PART I

PHILIPS

TUBES FOR AM/FM RECEIVERS

EABC 80 - EC 92 - ECH 81 - EF 85 - EZ 80

PHILIPS ELECTRONIC TUBE DIVISION

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RECEIVERS

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PREFACE

The problem of overcrowding in the medium-wave band is one that dates back to the years before 1940. After the war the situation in this respect grew even worse, so that in some European countries an immediate solution became imperative. This resulted in the adoption of Frequency Modulation as a technical and logical solution with the added advantage of static-free reception.

However, the cost of combined AM/FM receivers remained the barrier for the general acceptance of this type of broadcasting.

Thanks to an unconventional approach to V.H.F. circuitry a new range of receiving tubes was developed by our tube-designers in close collaboration with our Application Laboratories and the setmaking industry. Around these circuits and tubes high-quality receivers for AM/FM reception in a popular price-range can now be realised with five or even with four tubes.

In this Bulletin first a general review is given of the possibilities presented by the new tubes, followed by technical data of each new tube separately; space is then devoted to a detailed description of a complete five-tube receiver and a number of alternative front ends.

We are convinced that this information will enable those engaged in the development of high-quality AM/FM receivers at low cost to make high fidelity reproduction of music and word available to the public, which is and will always be the aim of our industry.

CONTENTS

GENERAL REVIEW

The range of new tubes for AM/FM receivers comprises the following types:

EABC 80	(UABC 80)	triple-diode triode;
EC 92	(UC 92)	R.F. triode;
ECH 81	(UCH 81)	triode heptode;
EF 85	(UF 85)	high-slope variable-mu pentode;
EZ 80		mains rectifier.

The **EABC 80** is a triple-diode triode in Noval technique, specially designed to perform the functions of ratio detector and A.F. voltage amplifier at F.M. With A.M. one of the diodes can be used as detector, the triode then also serving as A.F. amplifier. Two of the three diodes have a low internal resistance (approx. 200 Ω), one of these having a separate cathode, as required in a ratio detector circuit.

The triode section of the EABC 80 is identical with that of the EBC 41; the amplification factor is 70, so that a gain of about 50 can be obtained. When a pentode EL 41 is used in the output stage moderate negative feedback can therefore be applied.

The **EC 92** is an R.F. triode in 7-pin miniature technique for use either as a frequency changer or as a grounded-grid amplifier. When two EC 92 triodes are used in the front end of an AM/FM receiver, at F.M. a high gain and very low noise can be obtained.

For frequency changing at A.M. a tube of the triode-heptode type is required in the front end. A heptode system is to be preferred over a hexode, because, owing to the absence of secondary emission effects of the anode, the former has lower noise, whilst the screen grid can be fed via a simple series resistor. These considerations have governed the design of the **ECH 81**, which is a universal tube in 9-pin Noval technique, for use as frequency changer at A.M. and as H.F. amplifier (heptode section) and frequency changer (triode section) at F.M. Due to the low capacitance between anode and control grid it is also possible to use the heptode as I.F. amplifier at F.M., the triode then also serving as self-oscillating frequency changer.

For I.F. amplification at A.M. a variable-mu pentode is required, and when it is to be used at F.M. a high mutual conductance is desirable. For these functions the pentode **EF 85** is available, which has a variable-mu characteristic and a mutual conductance of 6.0 mA/V.

The total H.T. drain of an AM/FM receiver is usually somewhat greater than that of a normal A.M. receiver, so that a rectifier for a rectified current of approx. 80 mA is required. For receivers operating with a mains transformer the rectifying tube **EZ 80** can be used, the maximum output current of which is 90 mA. Since the EZ 80 has an indirectly-heated cathode and a high insulation between cathode and heater, the heater can be connected in parallel to those of the receiving tubes. This makes the use of a separate heater winding on the mains transformer superfluous. Moreover, an indirectly-heated rectifier has the advantage that the D.C. output voltage does not rise to the peak value of the applied A.C. voltage when the receiver is switched on. It is therefore possible to use filter capacitors with a lower working voltage than in the case of a directly-heated rectifier. For AC/DC receivers, equipped with the equivalent U-types, the UY 41 rectifying tube can be used.

Having discussed briefly the new range of tubes for AM/FM receivers, a number of block diagrams together with performance figures will now be given by way of example. Complete circuit diagrams together with all necessary data will be found at the end of this Bulletin.

1. AM/FM receiver with ECH 81 - ECH 81 - EF 85 - EABC 80 - EL 41 with crosswise distribution of functions in the front end to obtain low radiation

The block diagram of this receiver is represented in fig. 1. It will be noticed from this diagram that the H.F. amplifier and the frequency changer for F.M. are in separate envelopes. The purpose of this is to reduce radiation of oscillator voltage, which would otherwise reach the aerial the EF 85. In the latter case use is made of the above feedback to compensate the decrease in gain caused by the reduction of input impedance.

Performance figures of a receiver with this tube layout are given below for the case where the receiver is switched for F.M. reception. The sen-

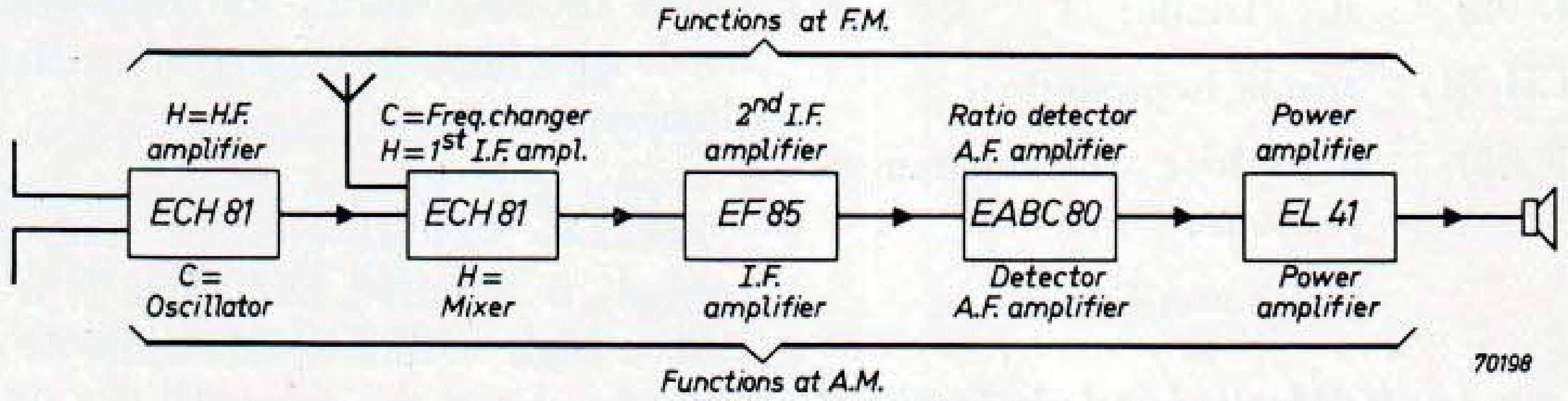


Fig. 1. Block diagram of a five-tube AM/FM receiver. The H.F. amplifier and the frequency changer are in different envelopes.

via the capacitances between the triode and heptode sections of the first ECH 81 tube. A very efficient screening can now be obtained between the aerial and the self-oscillating frequency changer.

With this arrangement, however, the feedback caused by the capacitive coupling between the anode of the triode frequency changer and the anode of the first I.F. amplifier (heptode section second ECH 81 tube) makes it necessary either to apply neutralization or to reduce the input impedance of the second I.F. transformer preceding

sitivity refers to the H.F. signal required at the aerial terminals (75 Ω feeder) for 50 mW A.F. output at a frequency sweep of 2 × 15 kc/s. Further, the equivalent r.m.s. noise voltage at the aerial terminals is given for a bandwidth of about 200 kc/s, and finally the radiation voltage — also measured at the aerial terminals — for the oscillator frequency range of 99 – 111 Mc/s.

Sensitivity		7 μV
Equivalent noise voltage		1.8 μV [1])
Radiation voltage	approx.	2 mV

2. AM/FM receiver with ECH 81 - ECH 81 - EF 85 - EABC 80 - EL 41 without special precautions against radiation

The tube layout of this receiver (see fig. 2) is the same as that previously dealt with, but in the front end the functions are distributed in a different way. The arrangement presented here has the advantage that there is no capacitive coupling between the anode of the frequency changer and the anode of the 1st I.F. amplifier. Owing to the fact, however, that the H.F. tube and the frequency changer are in one envelope, there is more radiation due to the capacitance between the triode and the control grid of the heptode. The performance figures at F.M. obtained with this receiver are:

Sensitivity	7 μV
Equivalent noise voltage	1.8 μV
Radiation voltage	20—40 mV

[1]) Of which 0.33 μV generated in aerial and input circuit.

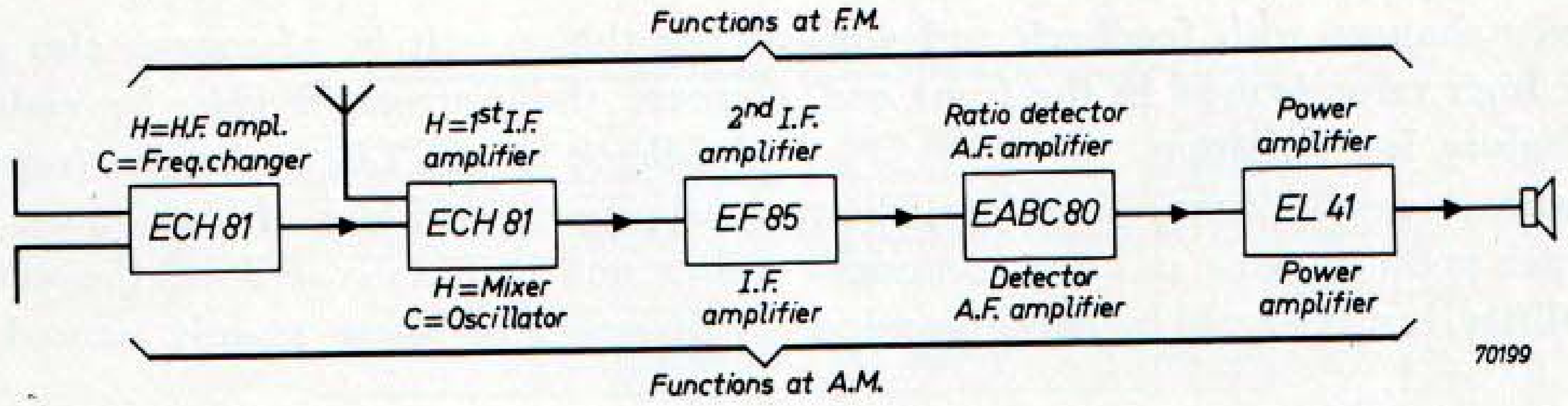


Fig. 2. Block diagram corresponding to that of fig. 1, with the difference that H.F. amplification and frequency changing are performed respectively by the heptode and triode sections of one ECH 81 tube.

3. AM/FM receiver with EC 92 - ECH 81 - EF 85 - EABC 80 - EL 41 without H.F. stage and with direct frequency changing by means of the EC 92

Compared with the block diagrams given above, in fig. 3 the first ECH 81 tube is replaced by the R.F. triode EC 92. Thus an H.F. stage has been dispensed with, so that the radiation voltage at the aerial terminals necessarily becomes higher. When the EC 92 is used in the normal circuit with a grid leak of 18 kΩ and no positive feedback of the I.F. the following performance figures can be obtained at F.M.:

Sensitivity	10 μV
Equivalent noise voltage	1.3 μV
Radiation voltage	15—80 mV

by employing a grid leak of high value, for example 1 MΩ. The input impedance of the frequency changer for the H.F. signal can then be increased, resulting in a greater aerial gain and reduced radiation. It must be admitted that a grid leak of high value involves the risk of squegging, but this can be suppressed by a suitable combination of self-inductance and resistance in the anode circuit. Secondly, the damping across the primary of the I.F. transformer, caused by the internal resistance of the oscillating triode, can be compensated by feeding back part of the I.F. voltage to the grid circuit. This results in a higher conversion gain.

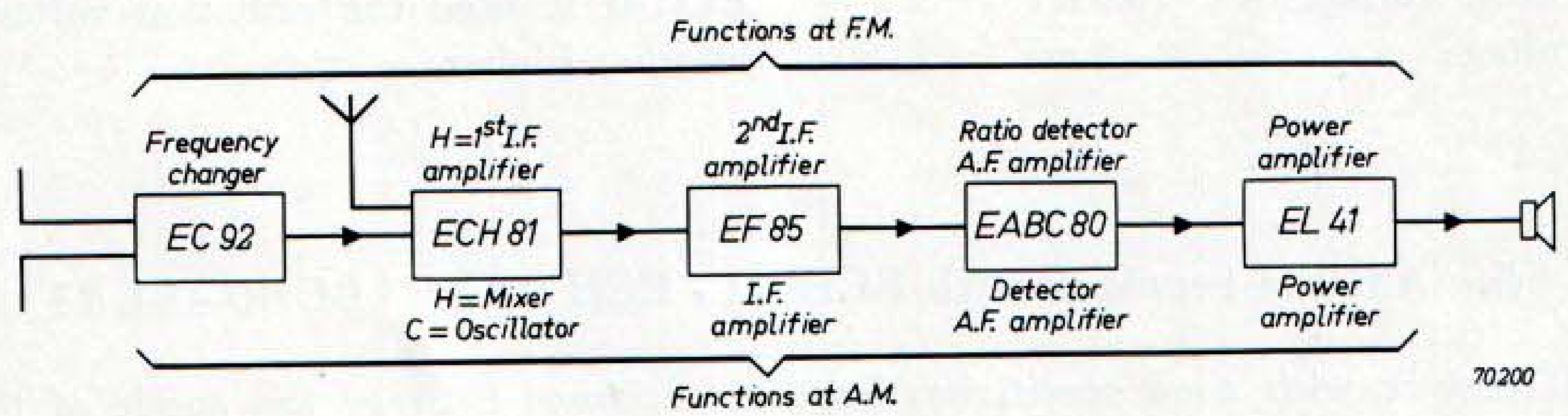


Fig. 3. Block diagram of a five-tube AM/FM receiver in the front end of which an EC 92 triode is used for direct frequency changing.

The figures given above can be considerably improved by two different means. It can be shown that the partition noise in a self-oscillating frequency changer is proportional to the control-grid current. The total noise can therefore be reduced

With the improvements as indicated the performance of the receiver at F.M. is as follows:

Sensitivity	5 μV
Equivalent noise voltage	0.5 μV [2])
Radiation voltage	4—15 mV

4. AM/FM receiver with EC 92 - EC 92 - ECH 81 - EF 85 (EF 41) - EABC 80 - EL 41, the EC 92 tubes operating as grounded-grid amplifier and frequency changer respectively

When a simple stage of H.F. amplification is added to the block diagram of fig. 3 the arrangement is as represented in fig. 4, in which the EC 92 R.F. triode is assumed to be used as a grounded-grid H.F. amplifier. The performance of such a receiver with regard to sensitivity and noise is about the same as that obtained when a single

[2]) Corresponding to a standard noise figure of $N = 2$ to 3.

EC 92 frequency changer with feedback and with a grid leak of high value is used in the front end, but there is slightly less radiation.

At first sight it might seem, therefore, that there is not much point in using an extra grounded-grid H.F. amplifier, but it should be borne in mind that the favourable results can be obtained without employing positive feedback of the I.F. or a grid leak of high value in the frequency changer stage. The circuitry of the frequency changer is thus kept simple. The F.M. performance figures given below refer to these operating conditions and an I.F. tube of the type EF 85.

Sensitivity	4.5 μV
Equivalent noise voltage	0.6 μV
Radiation voltage	4—6 mV

In this case it is, of course, also possible to increase the conversion gain by emloying positive feedback of the I.F. across the frequency changer and using a grid leak of high value. Although this does not materially reduce the equivalent noise voltage (this being mainly caused in the H.F. stage) or the radiation, the sensitivity can be improved by a factor of about 2. When in this case an EF 41 pentode is used in the second I.F. stage instead of an EF 85, the performance figures given above again apply.

Incidentally it may be noted that except for the radiation voltage similar results can be obtained by using one double triode ECC 81 in the front end instead of two EC 92 triodes. Owing to capacitance between the triode sections, when the ECC 81 is used the radiation voltage will be somewhat higher.

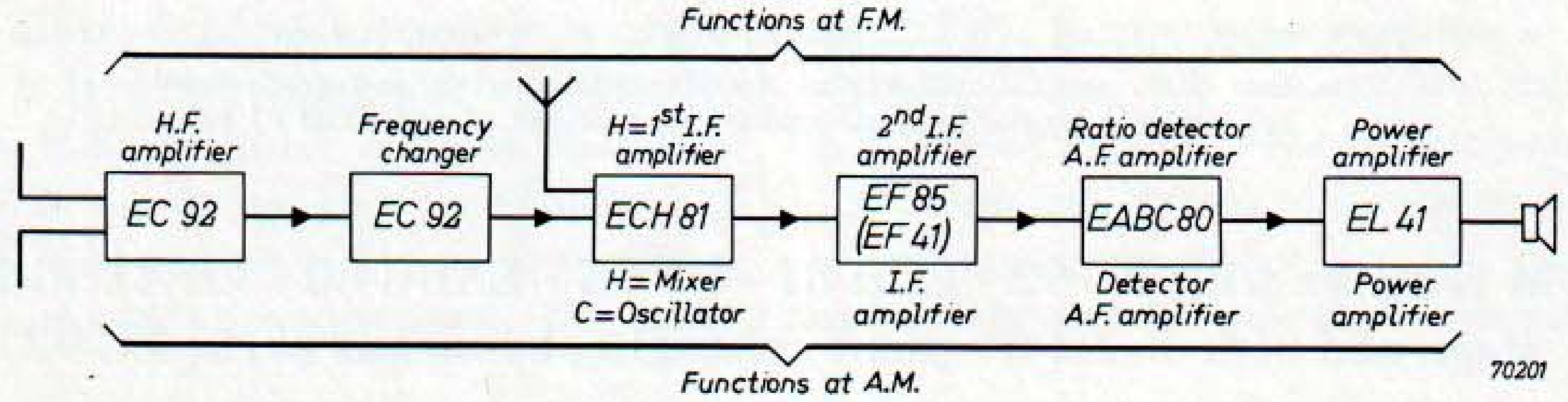


Fig. 4. Block diagram corresponding to that of fig. 3, with the difference that the frequency changer (EC 92) is preceded by a grounded-grid H.F. amplifier with EC 92.

