A NEW PUSH-PULL AMPLIFIER VALVE FOR DECIMETRE WAVES

by M. J. O. STRUTT and A. van der ZIEL.

537.543:621.385

For the reception of signals with wave lengths shorter than 1 metre electronic valves are needed with very low input and output damping, steep slope and low noise resistance. The socalled acorn pentode satisfies the first requirement but fails to satisfy the last two. In order to satisfy these last requirements electrode systems with larger dimensions must be used. At frequencies above 10^8 cycles/sec., however, such systems possess too great input and output damping. It is shown in this article that the imput and output damping of such systems can be considerably lowered by connecting two systems in a push-pull circuit in a suitable way. After an explanation of the construction and properties of the push-pull amplifier valve EFF 50 developed on this principle, the possibilities of its employment are dealt with. In particular a discussion is given of the results which can be obtained upon application of this valve in amplifying and mixing stages.

Methods of measurement have been developed in this laboratory in recent years by which currents, voltages and impedances at very high frequencies (up to about $1.5 \cdot 10^9$ c/s. corresponding to a wave length of 20 cm) can be accurately determined. These measurements have in the first place been applied to electronic valves in order to investigate the behaviour of these valves in detail [1]). On the basis of the insight obtained, new valves have been developed which give better results at very high frequencies than those used until now. After an explanation of the limitations in the application of the existing electron valves the construction and properties of one of these new types of valves, namely the push-pull amplifier valve EFF 50, is discussed in detail.

The function of an electron valve

The electron valve serves in general to amplify the incoming signal and to transmit it in some form or other to the following stage. In the case of a high-frequency amplifier, for instance, the requirement is that the character of the voltage transmitted shall be a faithful enlarged image of the incoming voltage within a certain frequency region. In the case of a mixing stage, on the other hand, it is desired that the modulation of the transmitted voltage shall have the same character as the modulation of the input voltage, while the character of the voltage itself is quite different; the latter has, namely, a much lower frequency than the input signal.

In addition to the quantitative requirement of a satisfactory enlargement of the amplitudes, there is the qualitative requirement that the desired relation between output voltage and input voltage shall be realized as fully as possible. According to whether the amplitude of the input voltage is very large or very small, two kinds of deviations may here occur. At very great amplitudes due to the curvature of the valve characteristics, the relation between input and output voltage, or between input and output modulation, deviates from true proportionality, or, in other words, distortion occurs. The relation is thus indeed unambiguous, but does not have the desired form. At very small amplitudes the reserve is true: the above mentioned distortion does not occur, but the relation between input and output voltage is no longer absolutely sharp: with a fixed input voltage the output voltage may still exhibit certain fluctuations, which are caused by incidental phenomena in the valve. If these fluctuations are of the same order of magnitude as the signal voltage obtained at the output, there can no longer be the least question of a relation between input and output voltage. These fluctuations, which are usually called noise, thus set a lower limit to the input voltage at which the valve can be used [2]). Since this limit is found to be of essential significance for the usefulness of a receiving installation, we arrive at the conclusion that, as far as the function of an electronic valve is concerned, *the valve must amplify as much as possible and give as little noise as possible.*

In the following we shall see how far valves of ordinary construction are capable of fulfilling this function.

Specification of the requirements made of electronic valves

The amplification of an electronic valve can be expressed quantitatively by four quantities which connect the output voltage and current with the input voltage and current. This is done by

[1]) M. J. O. Strutt: Moderne Kurzwellen-Empfangstechnik, Verlag Springer 1939; Moderne Mehrgitter-Elektronenröhren, 2nd edition, Verlag Springer 1940.

[2]) The factors which determine the noise of a receiving set were dealt with in detail in a previous article (M. Ziegler, Philips techn. Rev. 3, 189, 1938).

means of the equations:

$$\left.\begin{aligned} i_a &= A\,v_g + B\,v_a \\ i_g &= C\,v_g + D\,v_a \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots \quad (1)$$

which have been given and discussed previously in this periodical [3]). A, B, C and D are in general complex quantities depending upon the frequency: they are called the characteristic admittances of an amplifier valve. The admittance A is nothing other than the slope of the valve, B is the output admittance, C the input admittance and D the reaction admittance. If the admittances are known, the amplifying properties of the valve can be calculated in every connection. The noise properties are however not given thereby, and must be considered separately.

The most efficient way of characterizing the noise of an electronic valve is by the introduction of the concept of noise resistance. The definition of noise resistance is based upon the fact that a "noise voltage" appears in every resistance, *i.e.* that at its extremities certain voltage fluctuations occur due to the thermal motion of the electrons in the interior of the resistance. In effective magnitude these fluctuations are proportional to the square root of the resistance value and the temperature. By the noise resistance R of an electronic valve is understood that resistance whose voltage fluctuations (at room temperature) are of the same magnitude as those voltage fluctuations which would have to be introduced between grid and cathode of an electronic valve in order to cause the anode current to fluctuate as much as actually occurs due to the noise of the valve.

If we now return to the function of the electronic valve, it may be seen immediately from the above that it is desirable to make the slope A as steep as possible and the noise resistance R as small as possible. In order to understand the influence of the output admittance B and the input admittance C, we must consider the connection in which the valve is used. From equation (1), however, it follows immediately that the real parts of these admittances give rise to energy losses at the output and input ends, which is undesired in principle, so that it is important to make these admittances as small as possible.

Special cases

We shall confine ourselves here to the special case of high-frequency amplification, making a distinction between

1) the high-frequency amplifier stage of a cascade amplifier (two identical stages following one another), and
2) the high-frequency amplifier stage of a superheterodyne receiver (which is followed by a mixing stage).

