STANDARD NOISE SOURCES K 81A, K 50A and K 51A

In the performance of short wave apparatus, such as television and radar equipment, noise plays an important part. This is attributable to the inherent noise of the receivers and amplifiers used. An important property of amplifiers and receivers is the 'noise factor', which defines their noise properties under given conditions.

There are two main methods of determining the noise factor. The first is the one employing a standard signal generator. This method is rather time-consuming and inaccurate, since it necessitates absolute measurements of power and effective bandwidth. The other method is to employ a standard noise source, such as hot resistors, saturated diodes and gas discharge tubes. Since it would be necessary to heat resistors to 29000 °K for measuring a noise factor of 100, which may often be required, their use is, however, restricted.

Saturated diodes are only available for measurements at frequencies up to about 1000 Mc/s. However, at such frequencies it is hardly possible to effect good matching between the diode and its circuit. The K 81 A noise diode is designed for use at frequencies up to 300 Mc/s.

Specially designed gas discharge tubes have proved to possess properties that make them very suitable for use as standard noise sources at microwaves. The K 50 A and K 51 A are intended for use in the 3 cm and the 10 cm band respectively.

NOISE

Noise originates from the arbitrary motion of electrons in solids, liquids and gases. The electron motion may be due to temperature (thermal agitation- or Johnson noise) or to phenomena occurring in gas discharges (collisions of the electrons and the ions) or in vacuum tubes (shot noise, partition noise, induced grid noise).

It can be proved that the mean square noise voltage v_n^2 at the terminals of a resistor equals $4kTBR$, where k is Bolzmann's constant (1.38×10^{-23} Joule/°C), T the absolute temperature of the resistor, B the effective bandwidth of the frequency range considered and R the resistance of the resistor.

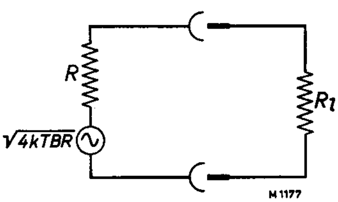

Fig. 58. Representation of a resistor as a noise source.

Accordingly, a resistor may be considered as a noise source of which the e.m.f. is $\sqrt{4kTBR}$ and whose internal resistance is R, which is assumed to be noise-free (fig. 58).

The maximum obtainable power from this

noise source is dissipated in a load resistor R_l, which is equal to R. This so-called 'available noise power' is thus:

$$W_{na} = \frac{\overline{v_n^2}}{4R} = \frac{4kTBR}{4R} = kTB \quad \text{.................................(1)}$$

The available noise power is therefore directly proportional to the absolute temperature T. Analogous to the noise from a resistor, the noise originating from a non-thermal noise source may be expressed in terms of the 'noise temperature', i.e. the temperature of a resistor that would deliver the same amount of noise as the non-thermal noise source.

THE NOISE FACTOR OF A POWER AMPLIFIER

For the sake of simplicity only the noise factor of a power amplifier will be discussed. The discussion is, however, also valid for any other four-terminal network.

Fig. 59 shows the block diagram of a power amplifier and the adjacent circuits. The input of the amplifier is matched to the driver, which has an internal resistance $'R$ and is thus equal to the input resistance of the amplifier.

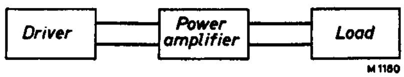

Fig. 59. Block diagram of a power amplifier and adjacent circuits.

The available noise power at the input is kT_0B, T_0 being the noise temperature of the driver.

The term 'available gain' is introduced, being the ratio of the available output power and the available power at the input of the amplifier.

If the available signal power at the input of the amplifier is assumed to be S, and the available gain of the amplifier to be G, the available signal power at the output is GS and the available noise power

$$W_n = GkT_0B + W_i\,, \quad \text{............................(2)}$$

where W_i is the inherent noise power of the amplifier available at the output.

The noise factor of the amplifier is defined as the ratio of the available signal-to-noise ratio at the input and the available signal-to-noise ratio at the output of the amplifier, hence:

$$N = \frac{S/kT_0B}{GS/W_n} = \frac{W_n}{GkT_0B}\,, \quad \text{............................(3)}$$

or:

$$N = \frac{GkT_0B + W_i}{GkT_0B}\,.$$

The last expression shows that the noise factor may also be defined as the ratio of the noise power actually available at the output to the noise power that would be available at the output if the amplifier were noiseless.