5. AM/FM receiver with ECH 81 - ECH 81 - EABC 80 - EL 41

An AM/FM receiver with good sensitivity, low noise and low radiation can be designed with four receiving tubes plus rectifier. The block diagram is given in fig. 5. The input signal is applied to the triode section of the first ECH 81 tube, which section operates as a self-oscillating frequency changer, giving an I.F. of, say, 26.3 Mc/s. This I.F. signal is amplified by the heptode section of the second ECH 81 tube and then applied to a second self-oscillating frequency changer (triode section of second ECH 81) converting the I.F. signal to 10.7 Mc/s. Final I.F. amplification is provided by the heptode section of the first ECH 81 tube preceding the ratio detector.

With the distribution of functions indicated here and owing to the fact that double frequency changing is used, coupling between I.F. transformers tuned to the same frequency, via the capacitance between the anode of the triode and that of the heptode, is avoided. At F.M. the triode section of the second ECH 81 tube operates at a fixed frequency, so that it can easily be switched over for use as a local oscillator at A.M. It may be seen that with A.M. a normal four-tube circuit is obtained, the heptode of the first ECH 81 then serving as I.F. amplifier.

A detailed circuit description of the receiver according to fig. 5 is not given in this Bulletin but will be issued later in the form of a supplement. Approximative performance figures can, however, be given, based on practical experience. With the figures given below it is assumed that in both the frequency changer circuits positive feedback of the I.F. is used to compensate for the internal resistance of the oscillating triode, and that grid leaks of 0.1 MΩ are employed to increase the input

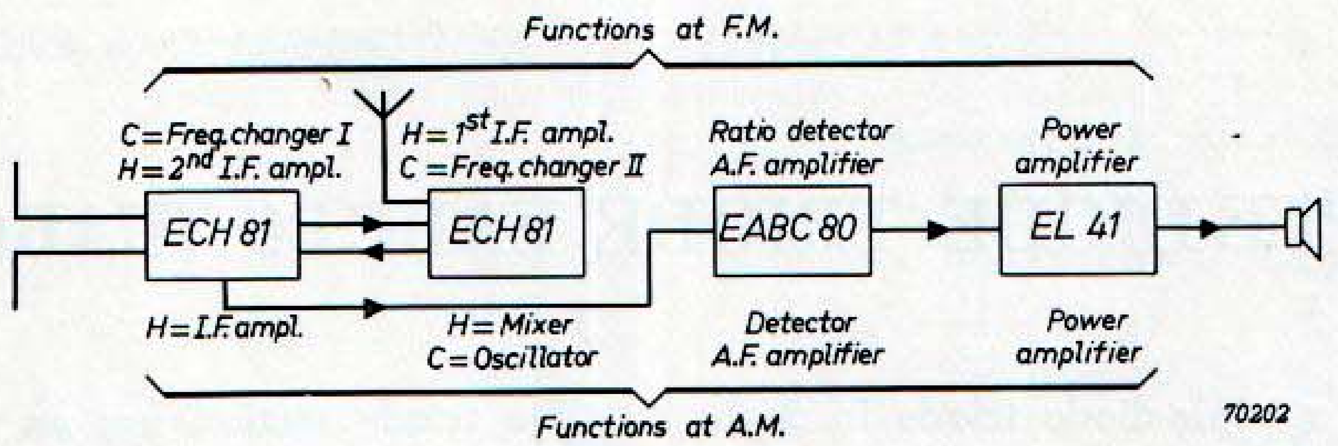


Fig. 5. Block diagram for a four-tube AM/FM receiver.

resistance and reduce the equivalent noise voltage measured at the aerial terminals.

Sensitivity	10—20 μV
Equivalent noise voltage	approx. 1 μV
Radiation voltage	approx. 15 mV

From the block diagrams and performance figures given above it may be seen that AM/FM receivers with excellent performance and a surprisingly small number of tubes can be designed. With the examples given the number of possible circuit arrangements is by no means exhausted and other new circuits may be expected to follow in the near future. This Bulletin gives detailed descriptions of a number of circuits with which practical experience has already been obtained.

TRIPLE-DIODE TRIODE EABC 80 (UABC 80)

The EABC 80 is a triple-diode triode in 9-pin Noval technique specially designed for use in AM/FM or F.M. receivers as a combined detector and A.F. voltage amplifier. It may also be used in television receivers for video or sound detection and its triode section for A.F. amplification or sync separation. Two of the three diodes, namely d_2 and d_3, have a low internal resistance and are therefore suitable for use in a ratio detector circuit, or in any other F.M. detector circuit operating with a balanced discriminator. The remaining diode (d_1) is available for use as A.M. detector.

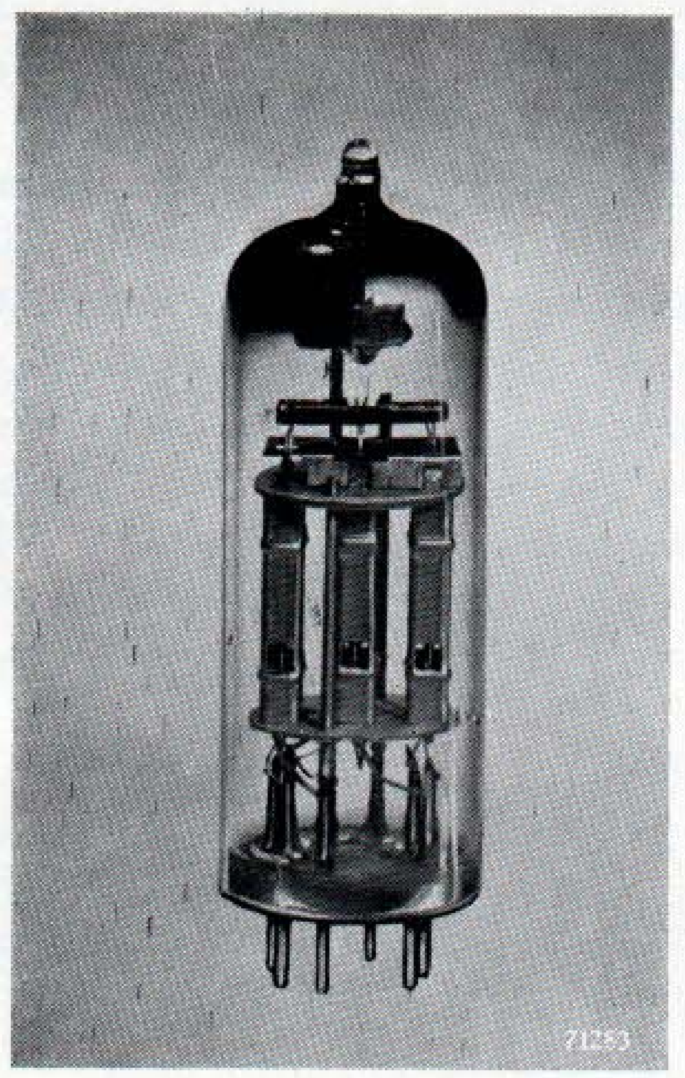


Fig. 6. The triple-diode triode EABC 80.

TECHNICAL DATA [3])

HEATER DATA

Heating: indirect by A.C. or D.C.;
EABC 80 for parallel supply,
UABC 80 for series supply.

Heater voltage	EABC 80	V_f	=	6.3 V
	UABC 80	V_f	=	28.5 V
Heater current	EABC 80	I_f	=	0.45 A
	UABC 80	I_f	=	0.1 A

[3]) Provisional data.

The triode section has an amplification factor of 70. With a total anode load of 180 kΩ and a grid bias of 1.25 V the voltage gain is 52, when the supply voltage is 250 V. The total distortion is then 0.55% at $V_o = 5\ V_{rms}$ and 0.9% at $V_o = 10\ V_{rms}$. When in the output stage of a receiver an EL 41 pentode is used the EABC 80 must give an output voltage of 3.8 V_{rms} for full output, or when negative feedback is applied across the output stage (feedback factor 2.5) the output voltage of the EABC 80 must be 9.5 V_{rms}. It is thus seen that in either case the EABC 80 is capable of providing ample output voltage to drive an EL 41 pentode with low distortion.

In order to avoid microphony the input signal required at the grid of the EABC 80 triode for 50 mW output of the final stage must be kept above a certain level. The permissible sensitivity depends, of course, upon the mechanical layout of the receiver and the acoustical efficiency of the loudspeaker. When a loudspeaker with an acoustical efficiency of 5% is used, in the average receiver the input signal required at the triode for 50 mW output should be at least 10 mV for frequencies of 800 c/s and higher. It will, however, often be desired to apply bass boost, so that the sensitivity at low frequencies becomes greater. For frequencies below 800 c/s this is permissible, provided the input signal required for 50 mW output is greater than that represented in fig. 7.

The data given below apply to both the EABC 80 and the UABC 80, the differences being indicated where necessary.

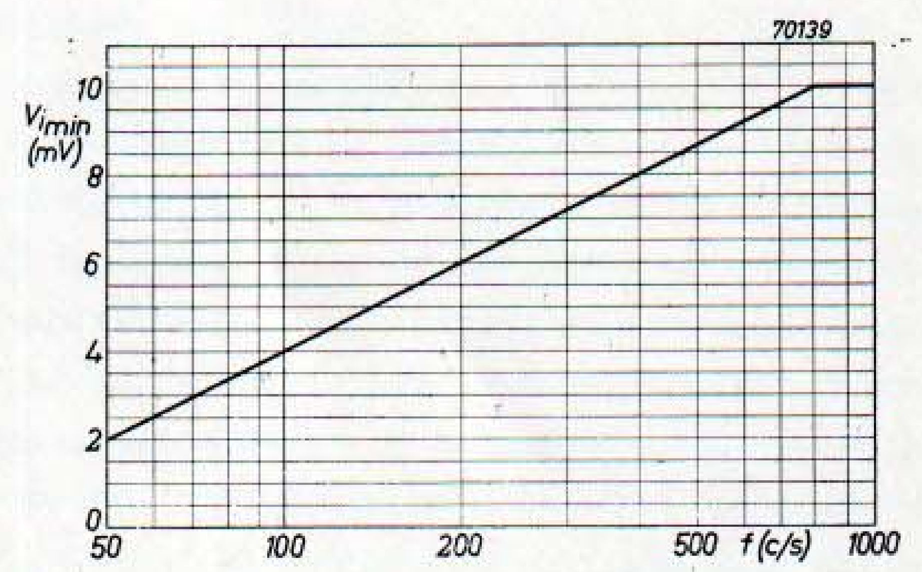


Fig. 7. Permissible sensitivity of the EABC 80 triode section as a function of frequency, for 50 mW output of the output stage.

BASE CONNECTIONS AND DIMENSIONS
(in mm)

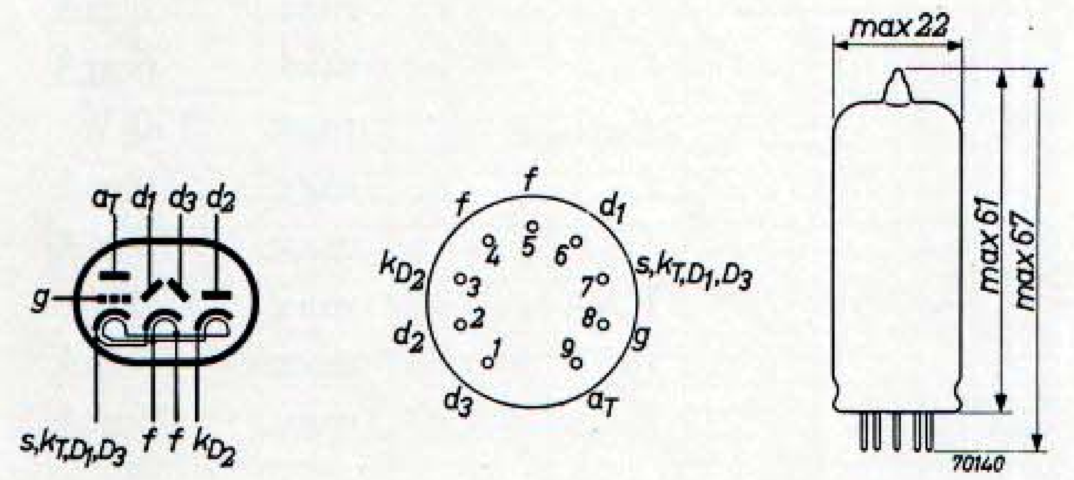


Fig. 8.

Mounting position: any

CAPACITANCES

Triode section			**Diode sections**		
C_g	=	1.9 pF	C_{d1}	=	0.8 pF
C_a	=	1.6 pF	C_{d2}	=	8.7 pF
C_{ag}	=	2.2 pF	C_{d3}	=	4.3 pF
C_{gf}	<	0.04 pF	C_{kD2}	=	6.3 pF
			C_{d1f}	<	0.25 pF
			C_{d3f}	<	0.10 pF
			C_{kD2-f}	=	4 pF

Between triode and diode sections

C_{gd1}	<	0.1 pF
C_{g-kD2}	<	0.01 pF
C_{gd3}	<	0.02 pF
C_{ad1}	<	0.2 pF
C_{a-kD2}	<	0.2 pF
C_{ad3}	<	0.2 pF

TYPICAL CHARACTERISTICS OF TRIODE SECTION

Anode voltage	V_a	=	100	250 V
Grid bias	V_g	=	—1	—3 V
Anode current	I_a	=	0.8	1.0 mA
Mutual conductance	S	=	1.3	1.2 mA/V
Amplification factor	μ	=	70	70
Internal resistance	R_i	=	54	58 kΩ

TYPICAL CHARACTERISTICS OF DIODE SECTIONS

Internal resistance of diode 1 at $V_{d1} = +10$ V	R_{id1}	=	6.25 kΩ
Internal resistance of diode 2 at $V_{d2} = +5$ V	R_{id2}	=	approx. 200 Ω
Internal resistance of diode 3 at $V_{d3} = +5$ V	R_{id3}	=	approx. 200 Ω
Ratio of internal resistances of diode 2 to diode 3 or vice versa		⩽	1.5

LIMITING VALUES OF TRIODE SECTION

Anode voltage at zero anode current	V_{ao}	=	max.	550 V
Anode voltage	V_a	=	max.	300 V
Voltage between heater and cathode	V_{fk}	=	max.	150 V
Grid voltage ($I_{g1} = +0.3\ \mu$A)	V_g	=	max.	—1.3 V
Cathode current	I_k	=	max.	5 mA
Anode dissipation	W_a	=	max.	1 W
External resistance between grid and cathode	R_g	=	max.	3 MΩ [4])
External resistance between heater and cathode	R_{fk}	=	max.	20 kΩ

[4]) With grid current biasing R_g = max. 22 MΩ.