We may begin by dealing with both together with reference to the scheme represented in *fig. 1.* The input and output circuits are formed by tuned oscillation circuits with the impedances Z_1 and Z_2. In parallel with Z_1 is the input impedance $1/C_1$. In parallel with Z_2 is the output impedance $1/B$ and, *via* the transformer T, the input impedance $1/C_2$ of the following stage. Although $1/Z_1$, $1/Z_2$, C_1, B and C_2 are in general complex, we shall in the following always confine ourselves to the real parts, since by correct tuning of the circuits the imaginary parts can always be made to compensate each other.

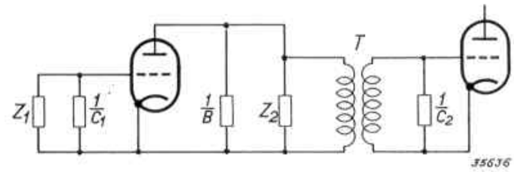


Fig. 1. Diagrammatic representation of a high-frequency amplifier stage connected to a second stage *via* a transformer T. Z_1 and Z_2 are the impedances of the input and output circuits, respectively, of the first stage; C_1 and C_2 are the input admittances of the first and second amplifier valves, respectively, B is the output admittance of the first amplifier valve.

If the amplification, *i.e.* the relation between the output voltage E_u and the input voltage E_i of the given circuit, is calculated for a transformation ratio n, one finds:

$$\frac{E_u}{E_i} = \frac{A\,n}{n^2 C_2 + \dfrac{1}{Z_2} + B}\,.$$

This expression as a function of n has a maximum for $n^2 = (B + 1/Z_2)/C_2$, and the maximum amplification amounts to:

$$\frac{E_u}{E_i} = \frac{A}{2\sqrt{\left(B + \dfrac{1}{Z_2}\right) C_2}} \quad \ldots\ldots \quad (2)$$

It is often possible to make $Z_2 \gg 1/B$. On this condition:

$$\frac{E_u}{E_i} = \frac{A}{2\sqrt{BC_2}}\,.$$

If $2\sqrt{BC} > A$, the ratio E_u/E_i becomes less than unity, and there is therefore no longer any ampli-

3) See in this connection the article by M. J. O. Strutt, and A. van der Ziel, Philips techn. Rev. 3, 103, 1938.

fication possible. If a given amplification is desired, for instance by a factor v, the condition

$$\sqrt{BC_2} < A/2\,v \quad . \quad . \quad . \quad . \quad . \quad . \quad (3);$$

holds for the input and output admittances, and it may therefore be seen that the two admittances may not exceed a certain magnitude.

As to the noise, it is more difficult to reach a numerical formulation of the requirements made. These requirements depend of course entirely upon the intensity of the available input signal. We may, however, state that a decrease in the noise of electronic valves is only of importance as long as this disturbance is not weak compared with the noise due to other sources. Besides the electronic valves it may be seen in the figure that there are other sources of noise, namely the impedances Z_1, $1/C_1$, $1/B$, Z_2 and $1/C_2$.

Let us first consider the noise from the first amplifier valve and the first oscillation circuit. In fig. 1 we see that between grid and cathode of the first valve the impedances Z_1 and $1/C_1$ are in parallel with each other, thus at the same spot as the imaginary noise resistance R. From this it follows that the noise from this noise resistance R must be small compared with the noise of the two impedances Z_1 and $1/C_1$ connected in parallel. If this condition is satisfied, the contribution of the first valve to the noise is small compared to that of the other sources of noise mentioned. This requirement thus indicates an upper limit for the noise resistance R. If we now consider first the case where $1/C_1$ is large compared with Z_1 our requirement amounts to

$$R \ll Z_1.$$

When, however, Z_1 is large compared with $1/C_1$ one would expect as condition

$$R \ll \frac{1}{C_1}$$

From a more detailed consideration it is found that in the last condition C_1 must be replaced by C_e, *i.e.* by that part of the input admittance which is due to the transit time of the electrons. The calculation, which we shall not reproduce here, shows that the product RC_e is a measure of the maximum value of the ratio between signal voltage and noise voltage which can be obtained by adapting the first stage to a given aerial. The larger this product, the less useful the valve.

Until now we have given the requirements for making the noise due to the first valve as small as possible compared with the noise from the input circuit. If we now make the requirement that the noise properties so obtained shall suffer as little disadvantage as possible from the following stages, it is found that a lower limit must be set to the amplification of the first stage. We must now make a distinction between the cases (1) and (2) mentioned above.

In case 1) (cascade amplification) the input resistance and noise resistance of the second valve are about as large as those of the first valve, the same is thus true of the fluctuations which occur in the second stage.

When we represent the total fluctuations of valve plus circuit of each stage by a noise resistance R_t, the noise resistance which, connected to the input of the first stage, represents the noise of both stages together, amounts to:

$$R_t + \frac{R_t}{v^2},$$

where v is the amplification. If v has the value 3, for example, the total noise resistance at the input of the first stage becomes only about 10 per cent greater due to the presence of the second stage, and the equivalent voltage fluctuations become only 5 per cent greater, since these fluctuations are proportional to the square root of the noise resistance. In cascade amplification, therefore, an amplification of 3 must be considered as sufficient in connection with the noise.

In the case of a mixing valve in the second stage, the total noise resistance of this stage is generally considerably greater than with a high-frequency amplifier valve in the second stage, for instance, a factor 10 greater. If the requirement is again made that the influence of the second stage on the noise shall be appreciably less than that of the first stage, the amplification must be made considerably higher, 5 to 10 times instead of 3 times.

Limitations of electronic valves at high frequencies

In the foregoing we have stated the requirements which must be met by the admittances of an electronic valve if it is to fulfil its function. Passing on to higher frequencies it becomes more and more difficult to fulfil this requirement.