From (3) it follows that:

$$W_n = NGkT_0B \; ; \quad \ldots\ldots (4)$$

since:

$$W_n = GkT_0B + W_i = NGkT_0B \, ,$$

$$W_i = (N - 1)\, GkT_0B \, . \quad \ldots\ldots (5)$$

THE SATURATED DIODE AS A STANDARD NOISE SOURCE

The operation of a diode as a noise source is based on the following principle. When the diode is saturated, all electrons emitted by the cathode will reach the anode. The number of electrons emitted during a time interval Δt, i.e. the charge transferred during this time interval, is not constant but fluctuates around a statistical average value due to the thermal movement of the electrons in the cathode. The charge transmitted per unit time corresponds to the direct anode current I_a, and on this average value a fluctuating current is superimposed. This effect is termed the shot effect. The mean square of the noise current within a frequency band B is given by:

$$i_n^{-2} = 2e \cdot I_a \cdot B \, , \quad \ldots\ldots (6)$$

in which e denotes the charge of an electron, i.e. 1.6×10^{-19} C.

Since the individual electrons do not influence each other, this expression is applicable to the entire frequency spectrum, but at extremely high frequencies the influence of the transit time effect becomes more and more noticeable and reduces the shot effect.

When a current $I_a + i_n$ passes through a resistance R_a included in the anode circuit of the diode, a noise voltage drop $v_n^2\, i_n \cdot R_a$ will be produced in addition to the voltage drop caused by the direct anode current. So long as the influence of the internal resistance of the diode is negligible compared with that of R_a, i.e. when $R_i \gg R_a$ (which will always be the case when the diode is saturated, since $\partial v_a / \partial i_a = \infty$), the resistance R_a may be considered as a noise source with an e.m.f. v_n and an internal resistance R_a. The noise voltage source may be represented by the equivalent diagram shown in fig. 60.

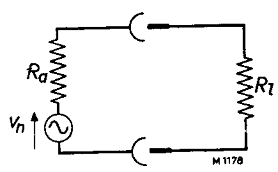

Fig. 60. Equivalent diagram of a saturated diode as a noise source.

The available noise power of this noise source is given by:

$$W_{na} = \frac{\overline{i_n^2} \cdot R_a}{4} \quad \text{.......} (7)$$

From (6) and (7) it follows that:

$$W_{na} = \frac{e \cdot I_a \cdot B \cdot R_a}{2} = 8\, I_a \cdot B \cdot R_a \cdot 10^{-20}. \quad \text{.......} (8)$$

The essential formulae having been given, we will now investigate the way in which the noise generator should be set up in order to be used as a standard noise source, and the requirements to be satisfied in order to obtain reliable results.

The requirement is imposed on the circuit that the internal resistance of the generator should be real and that no appreciable attenuation should be caused by the circuit at high frequencies. In order to ensure that the internal resistance of the generator is real, the capacitance introduced by the tube and the circuit may be neutralized by an inductance shunted across the tube. In this way a parallel tuned resonant circuit is obtained, which is heavily damped by the anode load resistance R_a (usually 60 Ω or 300 Ω).

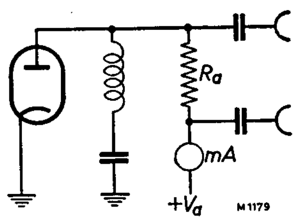

Fig. 61. Basic circuit of a noise generator equipped with a noise diode.

Fig. 61 shows the basic circuit of a noise generator equipped with a noise diode. The noise factor is measured in the following way.

As shown in fig. 62, the amplifier to be tested is connected to the noise generator. The anode load resistance R_a of the generator should be equal to the input resistance of the amplifier.

Fig. 62. Block diagram of the measuring set-up.

First the heater current of the diode remains switched off and a meter indicating the relative power output is connected to the output terminals of the amplifier. After a record has been made of the reading of this meter, which indicates a value corresponding to a power output $W_n = NGkT_0B$ (according to eq. (4)), the heater current of the diode is switched on and carefully adjusted to the value at which the output meter indicates twice the original power. The additional noise output power due to the energized diode is GW_{na} and exactly equal to the initial power $NGkT_0B$.

Hence:

$$GW_{na} = NGkT_0B, \quad \text{.......} (9)$$

which gives:

$$N = \frac{W_{na}}{kT_0B} = \frac{8 \cdot I_a B R_a \cdot 10^{-20}}{kT_0B}.$$

When T_0 is 288 °K:

$$N = 20\, I_a R_a\,, \qquad \text{(10)}$$

where I_a is expressed in mA and R_a in kΩ.