LIMITING VALUES OF DIODE SECTIONS

Inverse voltage at diode 1	$V_{d1\,inv\,p}$	=	max.	350 V
Average current of diode 1	I_{d1}	=	max.	1 mA
Peak current of diode 1	$I_{d1\,p}$	=	max.	6 mA
Inverse voltage at diode 2	$V_{d2\,inv\,p}$	=	max.	350 V
Average current of diode 2	I_{d2}	=	max.	10 mA
Peak current of diode 2	$I_{d2\,p}$	=	max.	75 mA
Inverse voltage at diode 3	$V_{d3\,inv\,p}$	=	max.	350 V
Average current of diode 3	I_{d3}	=	max.	10 mA
Peak current of diode 3	$I_{d3\,p}$	=	max.	75 mA

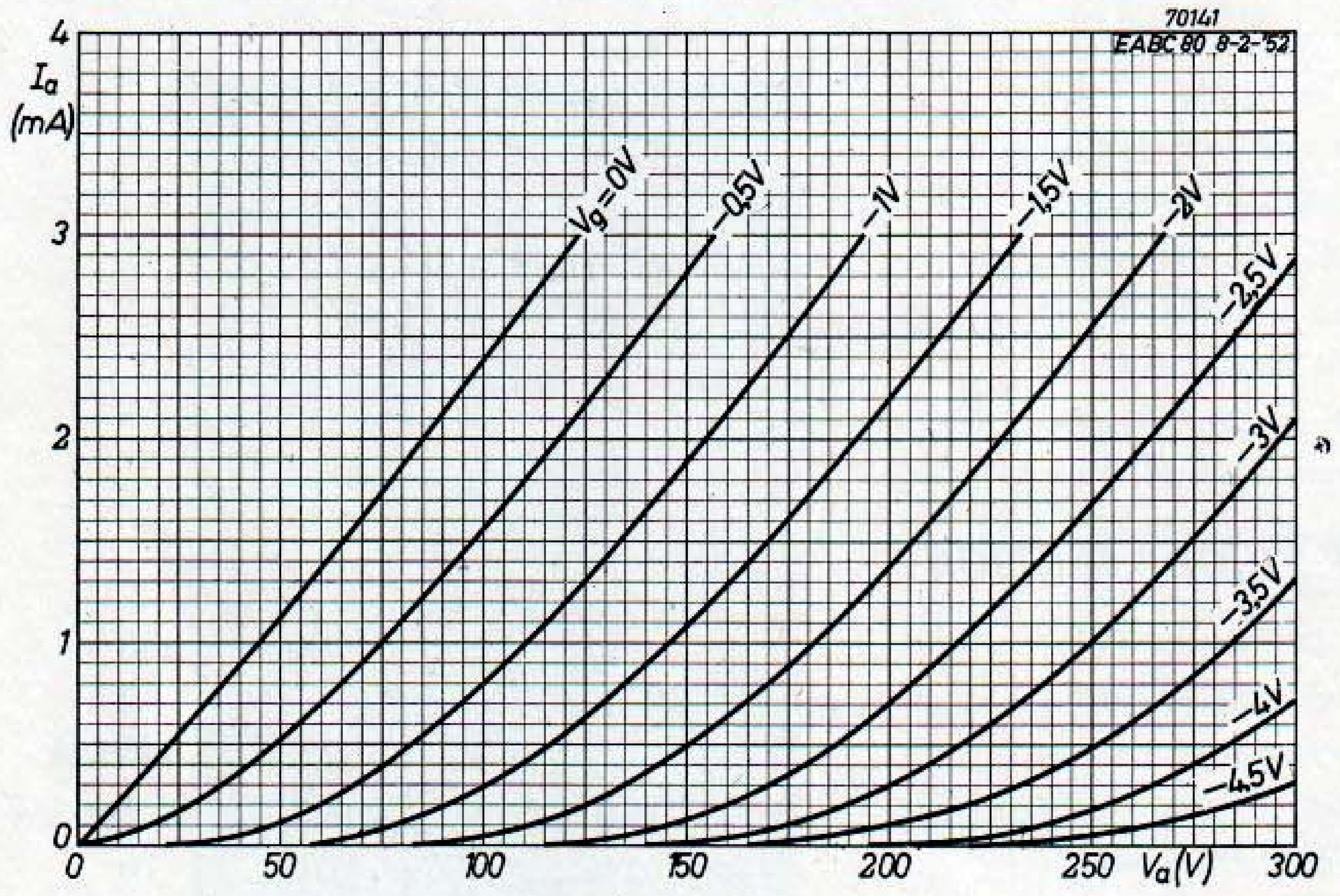


Fig. 9. **Anode current plotted against the anode voltage with the grid voltage as parameter.**

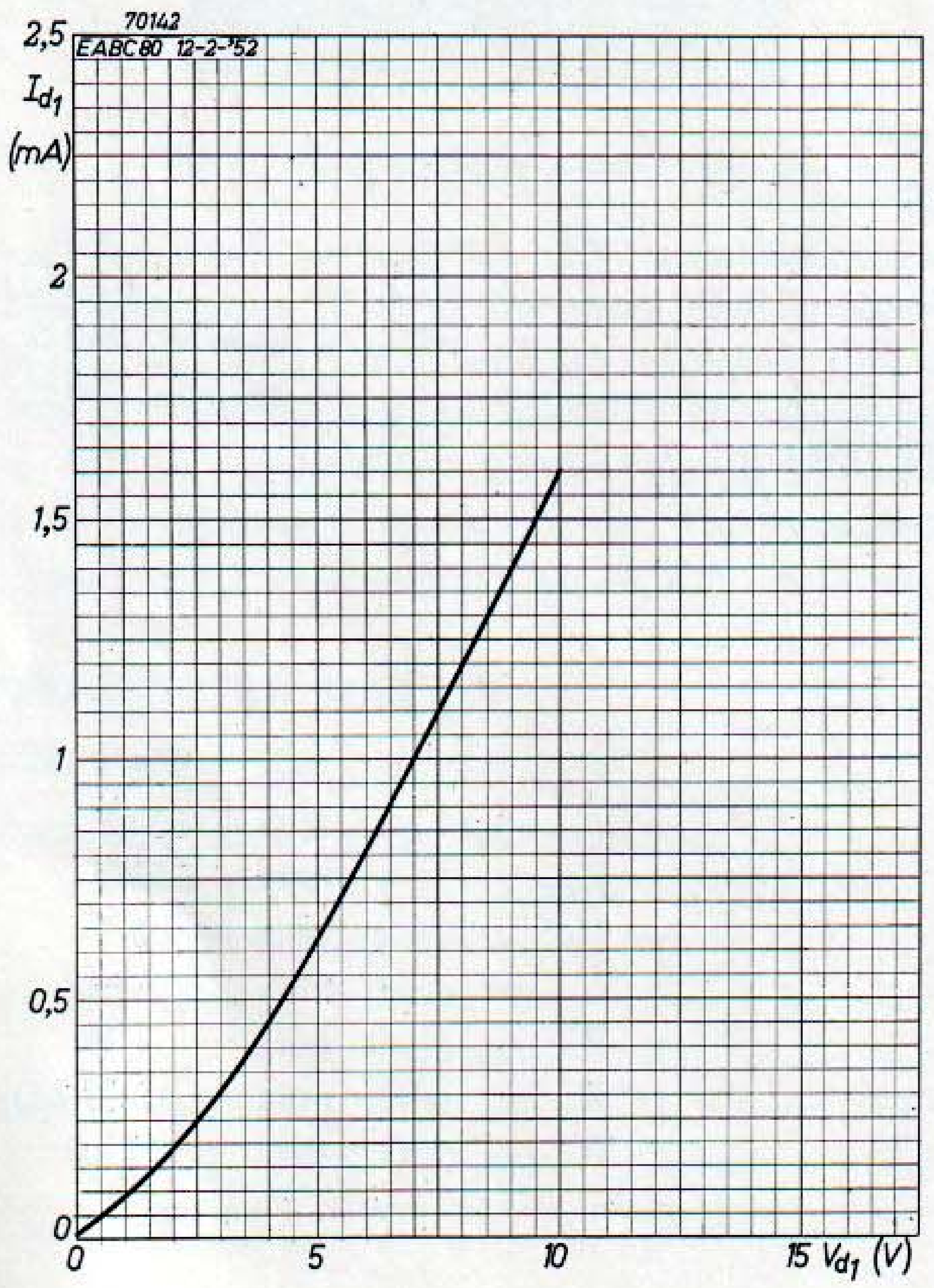


Fig. 10. **Current of diode 1 plotted against voltage.**

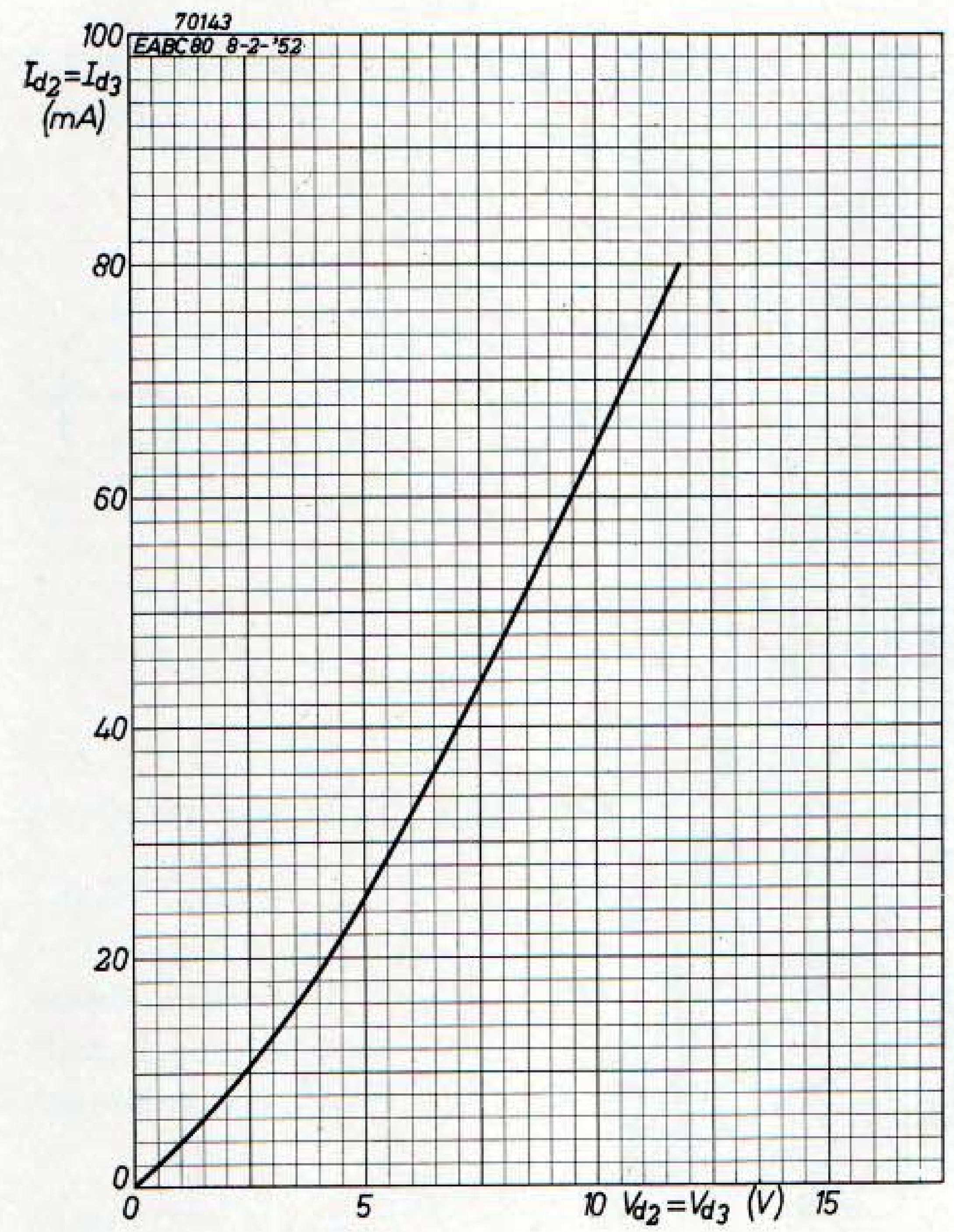


Fig. 11. Current of diodes 2 and 3 plotted against voltage.

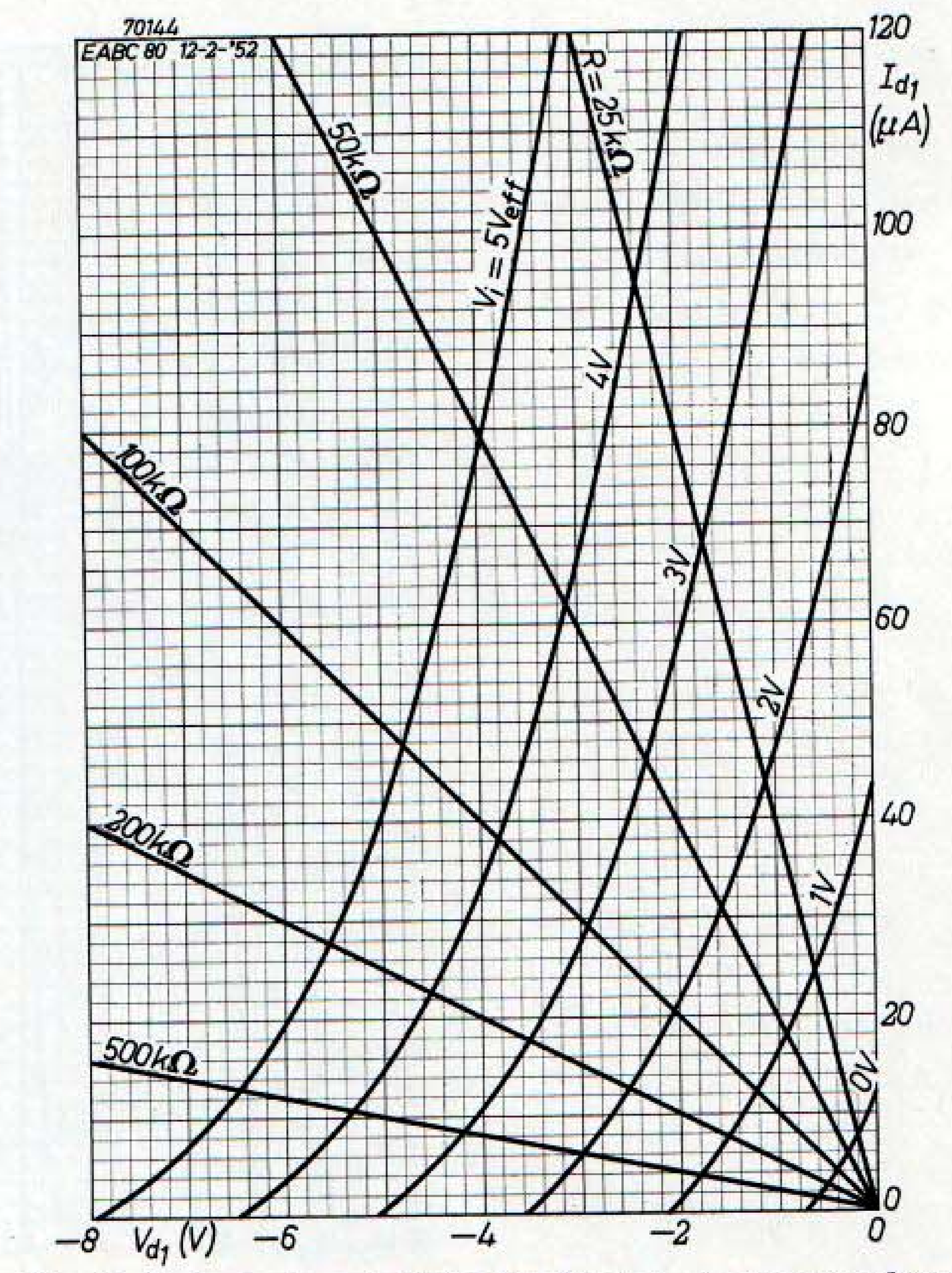


Fig. 12. Output characteristics for diode 1, for input voltages between zero and 5 V.

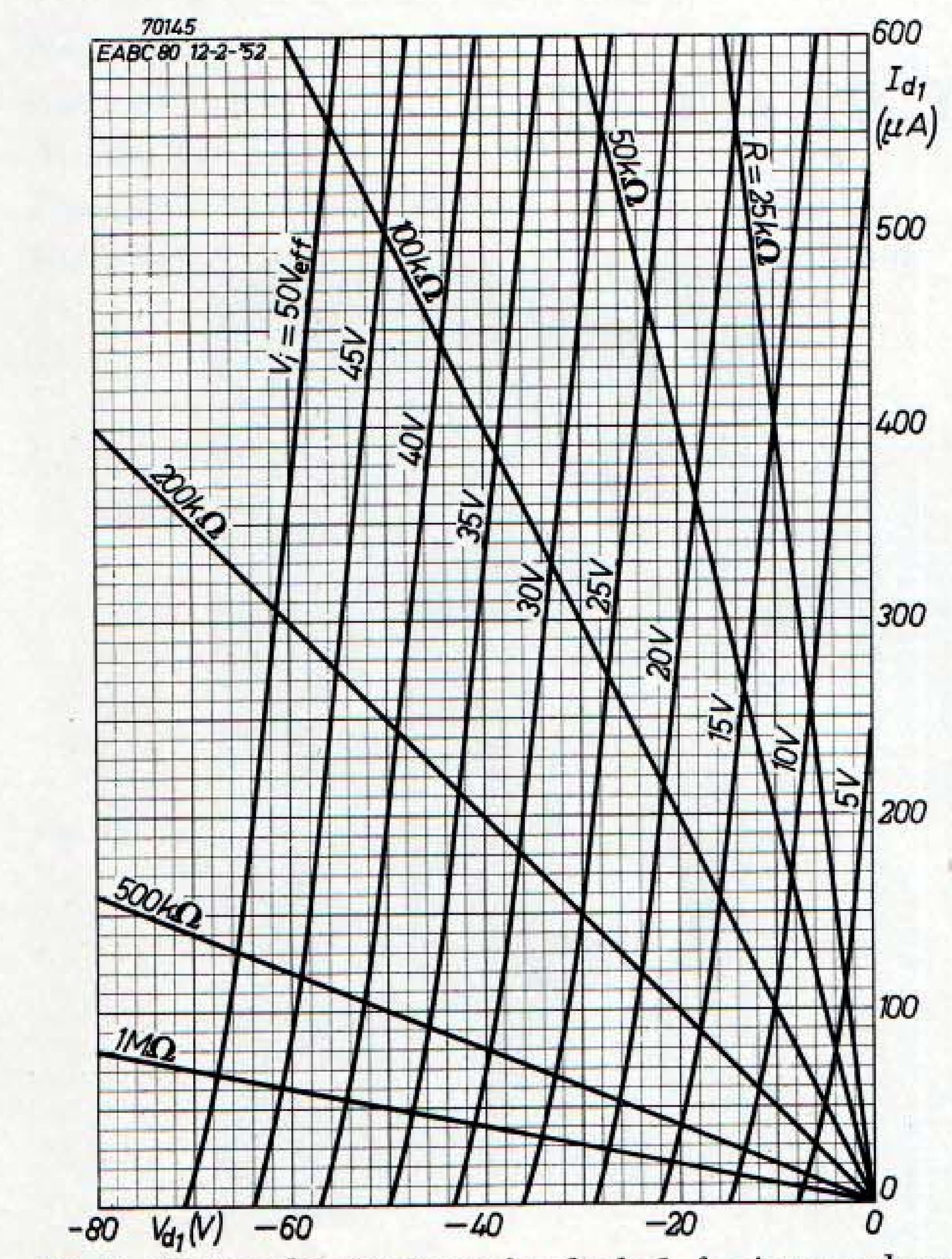


Fig. 13. Output characteristics for diode 1, for input voltages between 5 and 50 V.