As has been explained in detail in the article quoted about the behaviour of electronic valves, while the slope A remains unchanged, at least in absolute value, up to very high frequencies, both the input and the output admittances (we refer always to the real parts) increase steadily with increasing frequency, usually proportional to the square of the frequency. The result is that the left-hand side of equation (3) becomes steadily larger with increasing frequency, so that the equation no longer holds for valves of ordinary construction for frequencies above about 10^8 cycles/sec.

The cause of the undesired increase in input and output admittance lies, as explained in the article referred to, in two phenomena:

1) the finite transit time of the electrons between the electrodes in the valve;
2) the self-inductions and mutual inductions of the connecting wires of the various electrodes.

If it is desired to keep the input and output admittances small at high frequencies, therefore, it is necessary to combat these two phenomena.

The acorn pentode

A very obvious method of decreasing the inductive effects and the transit times is to diminish the dimensions of the valve. The result of the technical development which took place in this direction several years ago is the so-called acorn pentode, whose admittances are given in *fig. 2* as functions of the frequency.

The acorn pentode may be used for amplification purposes up to about 2×10^8 c/s. (1.5 m). At this frequency the input admittance C is 1/4 000 Ω, the output admittance B = 1/10 000 Ω and the slope A = 1.4 mA/V. With the help of equation (3) it may be calculated that at this frequency an amplification is possible by a factor

$$v = A/2\sqrt{BC} = 4.6.$$

If, in agreement with experience, it is assumed that the admittances increase with the square of the frequency, then for the case of cascade amplification (v = 3) an upper limit of about $2.5 \cdot 10^8$ c/s. (1.2 m) can be calculated.

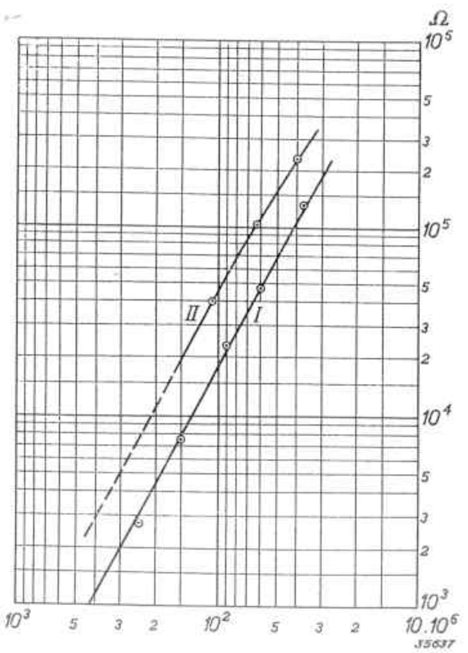


Fig. 2. Input resistance (curve *I*) and output resistance (curve *II*) of the acorn pentode 4 672 as function of the frequency in c/s.

The noise resistance of the acorn pentode amounts to about 8 000 ohms [4]). The product RC_e at $2 \cdot 10^8$ c/s is thus about 2, which may be considered tolerable. With increasing frequency, however, this product rapidly increases, so that as far as noise is concerned the application of the acorn pentode is subject to about the same limitations as set by the amplification.

A further reduction of the dimensions of the valve, which theoretically would mean an improvement, is at present not yet possible technically. Moreover it is very much a question whether the expected improvement would be realized. It is essential that the decrease in size of the valve should not result in a decrease in steepness of slope. Theoretically this requirement could be fulfilled, since the slope is entirely determined by the relations between the dimensions. Actually, however, there are a number of effects which, with decreasing dimensions, have an unfavorable influence upon the slope of a valve, so that the ratio $A/\sqrt{BC}$ will increase little or perhaps not at all upon further reduction of the dimensions. In the present position of technology the acorn pentode must be considered as the most satisfactory compromise as far as the dimensions of the valve are concerned, so that it will not be possible to develop a valve in this direction which is suitable for the amplification of higher frequencies than $2 \cdot 10^8$ c/s.

On the principles discussed above we shall now point out a new line of development which will carry us farther than the line employed until now of decreasing all the dimensions.

A new type of high-frequency amplifier valve

As we have seen, for frequencies higher than 2×10^8 c/s, 1.5 m) it is desirable to have a valve with a steeper slope and a lower noise resistance than the acorn pentode. Valves with steep slope can be constructed by applying various devices. One of these is the enlargement of the surface of the cathode while keeping the distance between the electrodes in the valve constant. This method is analogous to the connection in parallel of a number of elec-

[4]) It must be noted here that the noise of a valve is actually somewhat stronger than is indicated by the above-mentioned noise resistance. With the high frequencies in question the intensity of the noise of the valve is a function of the impedance between grid and cathode. The above-mentioned value of 8 000 Ω holds for a very small value of this impedance.

trode systems. It therefore also leads to a decrease in input and output resistance so that no advantage is gained. When this method is eliminated there remains as second possibility the method used in the acorn pentode, namely by decreasing the distance between control grid and cathode, using at the same time a thinner grid wire and a lower pitch. In this case the input and output resistance need not become smaller. Starting with electronic valves of ordinary construction we have applied this second device. The distance between grid and cathode was reduced to 90 μ, and the slope thereby obtained amounts in the normal adjustment of the valve to 11 mA/V at an anode current of 10 mA.

An increase on the slope of a valve involves automatically a lowering of the noise resistance. The greater the slope the smaller the amplitude of the grid A.C. voltage necessary to cause a given fluctuation of the current. In the construction of the new high-frequency amplifier valve, however, an attempt was made to combat noise even more fully by decreasing the noise A.C. itself. This could be done be keeping the screen grid current low.

The fluctuations of the anode current in a pentode are caused partly by the fact that the electron current emitted by the cathode itself fluctuates, and for an important part also they are caused by the fluctuations of the current distribution between screen grid and anode [5]). The latter fluctuations may be kept small by providing that the screen grid current itself amount to only a small percentage of the total cathode current. In this respect an improvement was obtained in the construction in question by taking thinner screen grid wires and making the pitch of the screen grid greater than is usual in ordinary high-frequency amplifier valves. This has indeed as result that the screen grid fulfils its shielding function less effectively, but it is just the amplification at very high frequencies which is found to suffer no serious disadvantage from this.