When the milliammeter incorporated in the anode circuit has been calibrated accordingly, the noise factor can be read directly, or it can be calculated by means of eq. (10).

STANDARD NOISE DIODE K 81 A

The K 81 A is a directly heated diode equipped with a noval base, intended for use as a standard noise source at frequencies up to 300 Mc/s. Owing to the small distance between the filament and the anode, the transit time is reduced to a large extent. In order to realize small self-inductances of the electrode leads, both the extremities of the filament and the anode are each connected to three pins of the base.

The filament is fairly thick, so that it can be fed from a 2 volts battery. The thermal inertia consequent upon this thickness is sufficient to prevent fluctuations in the saturation current when an a.c. supply is used. In this case the filament voltage should be very well stabilized. As a result of the diode's high internal resistance, the anode voltage need not be stabilized.

When a load resistor of 50 ohms is employed, a noise factor of 20 (13 dB) can be measured without exceeding the maximum admissible anode current and anode dissipation. When the load resistor is enlarged, it is possible to measure higher noise factors.

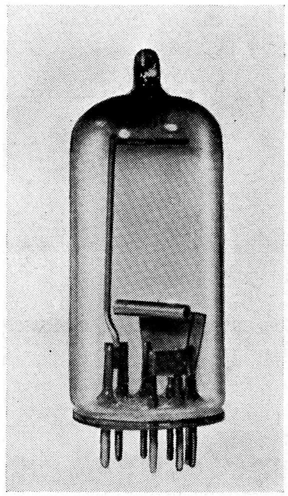

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Fig. 63. Photograph of the K81A (actual size).

TECHNICAL DATA

Heating: direct by a.c. or d.c.

CAPACITANCES

Capacitance between filament and anode . . . . . . $C_{af} = 2.2$ pF

MOUNTING POSITION: any

ELECTRODE ARRANGEMENT

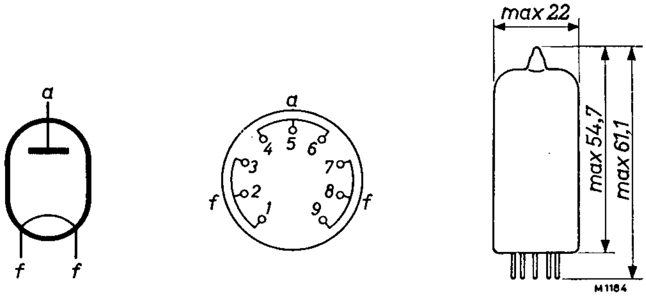


Fig 64. Electrode arrangement, electrode connections and maximum dimensions in mm (noval base).

TYPICAL CHARACTERISTICS

Filament voltage	V_f	=	1.85	V
Filament current	I_f	=	2.5	A
Anode voltage	V_a	=	100	V
Anode current	I_a	=	15	mA

LIMITING VALUES

Filament voltage	V_f	= max.	2	V
Anode voltage	V_a	= max.	150	V
Anode current	I_a	= max.	20	mA
Anode dissipation	W_a	= max.	3	W

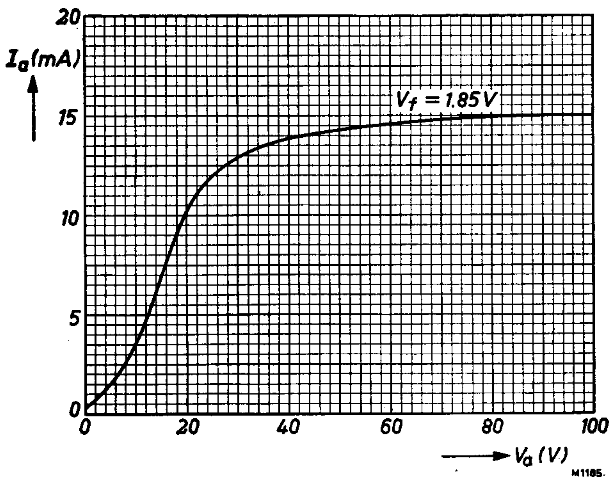


Fig. 65. I_a/V_a characteristic of the K81A at a heater voltage of 1.85 V.