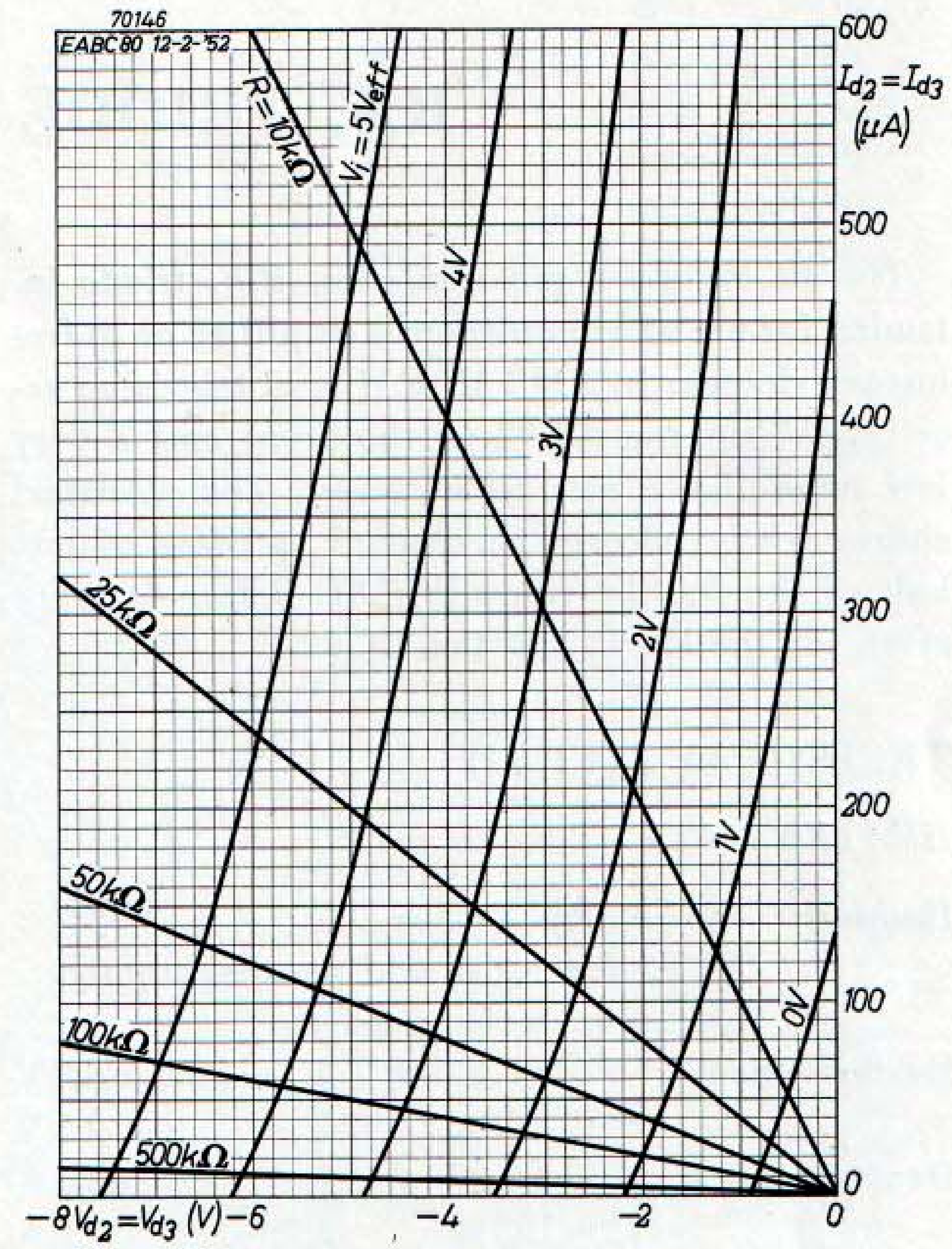


Fig. 14. Output characteristics of diodes 2 and 3, for input voltages between zero and 5 V.

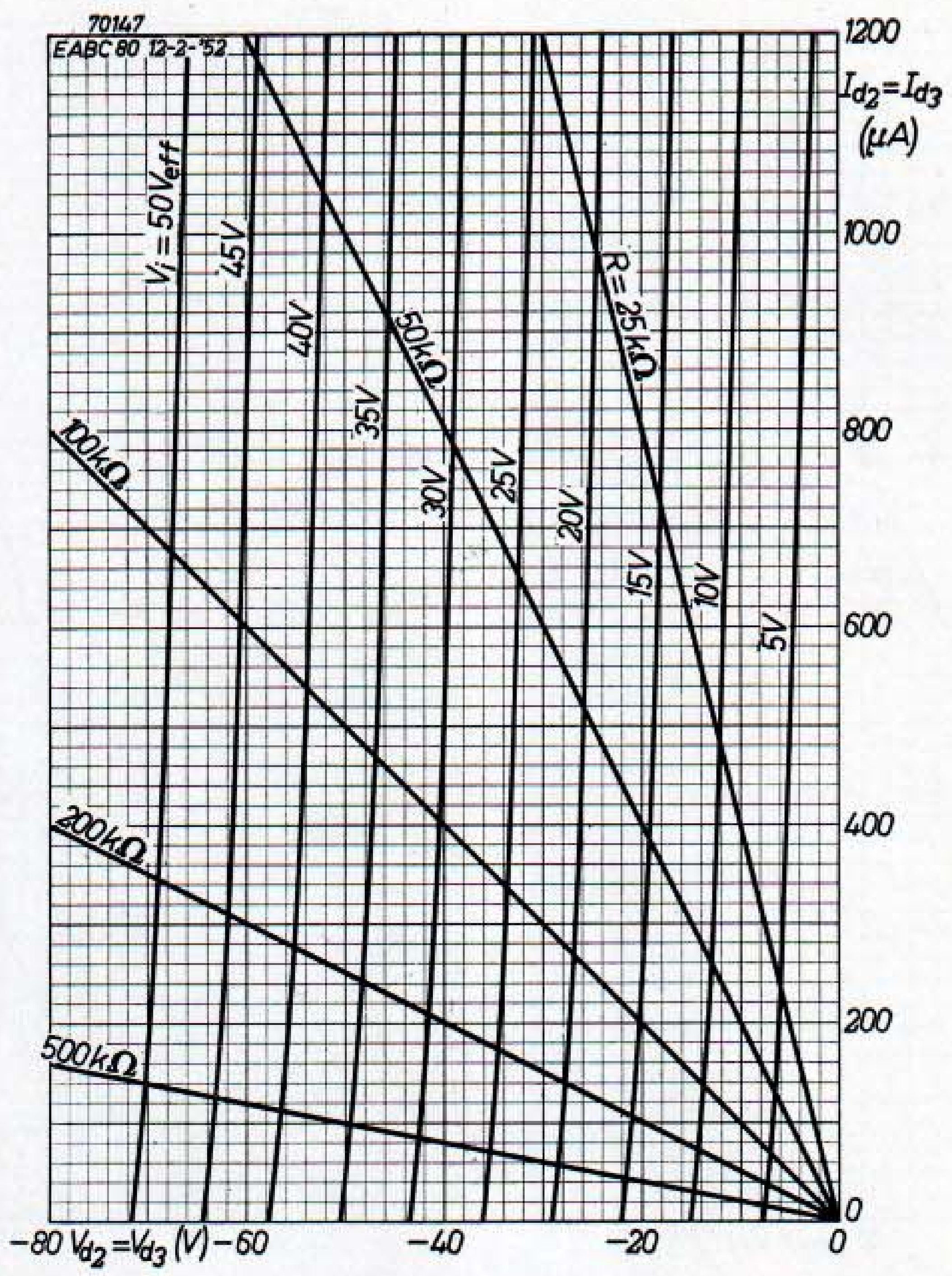


Fig. 15. Output characteristics of diodes 2 and 3, for input voltages between 5 and 50 V.

R.F. TRIODE EC 92 (UC 92)

The EC 92 is a 7-pin miniature R.F. triode intended for use as grounded-grid amplifier or as frequency changer in AM/FM, F.M. and television receivers. With the EC 92 in the front end a very low noise figure can be obtained. The electrical characteristics closely correspond to those of one half of the double triode ECC 81. Below data are given for the EC 92 and the UC 92.

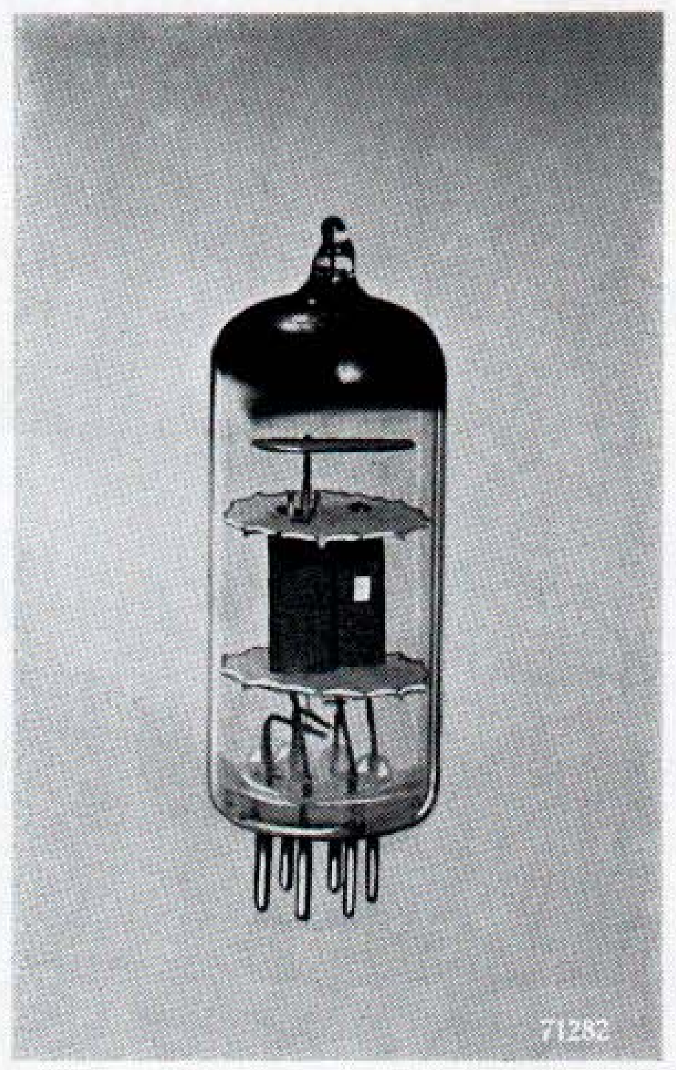


Fig. 16. The R.F. triode EC 92.

TECHNICAL DATA [5])

HEATER DATA

Heating: indirect by A.C. or D.C.;
EC 92 for series and parallel supply,
UC 92 for series supply.

Heater voltage	EC 92	V_f	=	6.3 V
	UC 92	V_f	=	9.5 V
Heater current	EC 92	I_f	=	0.15 A
	UC 92	I_f	=	0.1 A

[5]) Provisional data.

BASE CONNECTIONS AND DIMENSIONS
(in mm)

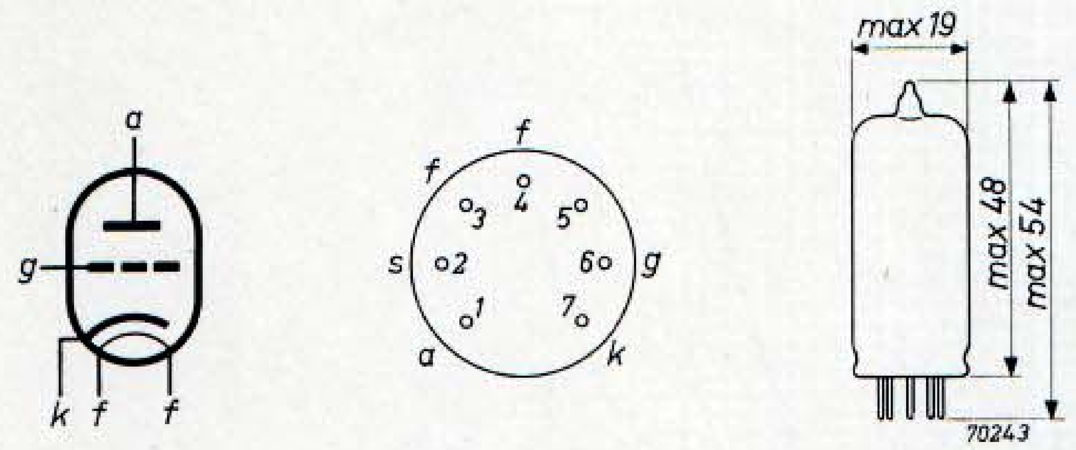


Fig. 17.

CAPACITANCES

C_g = 2.2 pF
C_a = 0.75 pF
C_{ag} = 1.5 pF
C_{ak} = 0.24 pF
C_{fk} = 2.3 pF

It is recommended to earth pin 2.

Grounded-grid operation with pin 2 earthed
$C_{a(g+f)}$ = 1.7 pF
$C_{(g+f)k}$ = 4.5 pF

Mounting position: any

TYPICAL CHARACTERISTICS

Anode voltage	V_a	=	100	170	200	250 V
Grid bias	V_g	=	—1	—1	—1	—2 V
Anode current	I_a	=	3	8.5	11.5	10 mA
Mutual conductance	S	=	3.5	5.5	6.4	5 mA/V
Amplification factor	μ	=	58	66	66	60

LIMITING VALUES

Anode voltage at zero anode current	V_{ao}	=	max.	550 V
Anode voltage	V_a	=	max.	300 V
Voltage between heater and cathode	V_{fk}	=	max.	90 V
Negative grid voltage	V_g	=	max.	—50 V
Cathode current	I_k	=	max.	15 mA
Anode dissipation	W_a	=	max.	2.5 W
External resistance between grid and cathode	R_g	=	max.	1 MΩ
External resistance between heater and cathode	R_{fk}	=	max.	20 kΩ

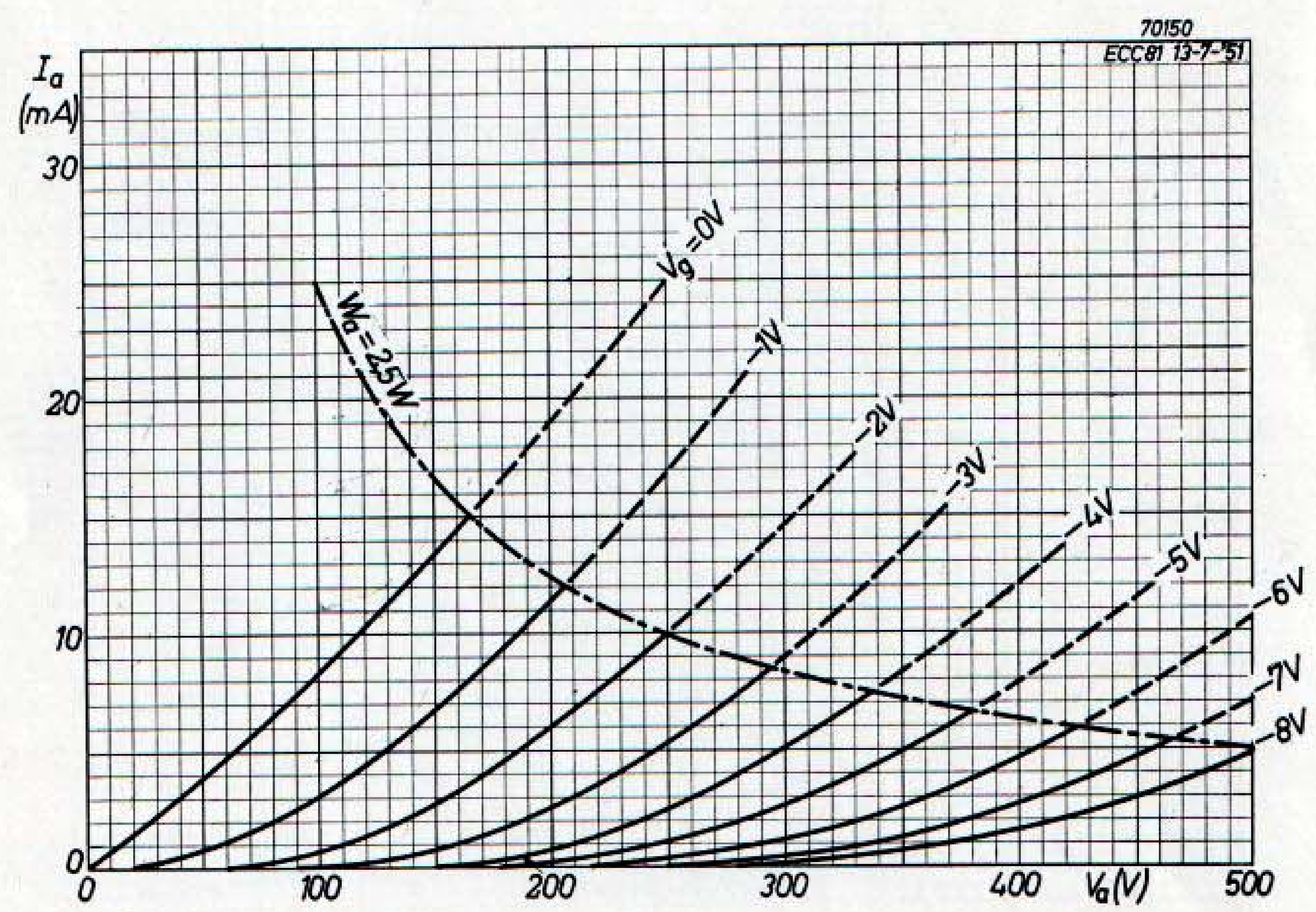


Fig. 18. Anode current plotted against voltage, with grid voltage as parameter.