The screen grid has the function of shielding the anode from the control, in order that a change in the anode voltage may have no influence on the anode current (high output resistance) and on the control grid voltage (small reaction).

In a valve of ordinary construction the output resistance is of the order of $10^6\ \Omega$ at low frequencies. No advantage could be taken of such a high output resistance in the case of the amplification of very high frequencies, since the resistance of the tuned circuits connected in parallel amounts only to several thousand Ω. As to the static output resistance, therefore, there is no objection to making the shielding between control grid and anode less effective than is usual in valves intended for lower frequencies.

The same result is reached as far as reaction is concerned. The reaction can be described by a capacity C_{ag} between control grid and anode, and is kept as small as possible by the screen grid. At high frequencies, however, the reaction is found to be caused to a large extent, not by the capacity between control grid and anode, but by the mutual capacities, self-inductions and mutual inductions of the various connections of the electrodes. The effect of this additional source has in many cases a greater absolute value and a sign opposite to that of the effect of the capacity C_{ag}. In these cases an increase of C_{ag} is immediately permissible and it even leads to a decrease in the total reaction.

By the decrease of the screen grid current, together with the increase in the slope, the noise resistance was reduced to 600 Ω, thus to about 1/13 of the value of the noise resistance of the acorn pentode. For the smallest input voltage to be amplified, which is proportional to the square root of the noise resistance, this means a gain by a factor 3.5.

As to the amplification, the improvement is even more important compared with the acorn pentode. The slope has increased from 1.4 to 11, thus by a factor 8, and when unput and output impedance are kept constant the same is true of the amplification.

The performance at high frequencies with the above-described construction is, however, not to be considered satisfactory. While the influence of the transit times will indeed be only relatively slight thanks to the short distance between control grid and anode, the inductive and capacitive effects of the connection wires are no smaller than in ordinary electronic valves, and these may have the well-known damping effect on the input and output circuit.

It has been found by measurements and calculations that this damping in the case of valves with steep slopes is mainly due to inductive effects of the cathode connections (inside and outside the valve) and is proportional to the slope. Since we are here concerned with a valve of very steep slope it is therefore necessary to combat the influence of the inductive effects of the cathode connections.

The push-pull amplifier valve EFF 50

The elimination of the inductive effects of the cathode connections is found to be possible by a special application of the push-pull principle. Two identical electrode systems fused together into a single bulb are provided as shown in *fig. 3a* with a common cathode connection. The voltage biases of

[5]) See in this connection the article by M. Ziegler, Philips techn. Rev. **2**, 329, 1937. In that article the phenomena which give rise to the noise in receiving valves are discussed in detail. From the discussion given the following formula can be derived for the noise resistance of a pentode:

$$R = \frac{4\,000}{S_a}\left[1 + 5\,\frac{I_{g2}}{S_a}\left(\frac{I_a}{I_{g2}+I_a}\right)\right]\ \Omega,$$

where the value of the slope S_a must be substituted in mA/V and the anode current I_a and the screen grid current I_{g2} in mA.

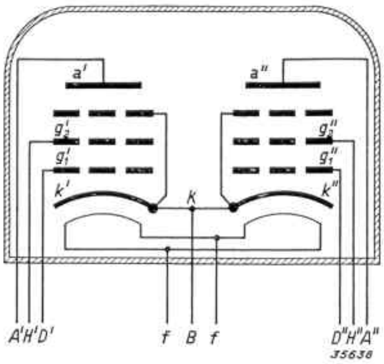
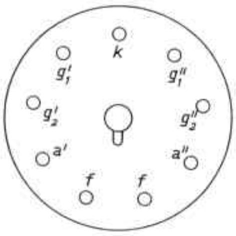


Fig. 3 a) Diagram of the electrode arrangement of the push-pull amplifier valve EFF 50. Two identical pentode systems with a common cathode connection B_k and indirect heating (ff) are mounted in an all-glass bulb.



b) Arrangement of the electrode pins in the base of the push-pull amplifier valve EFF 50.

corresponding electrodes are chosen equal, while the A.C. voltage of the control grid is supplied in opposite phase to the two halves of the system. The anode A.C.'s of the two halves of the system will then exactly cancel each other in part B^k of the cathode connection, so that inductive effects can only occur in the section $k'kk''$ of the cathode connection, which can be kept very short.

The input voltage acts over the terminals $D'D''$; the resistance between these terminals may therefore be considered the input resistance. The input resistance is obviously twice as high as that of a single system. Moreover, due to the employment of the push-pull principle by which the connection wire B^k is rendered ineffective, the input resistance of each separate system is increased by a factor of about 2.5, so that a total increase of the input resistance by a factor 5 is obtained. The remaining part of the input damping must be ascribed chiefly to the transit time of the electrons between cathode and control grid. The output resistance between A' and A'', which is affected to a smaller degree by the transit times of the electrons, amounts to even more than five times that of a single valve: it amounts, for instance, to ten times.

Another advantage of the push-pull principle is that the input and output capacities of the whole valve amount to only half of the capacities of each system separately, which makes these capacities not appreciably greater than in the acorn pentode.

Construction of the push-pull valve

A form has been chosen for the construction of the push-pull valve which is also used for modern receiving valves for ordinary broadcasting wave lengths, namely the so-called all-glass construction which has previously been described in this periodical [6]). This may be seen in *fig. 4* together with several developmental models of different construction.

[6]) See the article: A new principle of construction for radio valves, Philips techn. Rev. **4**, 162, 1939.