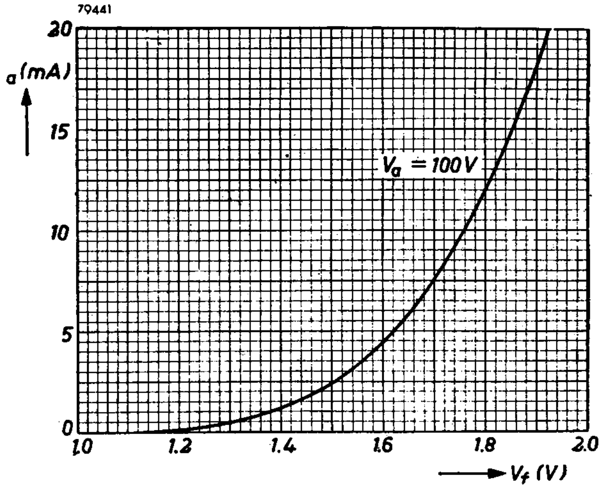


Fig. 66. I_a/V_f characteristic of the K81A at an anode voltage of 100 V.

PRACTICAL CIRCUIT

Fig. 67 shows the circuit diagram of a typical set-up for noise measurements with the K 81 A at 50 Mc/s. The h.f. section is mounted in a closed metal box. The filament and anode voltages are applied via low-pass filters, which prevent the noise originating in the power supply from entering the circuit.

The anode-filament capacitance and the parasitic capacitances are compensated by the self-inductance *L*.

P represents a coaxial output plug to which a coaxial cable with a characteristic impedance of 50 or 75 ohms should be connected, depending on the load resistor used.

CHARACTERISTIC DATA

L = 3 H (approx.)
C = 5000 pF
C' = 1000 pF
R_a = 50 or 75 Ω
V_a = 90 - 150 V

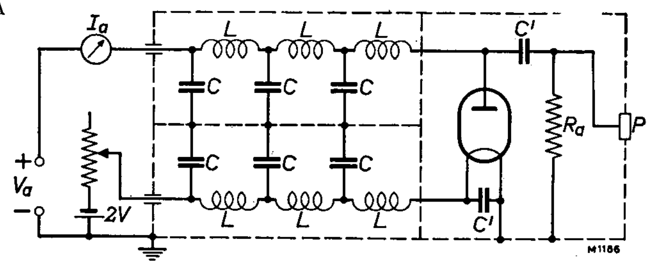


Fig. 67. Practical set-up for noise measurements at 50 Mc/s with the K81A.

GAS-DISCHARGE NOISE TUBES

The collisions between electrons and atoms and the mutual collisions of the electrons in a gas discharge give rise to an arbitrary motion of these electrons, the mean square velocity of which is of such a magnitude that an appreciable amount of noise is produced. It is possible to determine the noise temperature (or electron temperature), which may amount to a few tens of thousands of degrees Kelvin, depending on the type of gas, its pressure, etc.

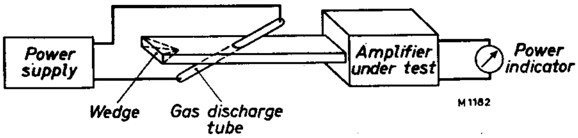


Fig. 68. Outline of a microwave set-up for noise measurements.

In fig. 68 an outline is shown of a typical microwave set-up for measuring the noise factor of an amplifier. In order to achieve wide-band matching, the gas-discharge tube penetrates the broad faces of the waveguide at an inclination of about 10°. The dissipating wedge, situated at the rear of the tube, provides a reflection-free termination when the tube is not ignited, damping then being small. The input of the amplifier is matched to the waveguide: the output terminals of the amplifier, which has an available gain G, are connected to a measuring instrument, indicating the relative output power $a \cdot W$, a generally being unknown.

A method of measuring the noise factor is as follows:

First the gas-discharge tube remains unenergized. The available noise power at the input of the amplifier is now kT_0B, where T_0 is the temperature of the wedge, which is mostly assumed to be at room temperature. The available noise output of the amplifier is $W_n = GkT_0B + W_i$, according to (2). The reading of the power indicator, being $a(GkT_0B + W_i)$, is recorded.

