}) / C_{ak}$. Here C_{gk} and C_{ak} are interelectrode capacitances within the tube. The amplitude of the oscillator is set by the value of C_{15}.

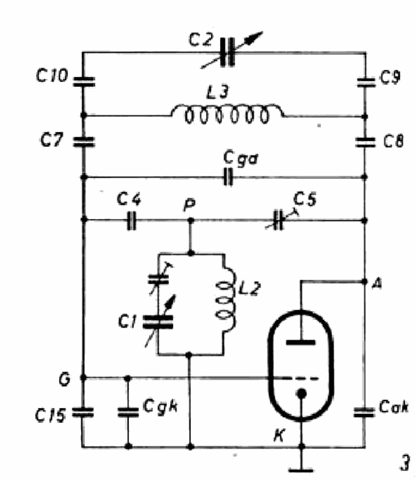

Fig. 3: Three-point oscillator circuit for the DC90

Input bridge circuit

In order to decouple the input circuit (L_2; C_3, C_1) and the oscillator circuit to reduce radiation of the oscillator signal, a so-called "oscillator bridge" is used, just like that used for the EC92.

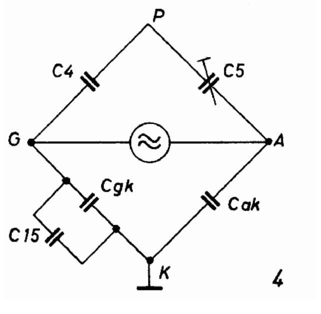

Fig. 4: Oscillator bridge

In Figs. 3 and 4, the relationship between the various components can be seen. Point *P* can have the same potential as the cathode *K* if C_4 and C_5 are chosen appropriately. In Fig. 4 the method of balancing the bridge can be seen. The ratio of $C_4 : C_5$ should be equal to $(C_{gk} + C_{15}) : C_{ak}$. The input circuit is connected between points *P* and *K*, upon which there is also a small fraction of the oscillator voltage.

On the grid of the DC90 there is the input voltage f_e coupled via C_4 and the necessary oscillator voltage f_o, as previously explained in the discussion of the three-point circuit.

In the anode circuit, in addition to many other frequencies, there is the frequency $f_z = f_o - f_e$, which is the intermediate frequency.

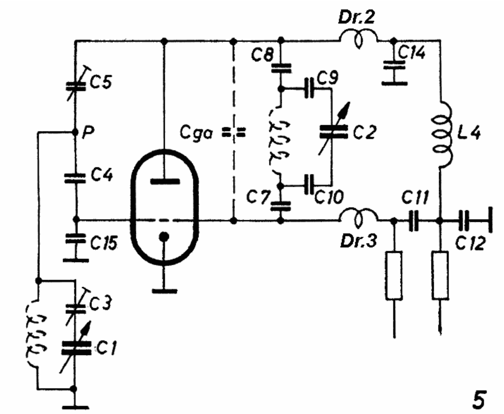

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Fig. 5: IF circuit for the DC90

IF bridge circuit

Figure 5 shows the key components for the IF signal; among these components there is an inductance L_z formed by the combination of $L_4 + Dr_2 + Dr_3$. The two VHF chokes have an inductance which cannot be ignored at the IF frequency. Figure 5 shows precisely which capacitances are tuned for the IF frequency. For clarification, the circuit is further simplified in Fig. 6. There the effective capacitance of the IF circuit is shown by C′, the value of which can be determined by including all the capacitances at work in the IF circuit and computing their effective value between the grid and anode. Point *T* is bypassed to ground by capacitor C_{12}. For illustration, assume all of the capacitances in the circuit are applied between the grid and anode, and assume point *T* is grounded through C_{12}. Assume also that C_{11} is removed, in which case the DC90 will also operate as a three-point oscillator at the IF frequency. If the value of C_{11} is chosen according to the equation $\omega_z Dr_3 = (\omega_z C_{11})^{-1}$, where ω_z is the IF frequency, then the grid is grounded via point *T* through the series resonant circuit Dr_3, C_{11}.

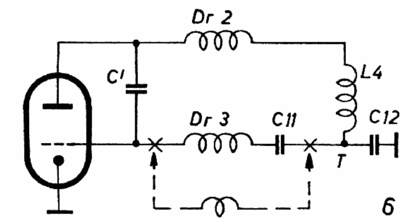

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Fig. 6: Elimination of loading of the EC90 at the IF frequency

The value of capacitor C_{11} must be chosen so that the effect of the aforementioned IF feedback is to increase the internal impedance of the tube R_i to nearly infinity. This operating point is not intended to bring the circuit into oscillation at the IF frequency, but rather to allow the DC90 to function like a pentode.

With the circuit designed as described above and operating with an anode voltage of 60-90 volts, a total amplification factor of 45 is achieved between the antenna terminal and the grid of the first IF tube. A normal dipole antenna, which is typically the first choice for a portable radio, with a base impedance of 60 ohms, is attached to the input. The gain in this overall circuit is divided into a 5X gain in the "antenna – DC90 grid" circuit and a 9X gain in the "DC90 grid – IF tube grid" circuit. At this point in the discussion, another comparison to the line-powered ECH42 multiplicative mixer can be made: the amplification of both tubes in the FM band is the same.

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