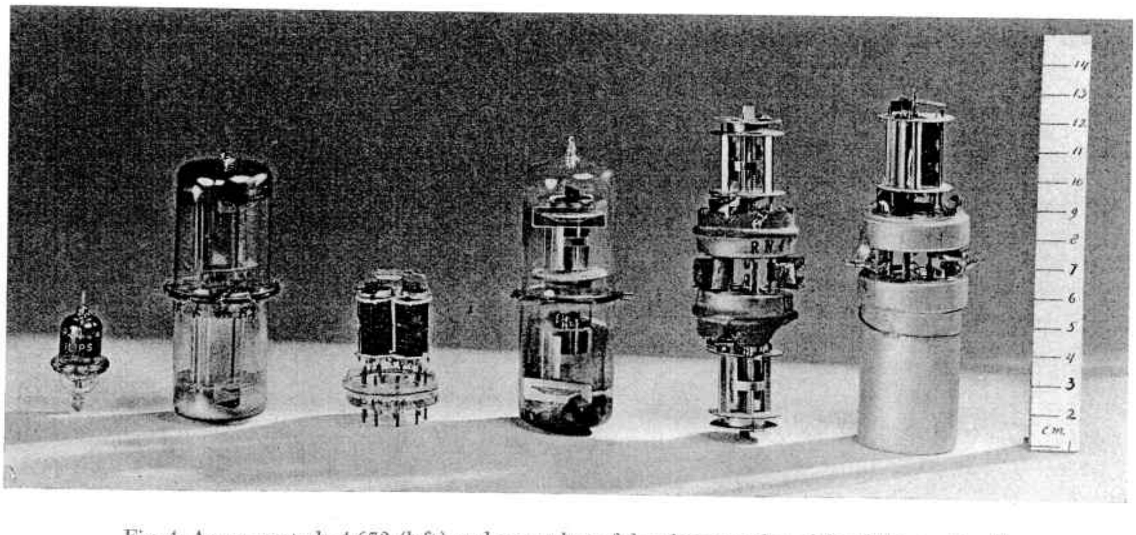


Fig. 4. Acorn pentode 4 672 (left) and a number of developmental models of the push-pull amplifier valve EFF 50. In the case of the first four of these models (second, fourth, fifth and sixth from the left) the systems are assembled end to end; in the final model (third from left) the systems are side by side. The two systems are surrounded not only by a glass bulb, but also by a common gauze cage which has been removed in order to show the assembly to better advantage. To the right a centimetre scale.

The connecting leads of the electrodes in the all-glass construction are all led out through a flat base plate. As may be seen in fig. 3*a* the push-pull valve has nine connections, the arrangement of the nine pins in the base is shown in fig. 3*b*.

The connecting pins which are fused into the glass base are often made of chrome-iron for reasons connected with glass technology. Due to the high magnetic permeability of this material considerable skin effect occurs at frequencies of the order of 10^8 c/s and higher, so that the resistance at these frequencies becomes several hundred times the resistance for direct current. A decrease of the resistance can be obtained by covering the surface of the pins with a non-magnetic material, such as copper or silver.

It is important to keep the resistance of the pins low, because this resistance contributes to the input and output damping. If, for example, we consider the input end, the admittance between the connecting pins is given by the substitution scheme sketched in *fig. 5*, where r_s represents the resistances and L_s the self-inductions of the grid connections, while C_{kg} stands for the capacity between control grid and cathode in each system. The real part of the admittance of this circuit is:

$$\frac{1}{R_p} = \frac{r_s\,\omega^2\,C_{kg}{}^2}{2\,(1-\omega^2\,L_sC_{kg})^2}$$

and thus gives rise to a damping which is proportional to r_s and to the square of the frequency (r_s also increases with the frequency and is approximately proportional to $\sqrt{\omega}$).

Measurements carried out on valves with pins of copper-covered wire indicated that R_p was still larger than 10 000 Ω at a frequency of 3×10^8 c/s.

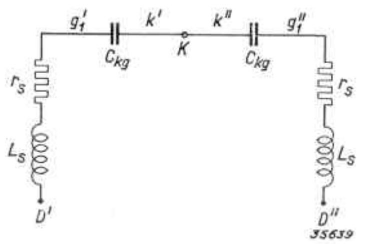


Fig. 5. Substitution diagram for the admittance between the connection terminals of the two control grids.

Application of the push-pull amplifier valve for high-frequency amplification

In the application of the push-pull valve for the amplification of high-frequency signals, various cases can be distinguished, such as the amplification of a carrier wave with a very broad modulation band (television) and the amplification of a carrier wave modulated with sound. Although the new push-pull valve also offers certain advantages for the first mentioned application, we shall confine ourselves to the second, which is at the moment the most important in the wave region below 2 m.

In *fig. 6* a diagram is given showing the principle of the amplifier. The input signal is induced in the coil S_p of a tuned oscillation circuit, whose extremities are connected to the grid connection pins D' and D'' of the push-pull valve [7]). The condenser C_1 we shall for the time being leave out of consideration, as well as several other components whose functions will be discussed later.

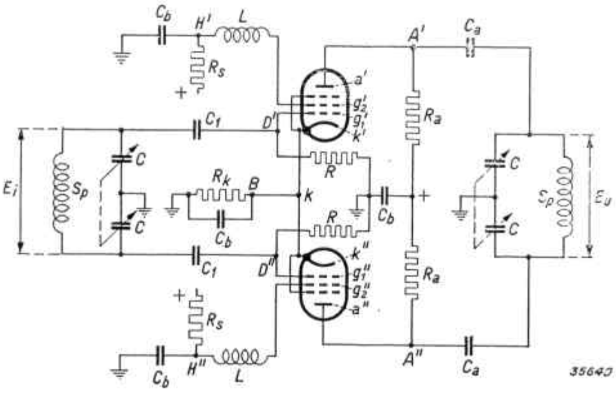


Fig. 6. Connections of a high-frequency amplifier with push-pull valve. The input voltage is applied to the two control grids in opposite phase; the output voltage is taken off from the two anodes in opposite phase. The self-inductions L serve to diminish the input damping, while by a suitable choice of the condenser C_1 and C_a the amplification E_u/E_i can be affected. S_p self-induction, with C, C tuned to the frequency of the A.C. voltage to be amplified; R_k cathode resistance, bridged by a block condenser C_b in order to obtain a negative control grid voltage; R grid leakage resistance; R_s supply resistances for the screen grids; R_a supply resistances for the anodes.