Then the gas-discharge tube is switched on. The available noise power at the input of the amplifier now amounts to kT_nB, T_n being the noise temperature of the tube. At the output of the amplifier a noise power of $GkT_nB + W_i$ is available. The corresponding reading on the power indicator, being $a(GkT_nB + W_i)$, is divided by the actual reading. This ratio, which is called Y, thus becomes:

$$Y = \frac{a(GkT_nB + W_i)}{a(GkT_0B + W_i)} = \frac{GkT_nB + W_i}{GkT_0B + W_i}.$$

Since, according to eq. (5):

$$W_i = (N - 1)\, GkT_0B.$$

$$Y = \frac{GkT_nB + (N - 1)\, GkT_0B}{GkT_0B + (N - 1)\, GkT_0B},$$

or:

$$Y = \frac{T_n + (N - 1)T_0}{T_0 + (N - 1)T_0},$$

whence:

$$N = \frac{T_n/T_0 - 1}{Y - 1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Since Y and T_n are known quantities, the noise factor N can be calculated from eq. (11).

As can be seen, the bandwidth B of the amplifier does not appear in (11), which makes this method more attractive than that using a standard signal generator, in which this is the case.

TUBES K 50 A and K 51 A

The K 50 A and the K 51 A are directly heated, neon-filled gas-discharge tubes for use as standard noise sources in the 3 cm and 10 cm wave bands respectively. They have been designed to be inserted in corresponding waveguides. In fig. 69 an outline of the recommended test mounts is drawn, in which the tubes, when adjusted as specified, are properly matched.

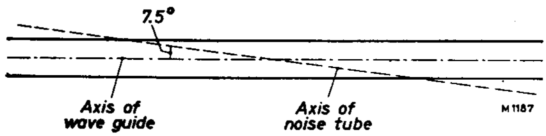


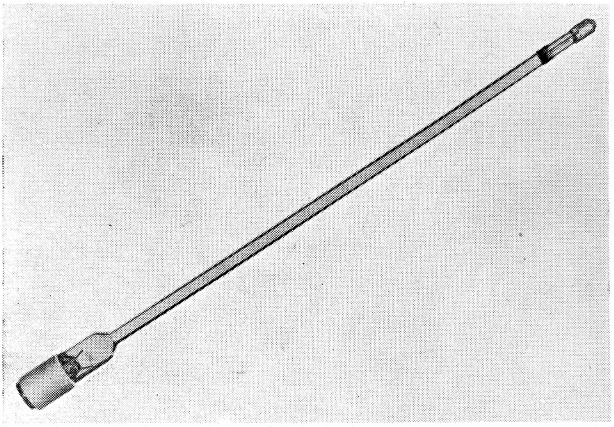
Fig. 69. Outline of the recommended test mount.

High stability is obtained owing to the rare-gas filling of the tubes; within wide limits the noise level is independent of the ambient temperature.

The ignition voltage of the tubes is about 6000 V, and the arc voltages amount to 165 and 140 V respectively. If a special starting device is used, it is not necessary to have a high-tension power supply. The recommended circuit is shown on page 59. The resistor R is designed so as to obtain the desired anode current.

In order to ignite the tube, the switch S is closed, which causes a rather large current to flow through the coil. When this current is interrupted by the switch being opened, a high voltage is induced in the coil, which is sufficient to ignite the tube.

For the tubes to function reliably, the following precautions should be taken:
a. The anode side of the tube should point in the direction of the device under test.
b. The tube should not touch the microwave part of the mount.
c. When using the tube in on-off conditions, it should be remembered that the tube represents a small damping when not ignited. In this condition the waveguide at the rear of the tube should be terminated in a matched load, or a dissipative attenuator of at least 30 dB should be inserted in the waveguide between the tube and the device under test.



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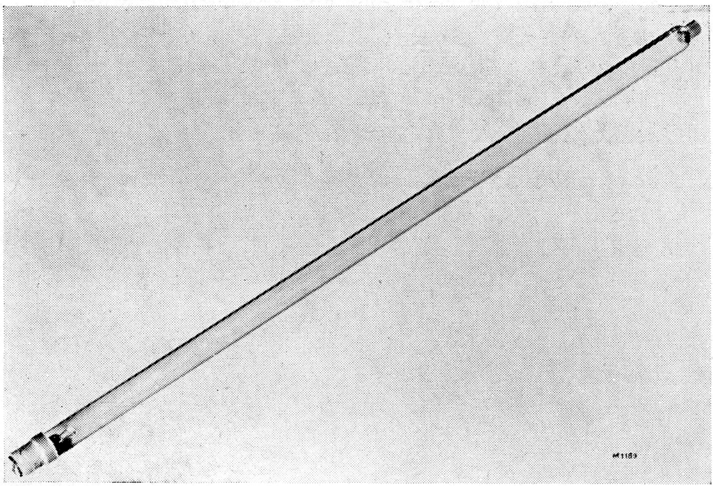

Figs 70 and 71. Photographs of the K50A (above) and K51A (below).