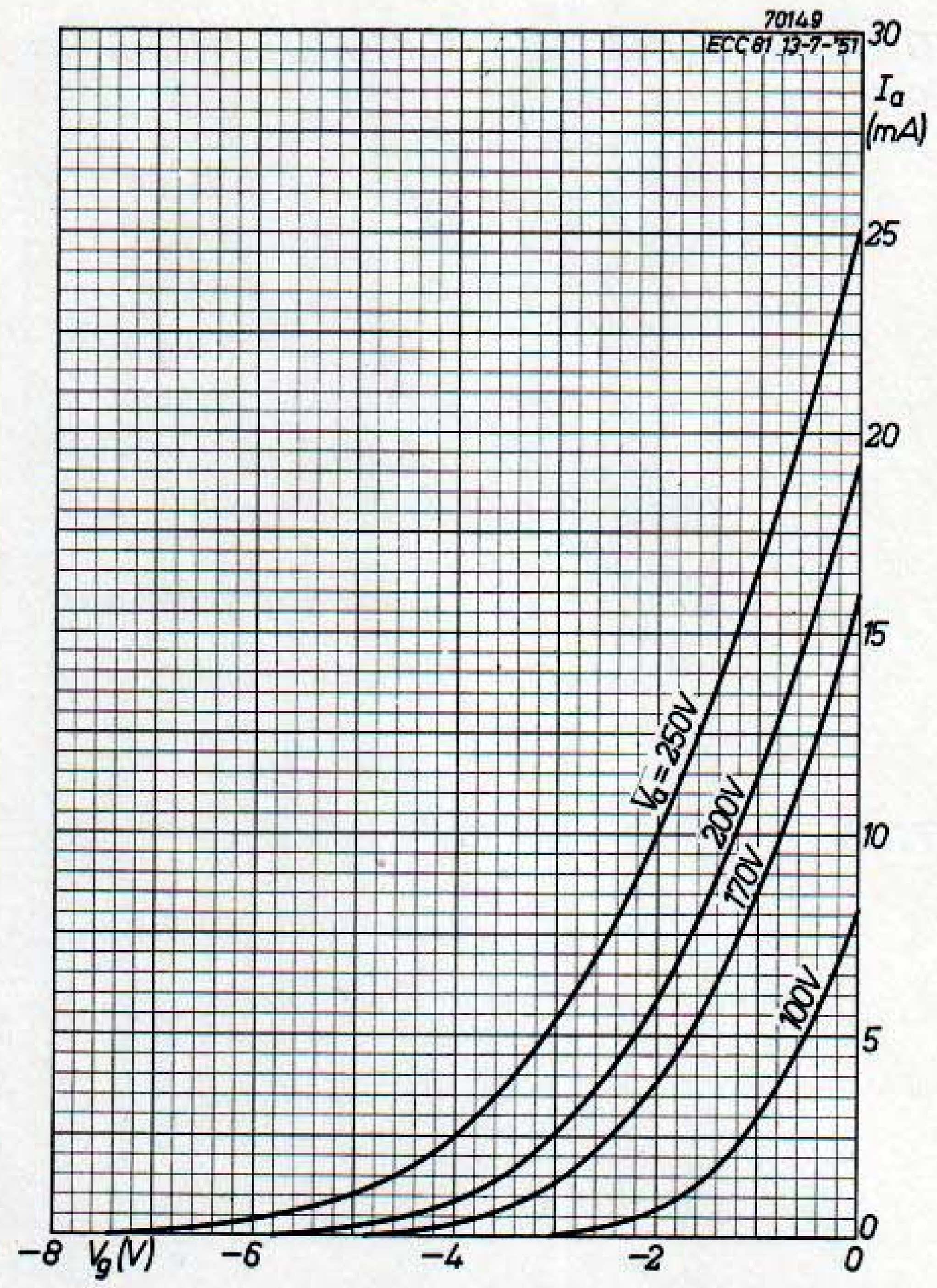


Fig. 19. **Anode current plotted against grid voltage, with anode voltage as parameter.**

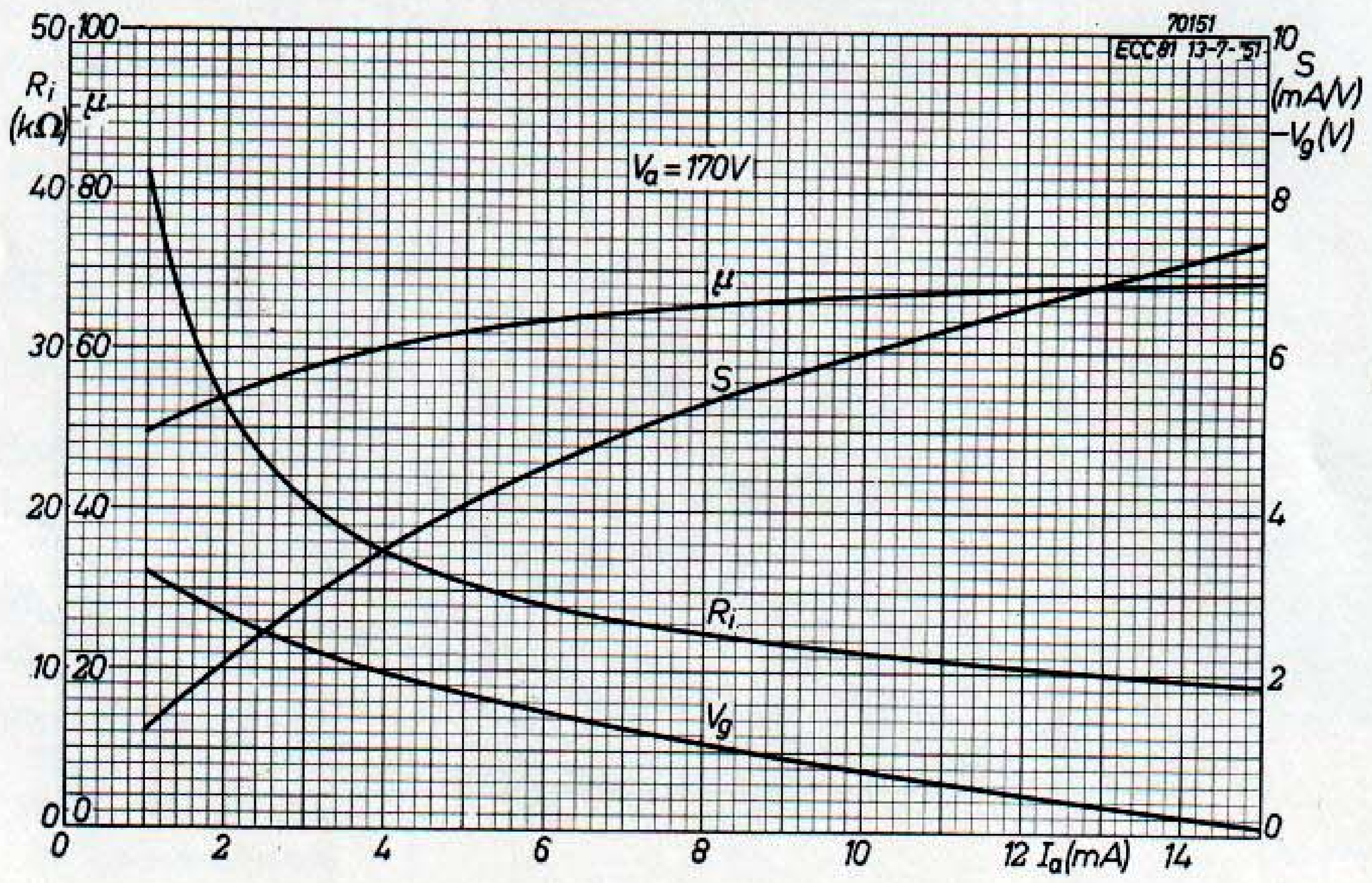


Fig. 20. **Mutual conductance, amplification factor, internal resistance and grid voltage plotted against anode current, for anode voltage of 170 V.**

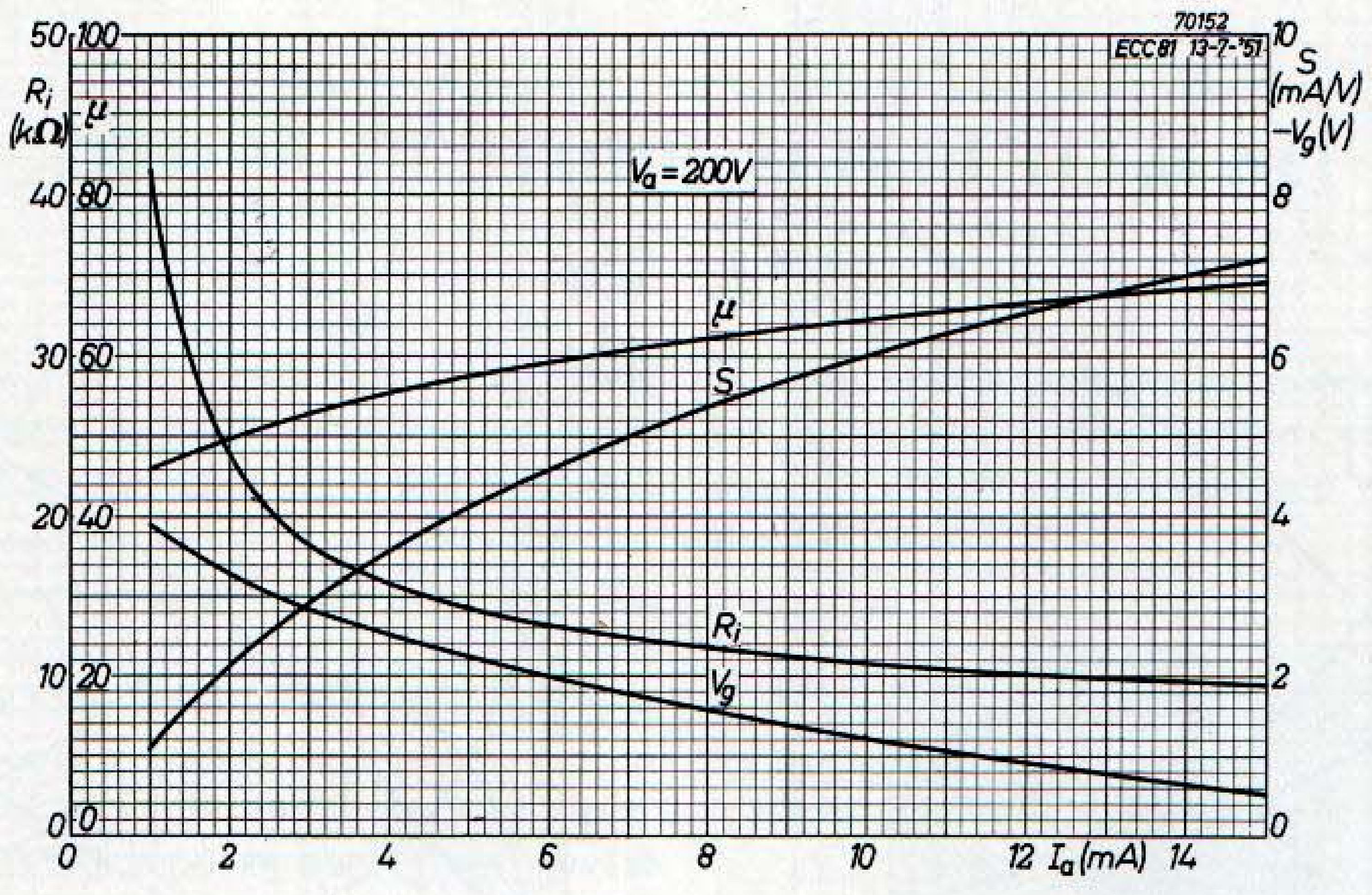


Fig. 21. **Mutual conductance, amplification factor, internal resistance and grid voltage plotted against anode current, for anode voltage of 200 V.**

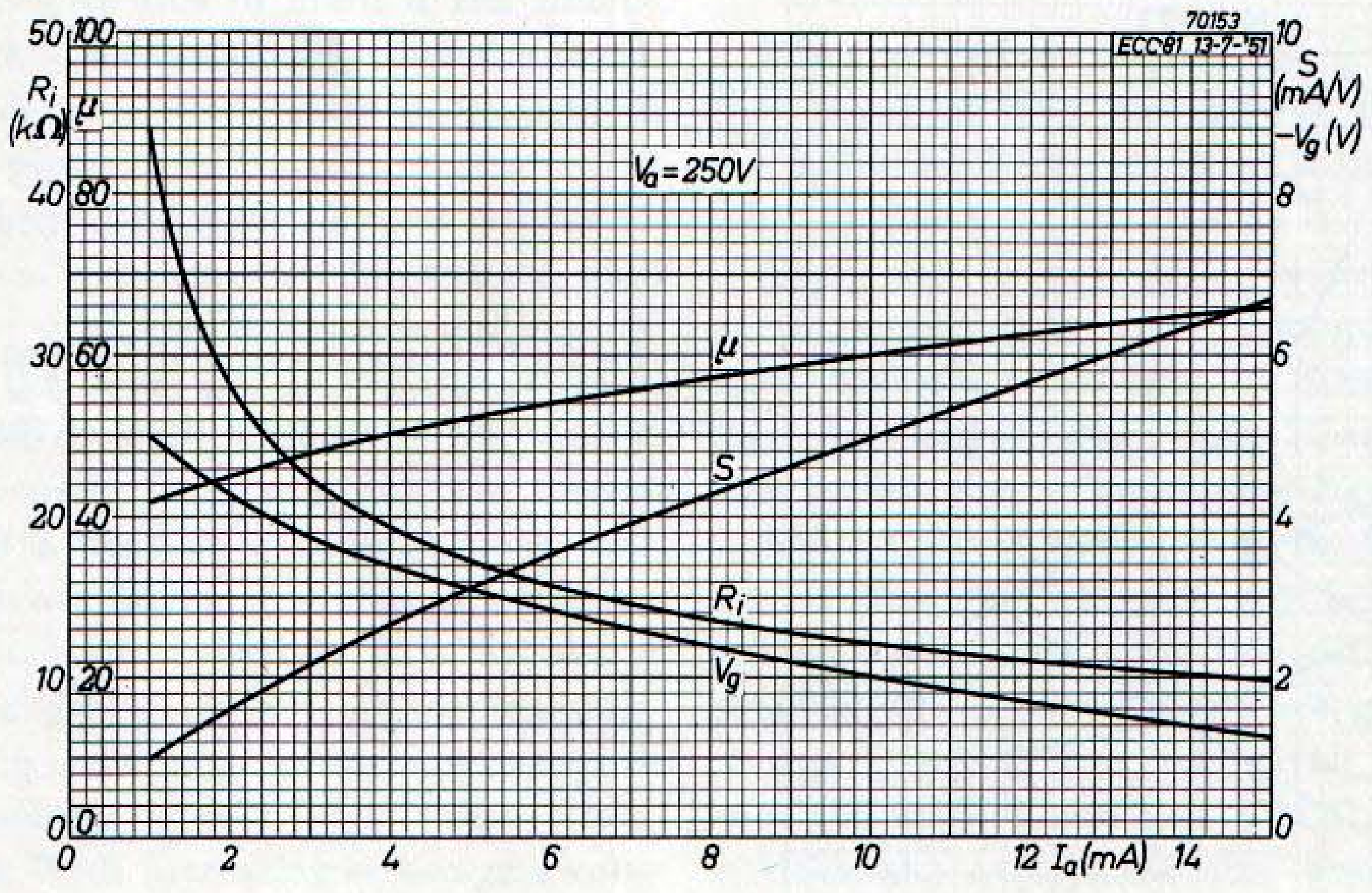


Fig. 22. **Mutual conductance, amplification factor, internal resistance and grid voltage plotted against anode current, for anode voltage of 250 V.**