The D.C. voltages for the screen grids and anodes are taken from a positive voltage source via the resistances R_s and R_a, respectively. The anode A.C. passes, via the anode terminals A' and A'', to the tuned output circuit giving the output voltage E_u on the latter.

If S is the slope of the valve, the following formula is found for the amplification of the stage:

$$\frac{E_u}{E_i} = {}^1\!/_2\, SZ_u\,. \quad \ldots\ldots \quad (4),$$

where Z_u is the impedance between the anodes. The value of Z_u depends upon the output impedance of the push-pull amplifier valve, upon the impedance of the oscillation circuit $Sp\ C\ C$ and on the input impedance of the next stage in the circuit. Here again we must make a distinction between cascade amplification and superheterodyne amplification.

If in the case of cascade amplification we go as far as frequencies higher than $3\cdot10^8$ c/s. the

7) The input circuit S_pCC may be considered as a symbol for some kind of aerial circuit, for instance for a dipole combined with a transmission line of suitable length. In any case it is advisable to employ a connection which is symmetrical with respect to earth. By this means it is possible with the help of a dipole to obtain an input voltage twice as great as in the ordinary input connection which is earthed at one end, and where often therefore only half of a dipole can be employed.

input impedance of the following stage becomes so low, even with a valve of the type EFF 50, that it is a serious obstacle to obtaining satisfactory amplification. It is found, however, that this damping can be eliminated to a large extent by including a self-induction in the screen connection. The A.C. voltage of the screen grid thereby generated produces, via the capacity between screen grid and control grid, a current in the control grid circuit which is opposite in phase to the control grid voltage, so that the real part of the input admittance is reduced [8]).

When the second stage is a mixing stage, care must also be taken that its input admittance is sufficiently high. Two diodes in push-pull connection

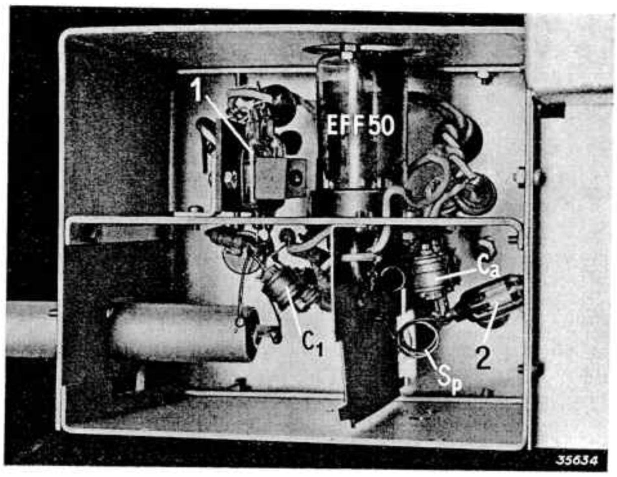


Fig. 8. Simple arrangement for the measurement of the amplification of push-pull valves in a circuit according to fig. 6 at a frequency of $3 \cdot 10^8$ c/s. *1* diodes for the measurement of the input A.C. voltage. *2* diodes for the measurement of the output A.C, voltage. The other symbols in the figure correspond to those of fig. 6.

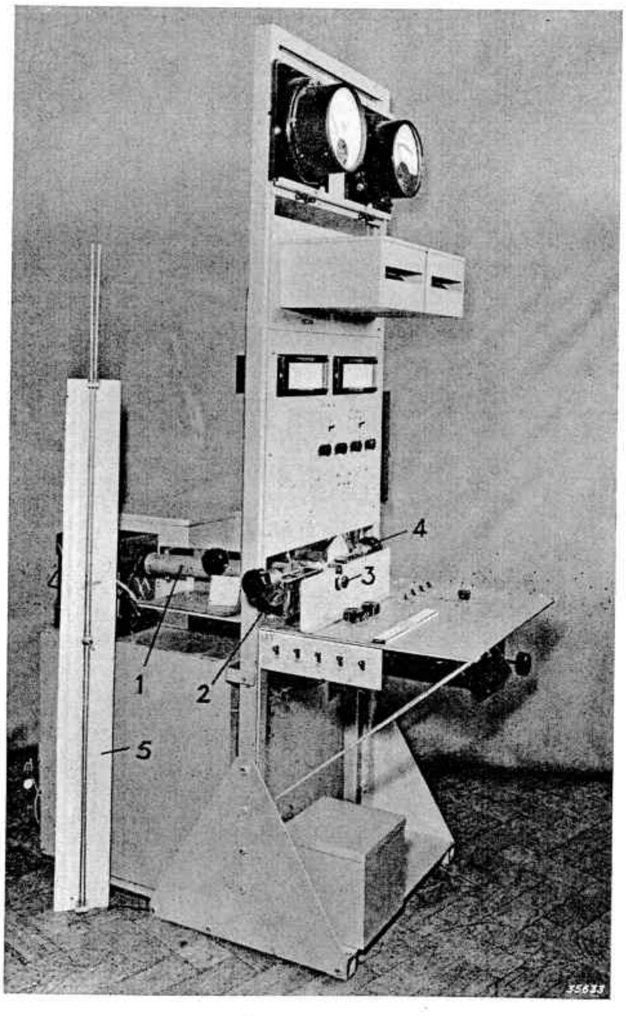


Fig. 7. Installation for the measurement of input and output admittance as well as amplification of push-pull valves at frequencies up to $6 \cdot 10^8$ c/s (50 cm). The meters at the top indicate the control grid voltages and the anode and screen grid currents. Underneath are two micro-ammeters, belonging to the diode voltmeters for the input A.C. voltages of the two control grids with respect to the cathode; below these, two similar micro-ammeters for the output end. *1* oscillator, *2* tunable input circuit consisting of two Lecher conductors with earthed covering; *3* valve to be measured; *4* tunable output circuit, *5* wave meter.