TECHNICAL DATA of the K 50 A

Heating: directly by a.c.: parallel supply

Heater voltage		2 V
Heater current		2 A
Heating time	min.	15 sec

DESIGN VALUE

Ignition voltage	approx.	6000 V [1])

[1]) For recommended circuit, see fig. 74.

The inductance of 8 H should be capable of producing the minimum value of the ignition voltage. This value is only valid if some ambient illumination is present. Hence, in darkness, the presence of a small light source (about 2 W) is necessary.

TYPICAL CHARACTERISTICS

Anode voltage	approx.	165	V
Anode current		125	mA
Noise level in test mount (see fig. 69)		19.3	dB [2]

LIMITING VALUES

Anode current	min.	50	mA
	max.	150	mA
Ambient temperature	min.	—55	°C
	max.	+75	°C

The K 50 A is intended to be used in a waveguide RG-52U or equivalent. The VSWR introduced by the tube in operation is less than 1.1 [3]).

It is recommended that the noise tube and the microwave part of the mount are not touching (minimum diameter of pipe: 7.5 mm).

TECHNICAL DATA of the K 51 A

Heating: directly by a.c.; parallel supply

Heater voltage		2	V ±7.5%
Heater current		3.5	A
Heating time	min.	15	sec

DESIGN VALUE

Ignition voltage	min.	6000	V [1])

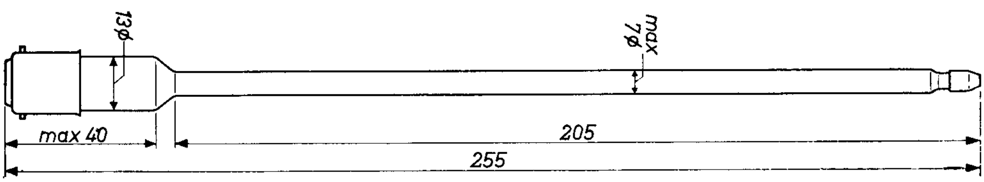

Fig. 72. Dimensions in mm of the K50A.

[1]) For recommended circuit, see fig. 74.
The inductance of 8 H should be capable of producing the minimum value of the ignition voltage. This value is only valid if some ambient illumination is present. Hence, in darkness, the presence of a small light source (about 2 W) is necessary.

[2]) With respect to 300 °K. Change in noise level over 200 hours of operation is negligible.

[3]) The tube can also be used in other types of waveguides. Care should then be taken not to exceed the minimum VSWR of 1.1. For this reason a matching transformer may be required.

TYPICAL CHARACTERISTICS

Anode voltage	approx.	140 V
Anode current		200 mA
Noise level in test mount (see fig. 69)		19.1 dB [1]

LIMITING VALUES

Anode current	min.	100 mA
	max.	300 mA
Ambient temperature	min.	—55 °C
	max.	+75 °C

The K 51 A is intended to be used in a waveguide RG-48U or equivalent. The VSWR introduced by the tube in operation in less than 1.1 [2]).

It is recommended that the noise tube and the microwave part of the mount are not touching (minimum diameter of pipe: 17 mm).

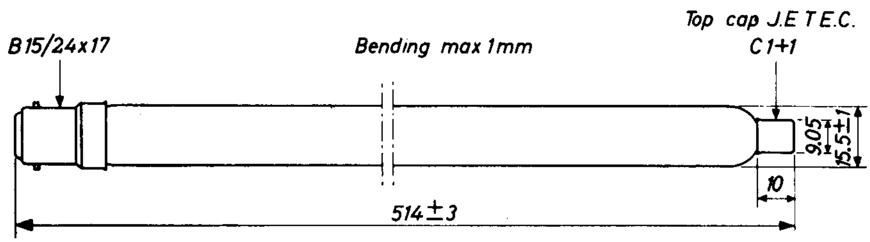

Fig. 73. Dimensions in mm of the K51A.