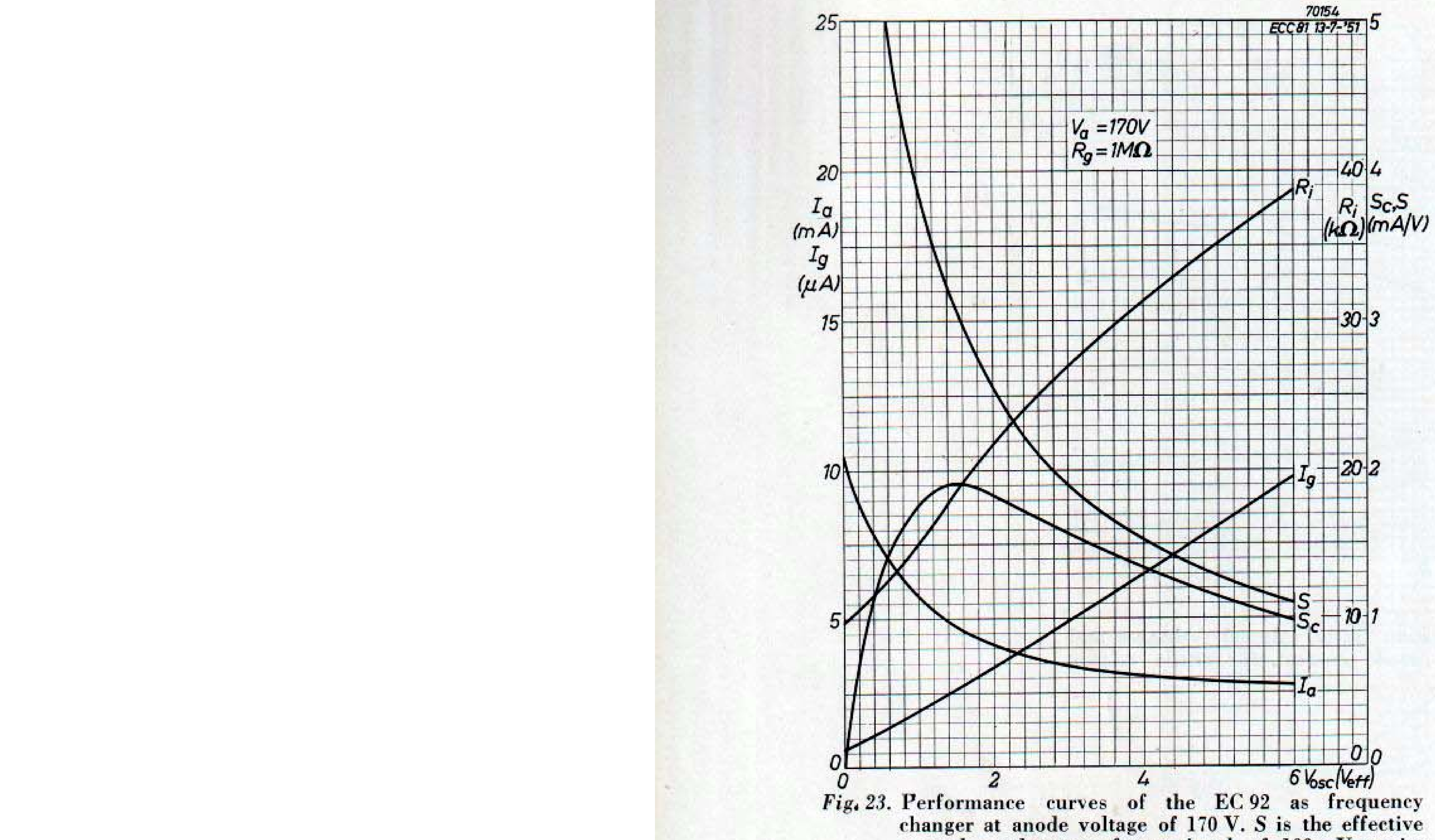


Fig. 23. **Performance curves of the EC 92 as frequency changer at anode voltage of 170 V. *S* is the effective mutual conductance for a signal of 100 mV at intermediate frequency.**

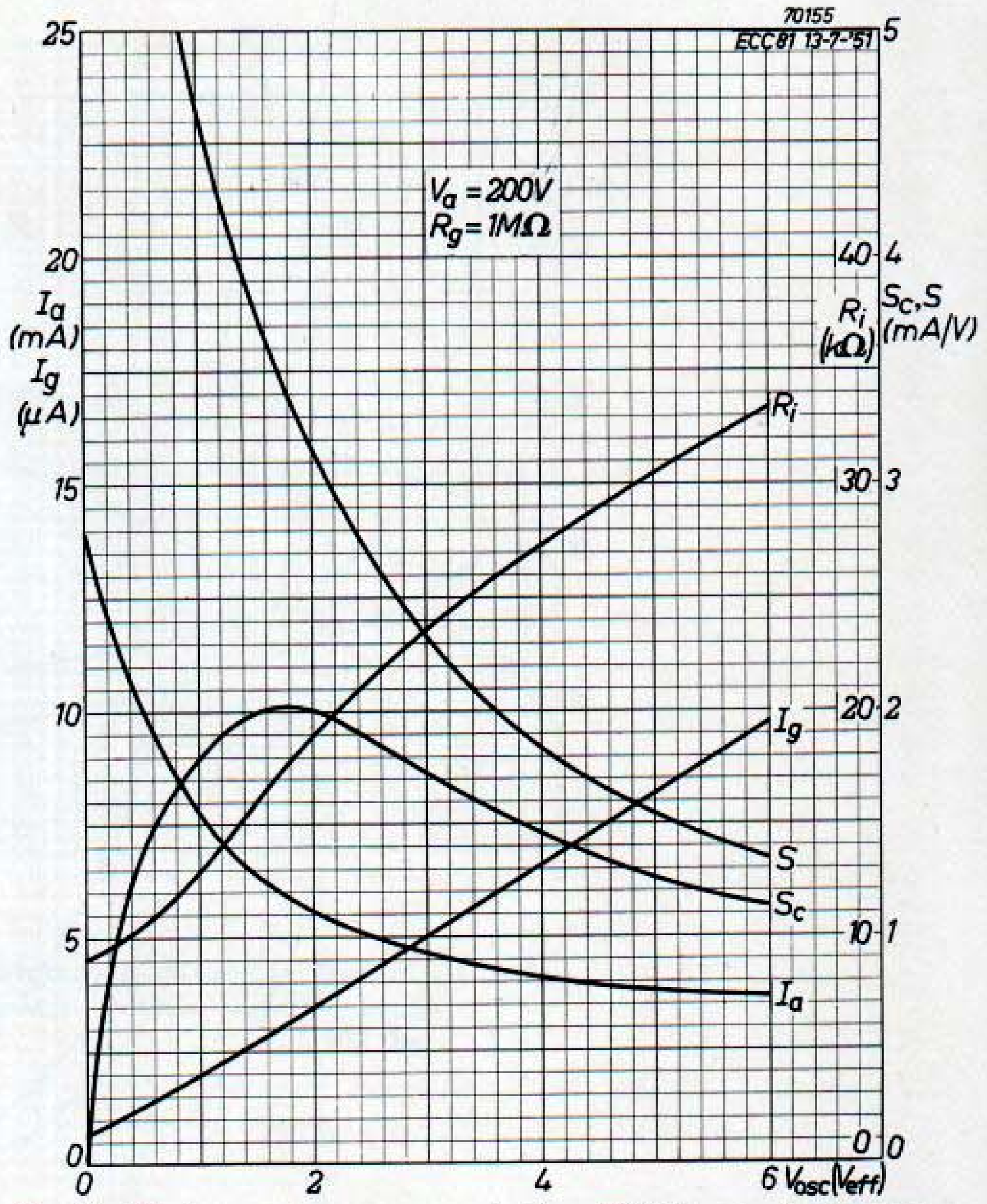


Fig. 24. **Performance curves of the EC 92 as frequency changer at anode voltage of 200 V. *S* is the effective mutual conductance for a signal of 100 mV at intermediate frequency.**

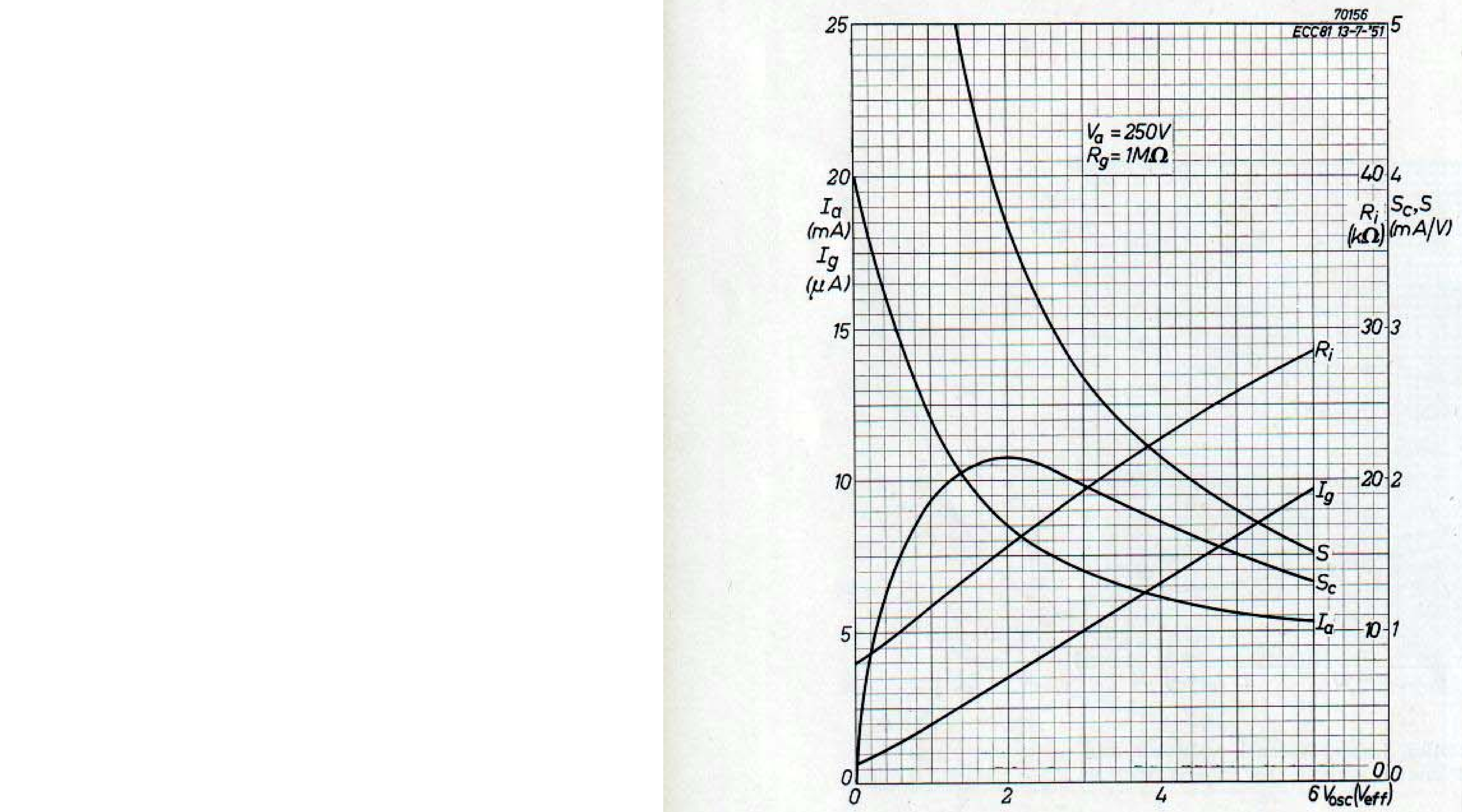


Fig. 25. **Performance curves of the EC 92 as frequency changer at anode voltage of 250 V. *S* is the effective mutual conductance for a signal of 100 mV at intermediate frequency.**

TRIODE HEPTODE ECH 81 (UCH 81)

The ECH 81 is a triode heptode in 9-pin Noval technique in which, in contrast to similar tubes such as the ECH 42, the triode grid and the third grid of the heptode are not tied to each other internally. It is intended to be a universal tube for use in the front ends of receivers for AM/FM, conventional A.M. or F.M. reception, whilst it may also be used in television receivers.

In the design of this tube the duties to be performed in an AM/FM receiver were given special consideration. In receivers of this type it will normally be desired to use a given set of tubes for F.M. as well as for A.M. reception, and to keep the total number of tubes employed as small as possible without, however, sacrificing F.M. performance.

For frequency changing at A.M. a tube of the triode-hexode or triode-heptode type is required and it is then immaterial whether the triode grid and the third grid of the hexode or heptode are interconnected internally or not. With F.M., however, low tube noise and a favourable conversion conductance can be obtained with a self-oscillating additive mixer, operating with a triode system. The hexode or heptode can then be used as an H.F. or I.F. amplifier. With this in mind it can immediately be seen that the triode grid and the third grid of the hexode or heptode must be connected to separate base pins.

A choice has then to be made between a hexode and a heptode, i.e. between systems without and with a suppressor grid between anode and screen grid. Owing to the fact that a suppressor grid prevents the electrons produced by secondary emission of the anode from reaching the screen grid, the noise of a heptode is usually lower and the internal resistance higher than that of a similar hexode. Moreover, with a hexode it is necessary to feed the screen grid via a potentiometer across the H.T. supply, in order to prevent the screen-grid voltage from reaching a very high value when A.G.C. is applied. With increasing screen-grid voltage, as a result of secondary emission of the anode, the internal resistance of a hexode decreases rapidly. Preference has therefore been given to a heptode system, making it possible to feed the screen grid via a series resistor, which can also be used to supply the screen grid of, for example, the I.F. tube.

Fig. 26. The triode heptode ECH 81.

The application of the ECH 81 in conventional A.M. receivers does not call for special comment, the operating being identical with that of former tubes of this type.

When the triode section is used as A.F. amplifier, in order to avoid microphony, the input signal required at the grid for 50 mW output of the final stage should be at least 25 mV. For the heptode section the corresponding figure is 50 mV.

For the use of the ECH 81 in AM/FM receivers brief indications have already been given in the general review preceding this data section, whilst detailed circuit descriptions are given at the end of this Bulletin. The data given below apply to both the ECH 81 and the UCH 81.

Although, except for the heater ratings, the electrical characteristics of the ECH 81 and the UCH 81 are identical, of course the ECH 81 will normally be used with a supply voltage of 250 V and the UCH 81 with 170 V or 100 V. In the latter case the performance will be somewhat different from the operating characteristics given below.

On account of the low capacitance between the anode and the control grid of the heptode section the ECH 81 may also be used as I.F. amplifier at A.M. The total gain from the combination of an ECH 81 tube used as frequency changer and the heptode section of a second ECH 81 tube used as I.F. amplifier is then approximately 10,000 when normal I.F. transformers are used.

TECHNICAL DATA [6])

HEATER DATA

Heating: indirect by A.C. or D.C.;
ECH 81 for series and parallel supply,
UCH 81 for series supply.

Heater voltage	ECH 81	V_f	=	6.3 V
	UCH 81	V_f	=	19 V
Heater current	ECH 81	I_f	=	0.3 A
	UCH 81	I_f	=	0.1 A

BASE CONNECTIONS AND DIMENSIONS

(in mm)

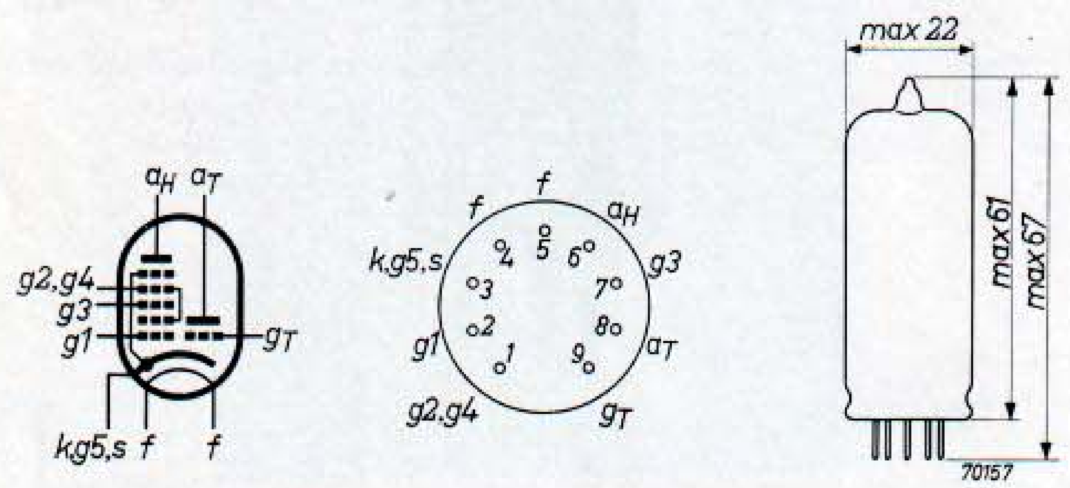


Fig. 27.

CAPACITANCES

Heptode section			Triode section		
C_{g1}	=	4.8 pF	C_g	=	2.7 pF
C_{g3}	=	5.8 pF	C_a	=	2.3 pF
C_a	=	7.9 pF	C_{ag}	=	1.0 pF
C_{ag1}	<	0.010 pF	C_{gf}	<	0.02 pF
C_{g1g3}	<	0.3 pF			
C_{g1f}	<	0.1 pF			
C_{g3f}	<	0.08 pF			

Between heptode and triode

C_{aHaT}	=	0.220 pF	($\sigma = 0.015$ pF) [7])
C_{aHgT}	<	0.09 pF	
$C_{aH(gT+g3)}$	<	0.35 pF	
C_{g1HaT}	<	0.06 pF	
C_{g1HgT}	<	0.17 pF	
$C_{g1H(gT+g3)}$	<	0.45 pF	

Mounting position: any

OPERATING CHARACTERISTICS AS FREQUENCY CHANGER

(Heptode as mixer, triode as local oscillator)

A. With separate screen-grid supply

Supply voltage	V_b	=	250		V
Anode voltage	V_a	=	250		V
Screen-grid resistor	R_{g2+g4}	=	22		kΩ
Oscillator grid leak	R_{gT+g3}	=	47		kΩ
Oscillator grid current	I_{gT+g3}	=	200		μA
Grid bias	V_{g1}	=	—2	—28.5	V
Screen-grid voltage	V_{g2+g4}	=	103		V
Anode current	I_a	=	3.25	—	mA
Screen-grid current	I_{g2+g4}	=	6.7	—	mA
Conversion conductance	S_c	=	775	7.75	μA/V
Internal resistance	R_i	=	1	>3	MΩ
Equivalent noise resistance	R_{eq}	=	70		kΩ

[6]) Provisional data.

[7]) Standard deviation is 0.015 pF.