may for instance be used as mixing stage, or one EFF 50 in a connection which will shortly be discussed. In both cases at a frequency of 3×10^8 c/s. a value of Z_u of about 3 000 Ω can be obtained. Since at this frequency the slope corresponds approximately to its static value of 11 mA/V, the amplification $v = {}^1/_2 \times 11 \times 10^{-3} \times 3\,000 = 16.5$.

In testing this result experimentally a complication occurred which we shall discuss in detail, because it involves a point which may also be important in the practical application of the valve. If we consider fig. 6 we see that the input voltage as well as the output voltage is measured at the extremities of a coil. In the above calculation we have assumed that these voltages correspond to the voltages between the control grids g_1', g_1'' and between the anodes $a'a''$, respectively. For frequencies like those in question this is, however, not true, since the connecting wires of the coil to the grids (or anodes) possess considerable self-induction. This has already been pointed out in the discussion of the influence which the resistance of the grid connection pins has on the input damping, and we may use the substitute circuit, fig. 5, there derived in order to calculate the relation between the voltage E_i across the coil and the true input voltage E_i' between the control grids. If the series resistance r_s

[8]) In principle the application of this method is not limited to the push-pull amplifier valve, but offers a possibility of eliminating the input damping in the case of any amplifier valve. In practice, however, this method has the objection for most valves that the self-induction needed for a satisfactory lowering of the input damping is 20 to 30 times as great as with the push-pull valve EFF 50. Self-inductions of this order of magnitude, at the frequencies of decimetre waves, exhibit resonance phenomena which give rise to undesired effects.

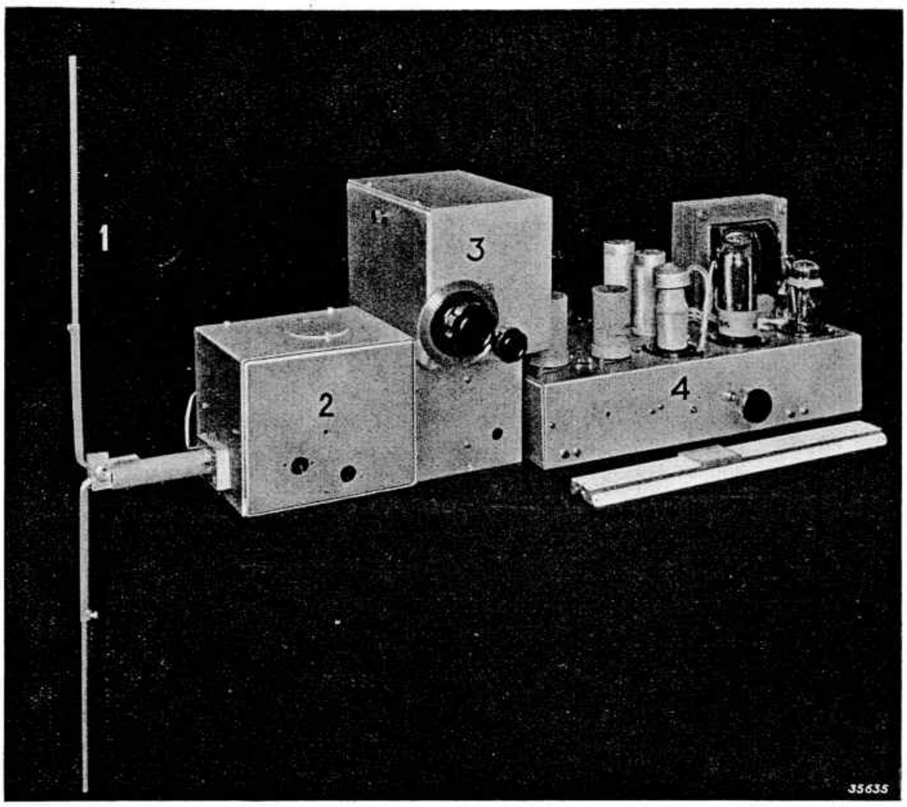


Fig. 9. Complete receiver for signals with a frequency of about $3 \cdot 10^8$ c/s. *1* dipole aerial; *2* box containing the circuit of fig. 6; *3* mixing stage; *4* intermediate and low-frequency part. To give some idea of the dimensions a slide rule about 25 cm long may be seen to the right.

is hereby neglected, we find for sufficiently large values of C_1:

$$\frac{E_i}{E_i'} = 1 - \omega^2 L_s C_{kg}$$

and an analogous relation holds for the output end. It may be seen that the voltage at the extremities of the coil is in general smaller than the voltage between the electrodes.

As to the measurement of the amplification, the condensers C_1 and C_a were so chosen that in the input as well in the output circuit, at the frequency for which the amplification was being investigated, series resonance occurred between these capacities and the self-inductions of the connecting wires (about $4 \cdot 10^{-8}$ henries), so that the total impedance of the connection between the coil and the electrodes is zero. In that case E_i and E_u corresponds to the actual input and output voltages, respectively, so that equation (4) can be tested. The measurements were carried out with the help of apparatus especially developed for that purpose (see *figs. 7, 8* and *9* with the text under the figures), and gave the theoretically expected results at frequencies of $3 \cdot 10^8$ c/s. It may be concluded from this that, within the limits of the experimental error, which may be taken as about 5%, the slope of the valve does not change up to frequencies of $3 \cdot 10^8$ c/s. As stated, at a frequency of $3 \cdot 10^8$ c/s, an amplification by a factor 16.5 is obtained when an output circuit with an impedance of 3 000 Ω is used. At a frequency of $5 \cdot 10^8$ c/s (60 cm wave length) the amplification might still amount to 8 under certain circumstances. These figures, which by no means represent an upper limit since impedances higher than 3 000 Ω can also be realized, are appreciably larger than what can be attained with the help of the acorn pentode.