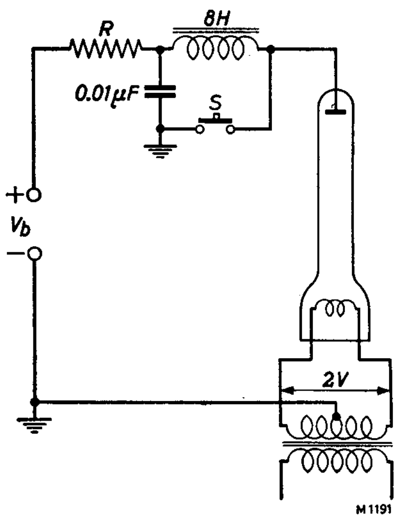

Fig. 74. Recommended ignition circuit for the K 50 A and K 51 A.
K 50 A V_b = 500 V, *R* = 2700 Ω.
K 51 A V_b = 350 V, *R* = 1000 Ω.

[1]) With respect to 300 °K. Change in noise level over 200 hours of operation is negligible.

[2]) The tube can also be used in other types of waveguides. Care should then be taken not to exceed the minimum VSWR of 1.1. For this reason a matching transformer may be required.

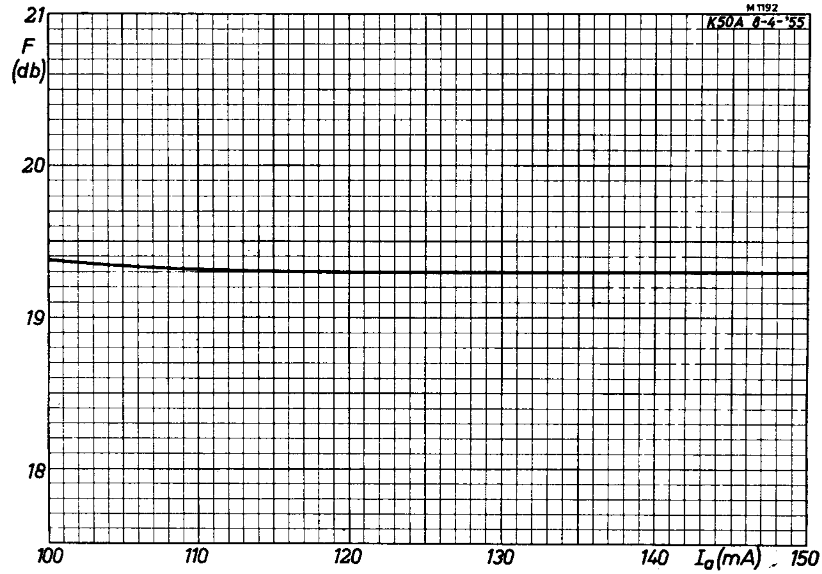

Fig. 75. Noise level (F) of the K50A with respect to 300 °K as a function of the anode current.

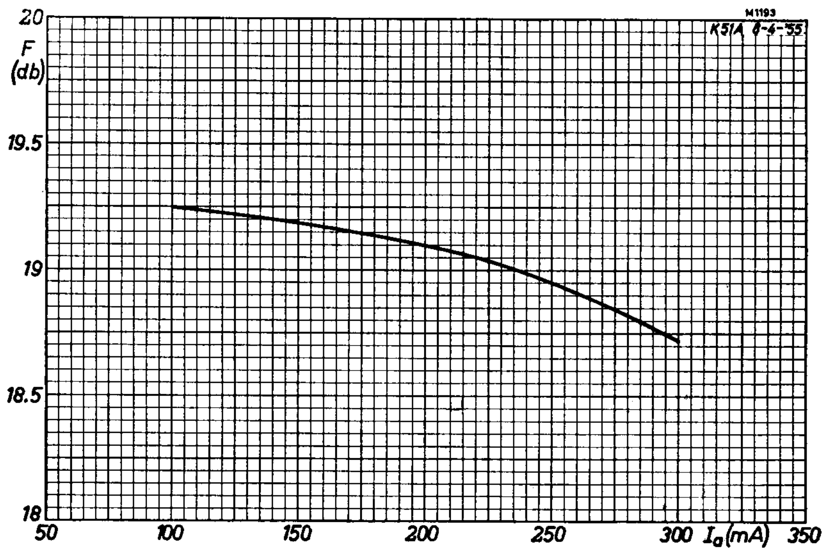

Fig. 76. Noise level (F) of the K51A with respect to 300 °K as a function of the anode current.