B. Common screen-grid supply with EF 85

Supply voltage	V_b	=	250		V
Anode voltage	V_a	=	250		V
Screen-grid resistor	R_{g2+g4}	=	18		kΩ
Oscillator grid leak	R_{gT+g3}	=	47		kΩ
Oscillator grid current	I_{gT+g3}	=	200		μA
Grid bias	V_{g1}	=	—2	—28.5	V
Screen-grid voltage	V_{g2+g4}	=	97		V
Anode current	I_a	=	3	—	mA
Current in screen-grid resistor		=	8.5	—	mA
Conversion conductance	S_c	=	750	7.5	μA/V
Internal resistance	R_i	=	1	>3	MΩ
Equivalent noise resistance	R_{eq}	=	70		kΩ

C. Common screen-grid supply with EBF 80

Supply voltage	V_b	=	250		V
Anode voltage	V_a	=	250		V
Screen-grid resistor	R_{g2+g4}	=	22		kΩ
Oscillator grid leak	R_{gT+g3}	=	47		kΩ
Oscillator grid current	I_{gT+g3}	=	200		μA
Grid bias	V_{g1}	=	—2	—28.5	V
Screen-grid voltage	V_{g2+g4}	=	92		V
Anode current	I_a	=	2.5	—	mA
Current in screen-grid resistor		=	7.2	—	mA
Conversion conductance	S_c	=	700	7	μA/V
Internal resistance	R_i	=	1	>3	MΩ
Equivalent noise resistance	R_{eq}	=	66		kΩ

OPERATING CHARACTERISTICS OF HEPTODE SECTION AS H.F. OR I.F. AMPLIFIER

A. With separate screen-grid supply

Supply voltage	V_b	=	250		V
Anode voltage	V_a	=	250		V
Voltage at third grid	V_{g3}	=	0		V
Screen-grid resistor	R_{g2+g4}	=	39		kΩ
Grid bias	V_{g1}	=	—2	—42	V
Screen-grid voltage	V_{g2+g4}	=	102		V
Anode current	I_a	=	6.5	—	mA
Screen-grid current	I_{g2+g4}	=	3.8	—	mA
Mutual conductance	S	=	2400	24	μA/V
Internal resistance	R_i	=	0.7	>10	MΩ
Amplification factor between screen grid and control grid	$\mu_{g2\,g1}$	=	20		
Equivalent noise resistance	R_{eq}	=	8.5		kΩ
Input damping at 100 Mc/s	r_{g1}	=	1.6		kΩ

B. Common screen-grid supply with EF 85

Supply voltage	V_b	=	250		V
Anode voltage	V_a	=	250		V
Voltage at third grid	V_{g3}	=	0		V
Screen-grid resistor	R_{g2+g4}	=	22		kΩ
Grid bias	V_{g1}	=	−2	−42	V
Screen-grid voltage	V_{g2+g4}	=	105		V
Anode current	I_a	=	6.5	—	mA
Current in screen-grid resistor		=	6.6	—	mA
Mutual conductance	S	=	2400	24	μA/V
Internal resistance	R_i	=	0.7	>10	MΩ
Amplification factor between screen grid and control grid	μ_{g2g1}	=	20		
Equivalent noise resistance	R_{eq}	=	8.5		kΩ

TYPICAL CHARACTERISTICS OF TRIODE SECTION

Anode voltage	V_a	=	100 V
Grid voltage	V_g	=	0 V
Anode current	I_a	=	13.5 mA
Mutual conductance	S	=	3.7 mA/V
Amplification factor	μ	=	22

OPERATING CHARACTERISTICS OF TRIODE SECTION AS OSCILLATOR

Supply voltage	V_b	=	250 V
Anode resistor	R_a	=	33 kΩ
Grid leak	R_{gTg3}	=	47 kΩ
Grid current	I_{gTg3}	=	200 μA
Anode current	I_a	=	4.5 mA
Effective mutual conductance	S_{eff}	=	0.55 mA/V

LIMITING VALUES

Heptode section

Anode voltage at zero anode current	V_{a0}	= max. 550 V
Anode voltage	V_a	= max. 300 V
Screen-grid voltage at zero screen-grid current	$V_{(g2+g4)0}$	= max. 550 V
Screen-grid voltage in normal operation	V_{g2+g4}	= max. 125 V
Screen-grid voltage at I_a <1 mA		= max. 300 V
Voltage between heater and cathode	V_{fk}	= max. 100 V
Voltage at g_1 for $I_{g1} = +0.3$ μA	V_{g1}	= max. −1.3 V
Voltage at g_3 for $I_{g3} = +0.3$ μA	V_{g3}	= max. −1.3 V
Cathode current	I_k	= max. 12.5 mA
Anode dissipation	W_a	= max. 1.7 W
Screen-grid dissipation	W_{g2+g4}	= max. 1 W
External resistance between control grid and cathode	R_{g1}	= max. 3 MΩ
External resistance between third grid and cathode	R_{g3}	= max. 3 MΩ
External resistance between heater and cathode	R_{fk}	= max. 20 kΩ

Triode section

Anode voltage at zero anode current	V_{a0}	= max. 550 V
Anode voltage	V_a	= max. 250 V
Voltage between heater and cathode	V_{fk}	= max. 100 V
Grid voltage for $I_g = +0.3\ \mu A$	V_g	= max. −1.3 V
Cathode current	I_k	= max. 6.5 mA
Anode dissipation	W_a	= max. 0.8 W
External resistance between grid and cathode	R_g	= max. 3 MΩ
External resistance between heater and cathode	R_{fk}	= max. 20 kΩ

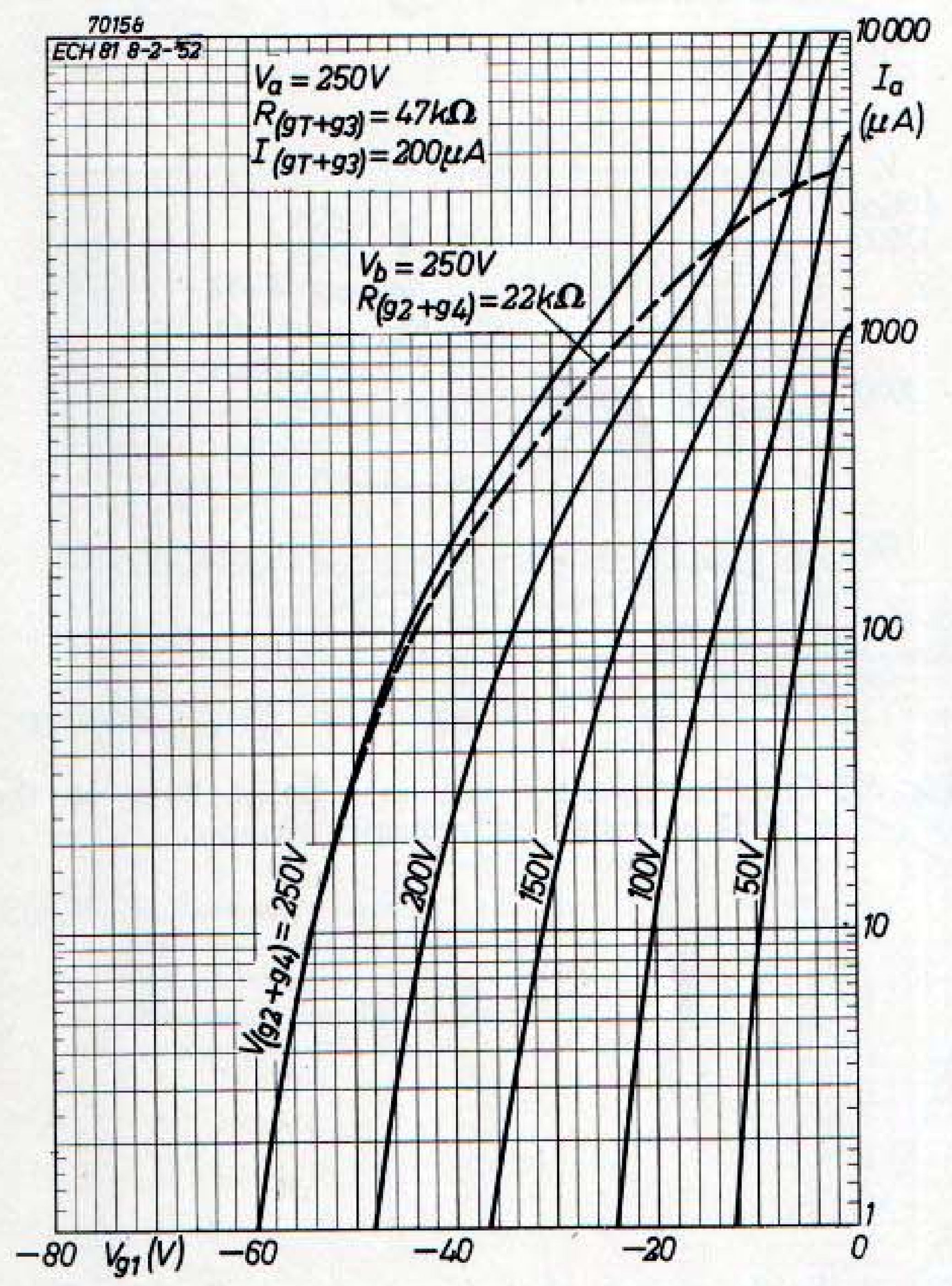


Fig. 28. Anode current plotted against control-grid voltage, with the screen-grid voltage as parameter, for the ECH 81 operating as frequency changer.

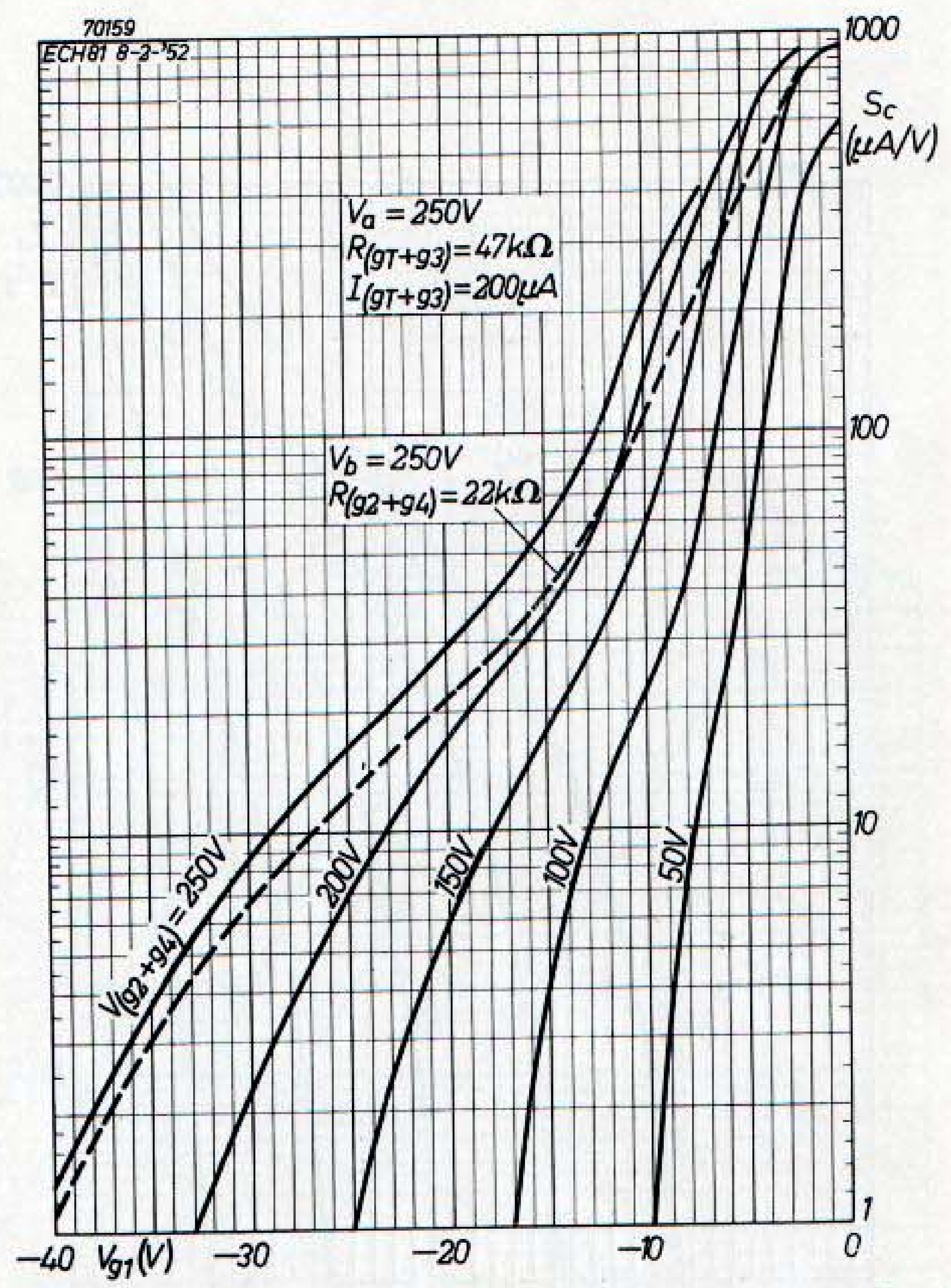


Fig. 29. Conversion conductance plotted against control-grid voltage, with the screen-grid voltage as parameter, for the ECH 81 operatings as frequency changer.

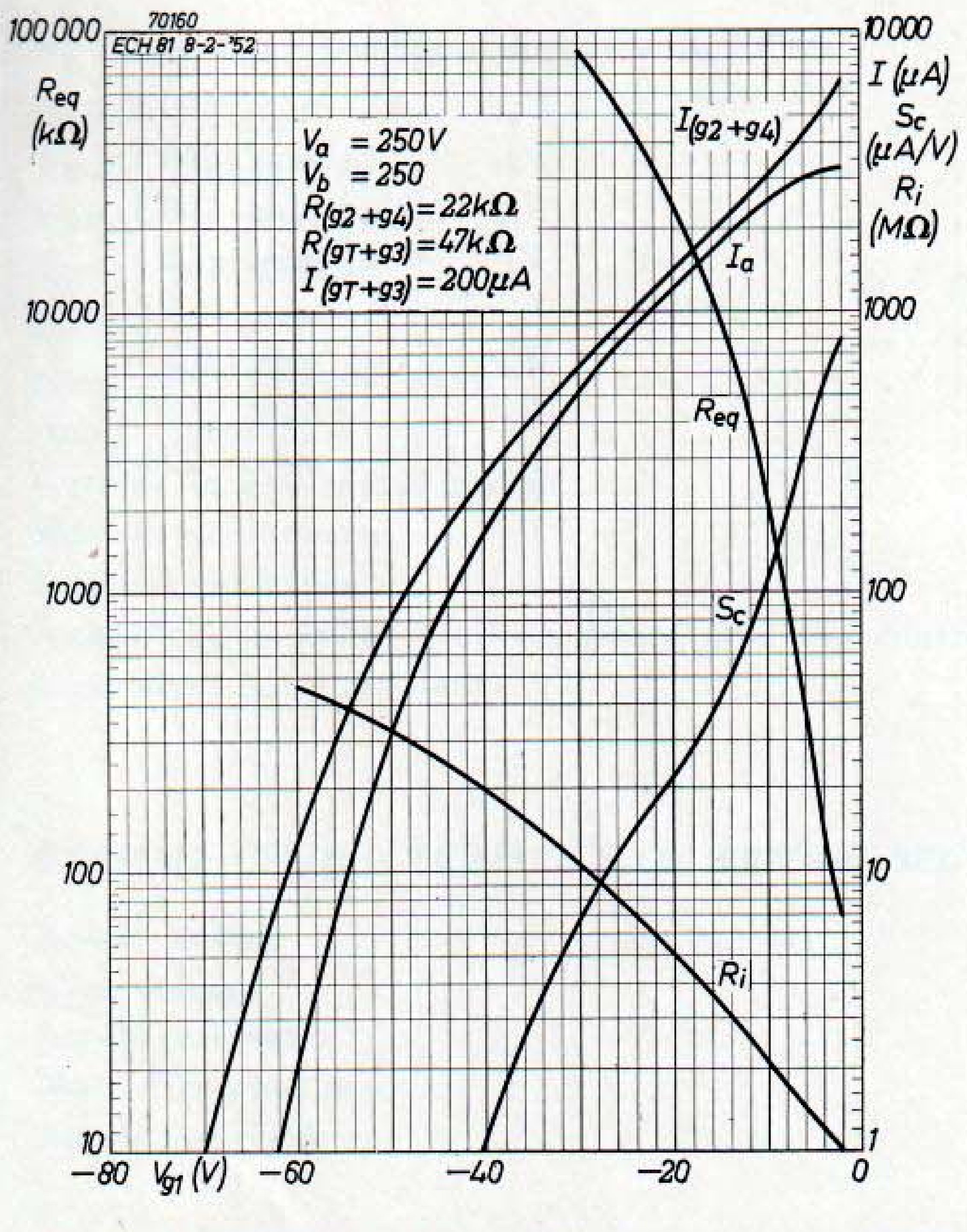


Fig. 30. Performance of the ECH 81 as frequency changer plotted against the control-grid voltage.