As for noise also, the push-pull amplifier valve is appreciably better than the acorn pentode. At a frequency of $3 \cdot 10^8$ c/s the electron part of the input admittance for the push-pull amplifier valve is $C_e = 1/600\ \Omega^{-1}$, while the noise resistance $R = 1\,200\ \Omega$, both values calculated between g_1' and g_1'' (see figs. 3*a* and *6*). The acorn pentode, on the other hand, has at the same frequency an input admittance of $1/2\,000\ \Omega^{-1}$, almost entirely due to the transit times of the electrons, and a noise resistance of 8 000 Ω. The product RC_e, which, as already mentioned, determines the noise prop-

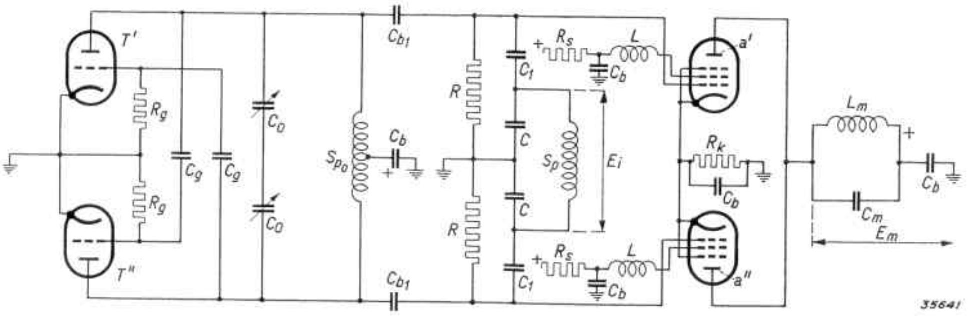


Fig. 10. Circuit of a mixing stage with the help of the push-pull amplifier valve EFF 50. The input voltage E_i is applied to the two control grids in opposite phase. The same is done via the small capacities C_{b1} with the oscillator voltage generated by the triodes T' and T''. The necessary oscillator voltage is of the order of 1 V, while the necessary negative bias is 2 V higher than the oscillator voltage. The intermediate-frequency output voltage E_m is taken from the two anodes in the same phase with the help of the intermediate frequency circuit $L_m C_m$. R_g grid leakage resistances of the triodes; C_g grid condensers of the triodes; $C_0 C_0 Sp_0$ oscillator circuit. The other symbols correspond to those of fig. 6.

erties of a valve [9]), therefore, in the case of the acorn pentode, in spite of its lower input admittance, is twice as unfavourable as in the case of the push-pull amplifier valve.

For the practical application of the push-pull amplifier valve it is very important to know whether or not any slight differences between the two halves of the valve which may occur during manufacture, are detrimental to the performance of the whole valve. This was investigated experimentally with the help of the measuring arrangement shown above. It was found that large differences in the anode currents (for instance 5 mA in one half and 15 mA in the other) cause the amplification, the input resistance and the output resistance to change by several per cent at the most.

This good performance may also be explained theoretically. Since at the high frequencies of decimetre waves the capacitive impedances between cathode, control grid and anode are small compared with the internal resistance of the valve, the anode A.C. in the two halves of the system will be exactly in opposite phase, if care is only taken that the external impedance of both systems with respect to earth is the same, and that the anode A.C. voltage varies exactly in opposite phase in the two systems. Both conditions can be satisfied by providing that the two halves of the coil S_p (fig. 6) are sufficiently strongly coupled with each other.

Although slight asymmetries have little unfavourable effect on the amplification of the valve, it remains nevertheless undesirable that one half of the valve should give much more direct current than the other half. This can be prevented by a suitable choice of the supply resistances of each of the screen grids (see fig. 6).

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[9]) As we have seen the input resistance can be made very large by the introduction of a self-induction in the screen grid connection, and at first glance it might be supposed that a favourable influence might be exerted hereby on the ratio between signal and noise. This is found, however, not to be the case. Closer investigation shows that the ratio between signal voltage and noise voltage does not become better by the application of this device.

Application of the push-pull amplifier valve in mixing stages

In receiving sets it is also possible to use the valve EFF 50 as a mixing valve. Several different connections have been tried out for this purpose. One of these is shown in *fig. 10*. Several of the desirable properties of the valve, namely the slight noise resistance, the steep slope and the possibility of obtaining a high input resistance are also useful in this application. With the scheme of fig. 10, with suitably chosen voltages for each half of the valve, a so-called conversion slope of 2.8 mA/V can be obtained. This conversion slope indicates the ratio between the amplitude of the intermediate-frequency signal in the anode current and the amplitude of the high-frequency signal on the control grid. The amplification (intermediate-frequency output voltage divided by high-frequency input voltage) is, in the scheme shown, equal to the product of the conversion slope of one half of the valve and the impedance of the output circuit for the intermediate frequency used.

If the mixing stage is connected behind a high-frequency amplifier stage, it is desirable to make the input resistance of the mixing stage high by the use of self-inductions in the screen grid circuit, as was already explained.

The noise resistance of the push-pull amplifier valve when used in a mixing stage amounts to about 5 000 Ω between the input terminals, which may be considered unusually low. If the input resistance of the valve is increased to improve the amplification of the first stage, the noise of course also becomes stronger.