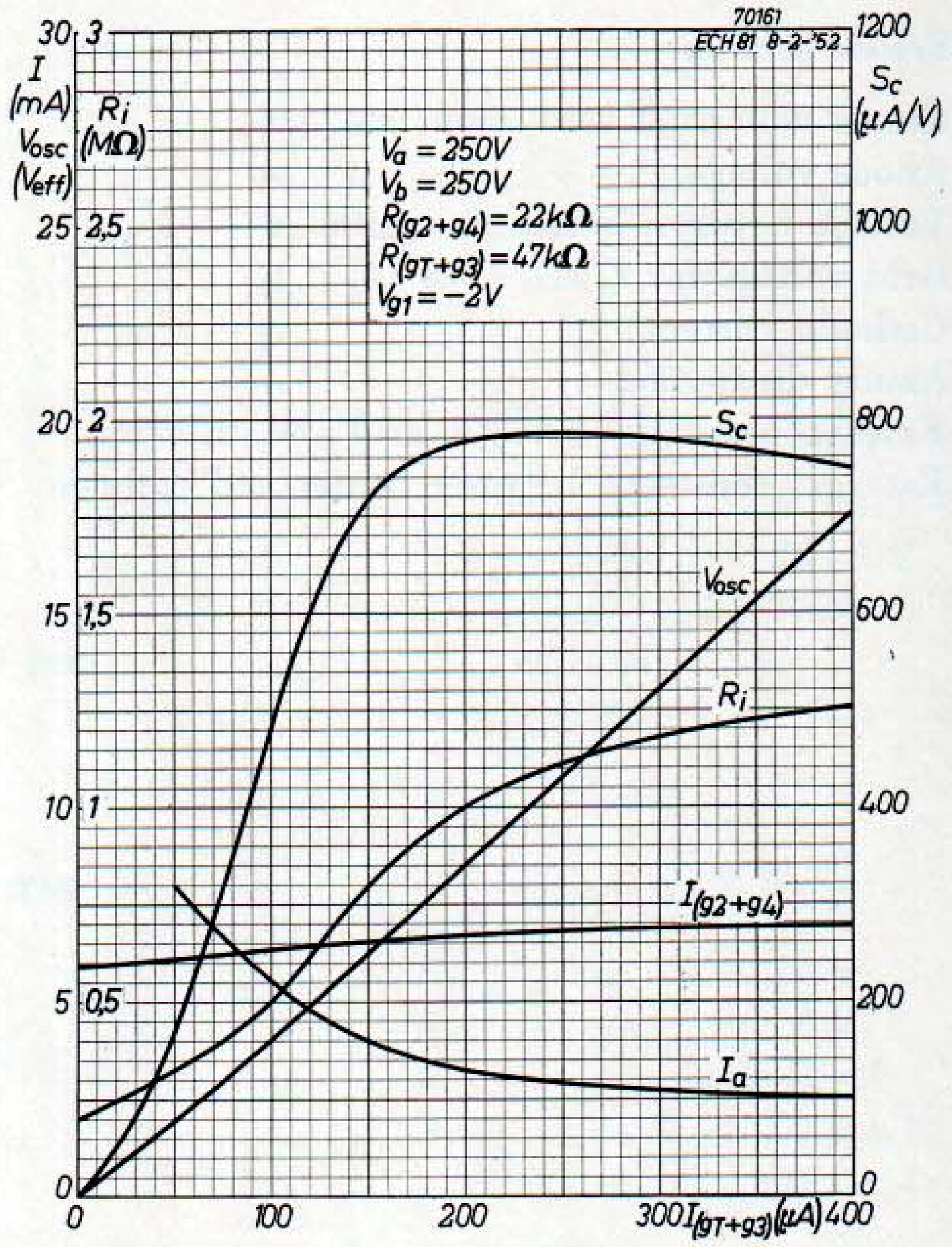
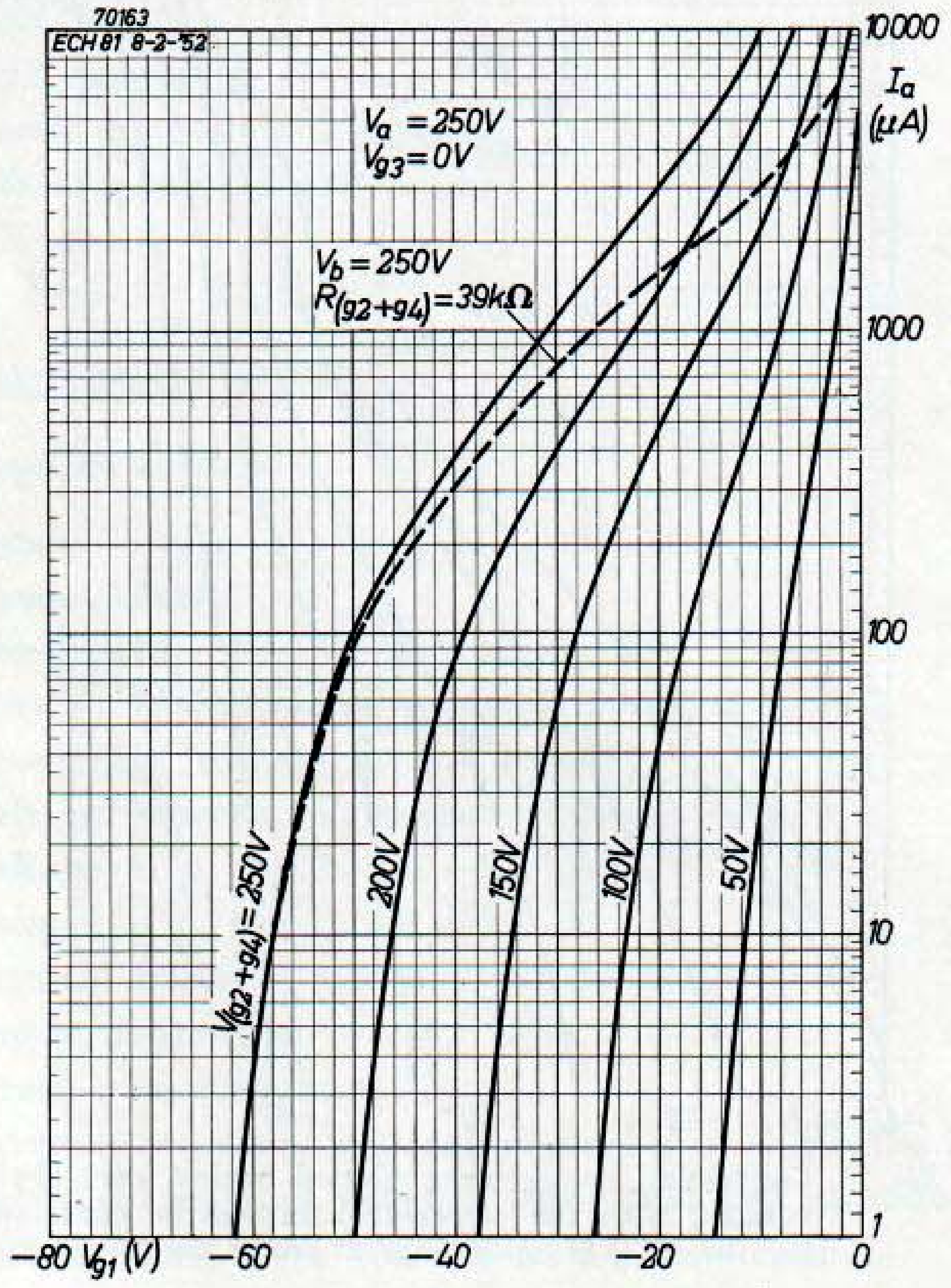


Fig. 31. Performance of the ECH 81 as frequency changer plotted against the current in the grid leak of the local oscillator.



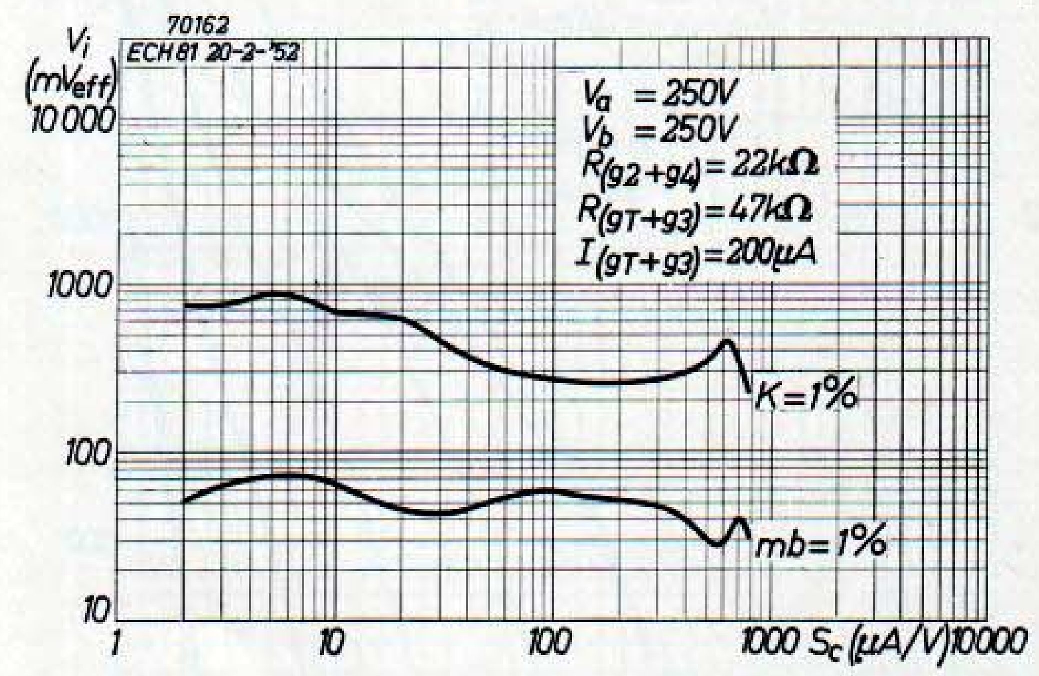


Fig. 32. Cross modulation and modulation hum of the ECH 81 operating as frequency changer.

Fig. 33. Anode current plotted against control-grid voltage, with the screen-grid voltage as parameter, for the ECH 81 operating as H.F. of I.F. amplifier (heptode section).

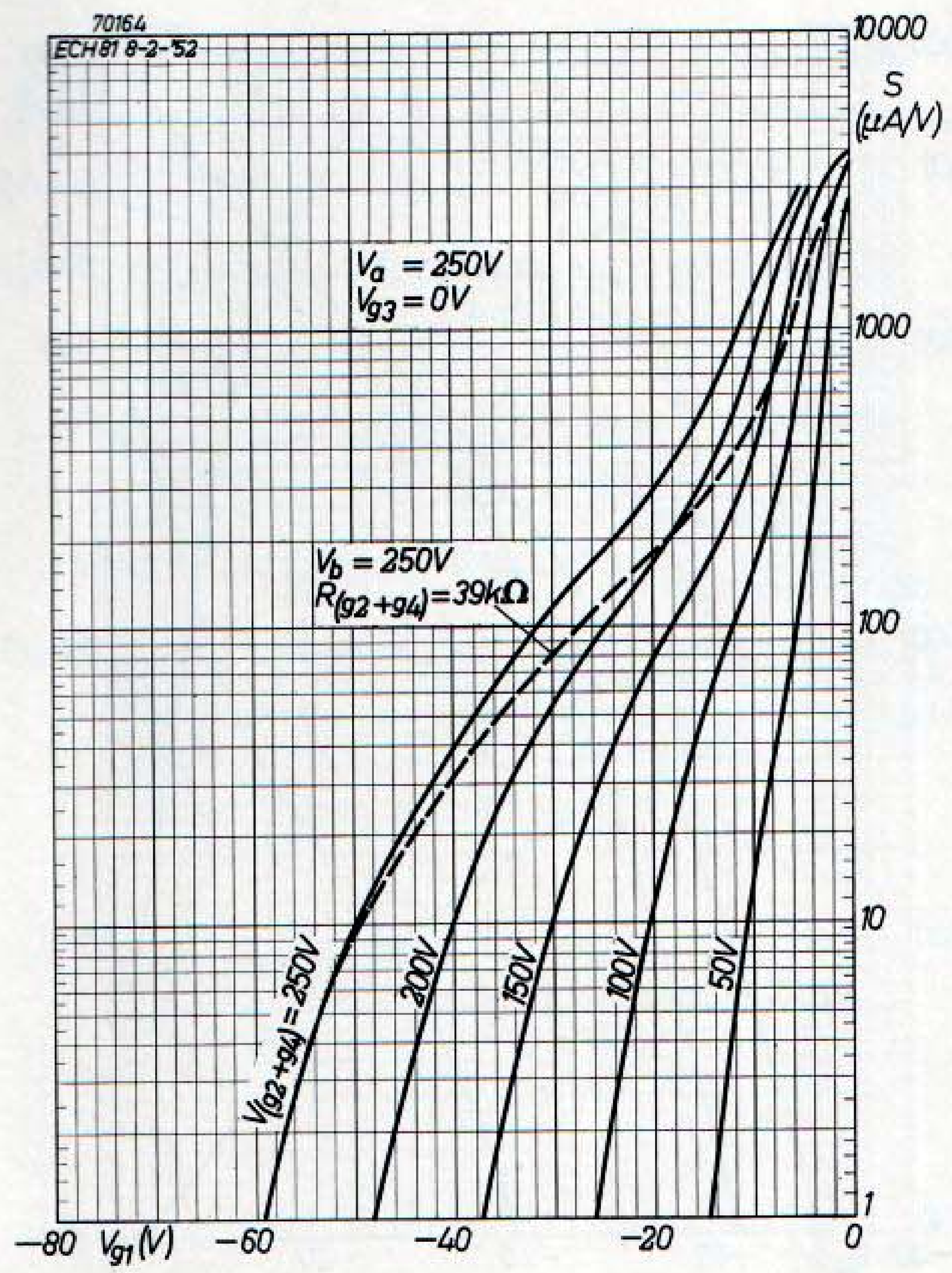


Fig. 34. **Mutual conductance plotted against control-grid voltage with the screen-grid voltage as parameter, for the ECH 81 operating as H.F. or I.F. amplifier (heptode section).**

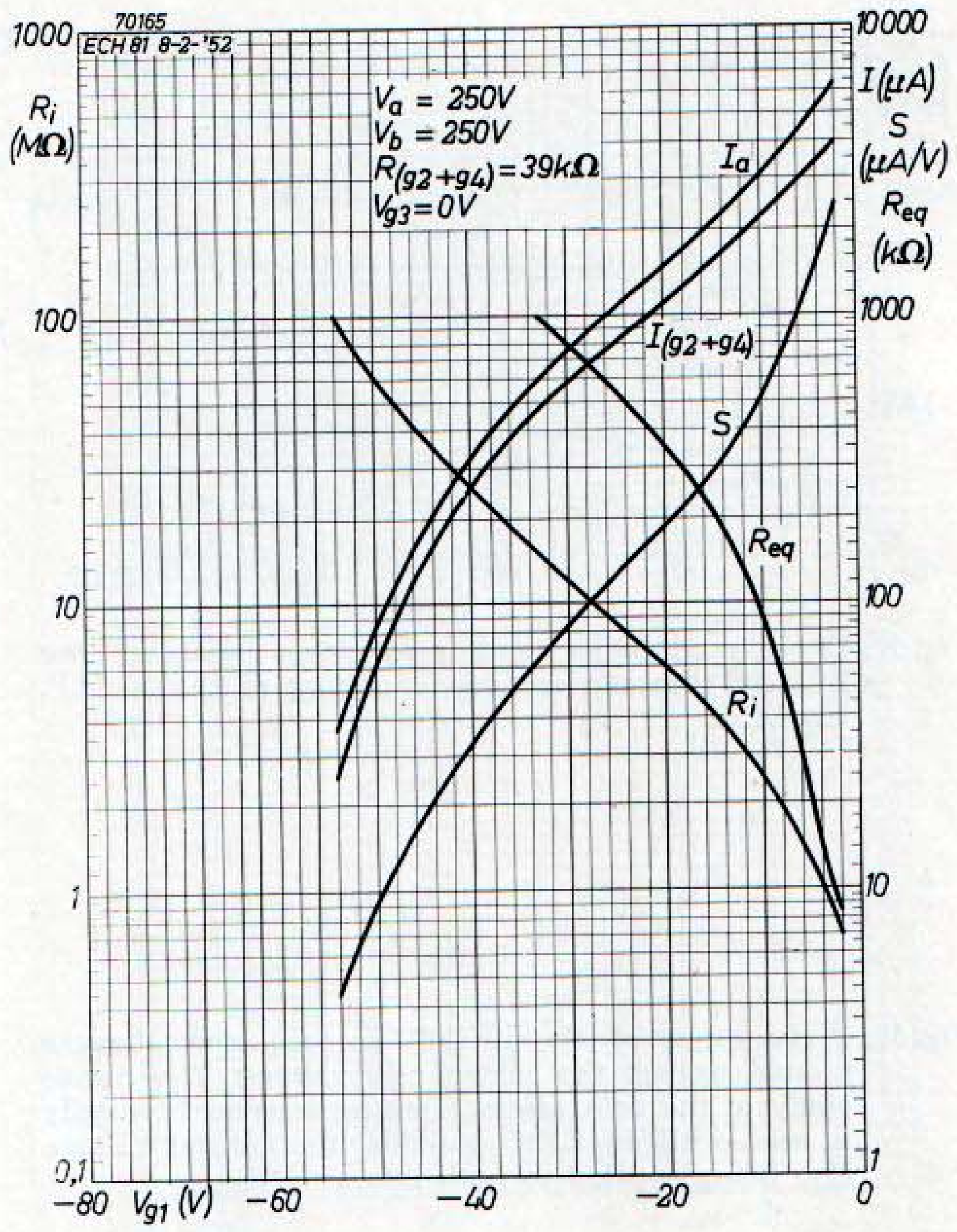
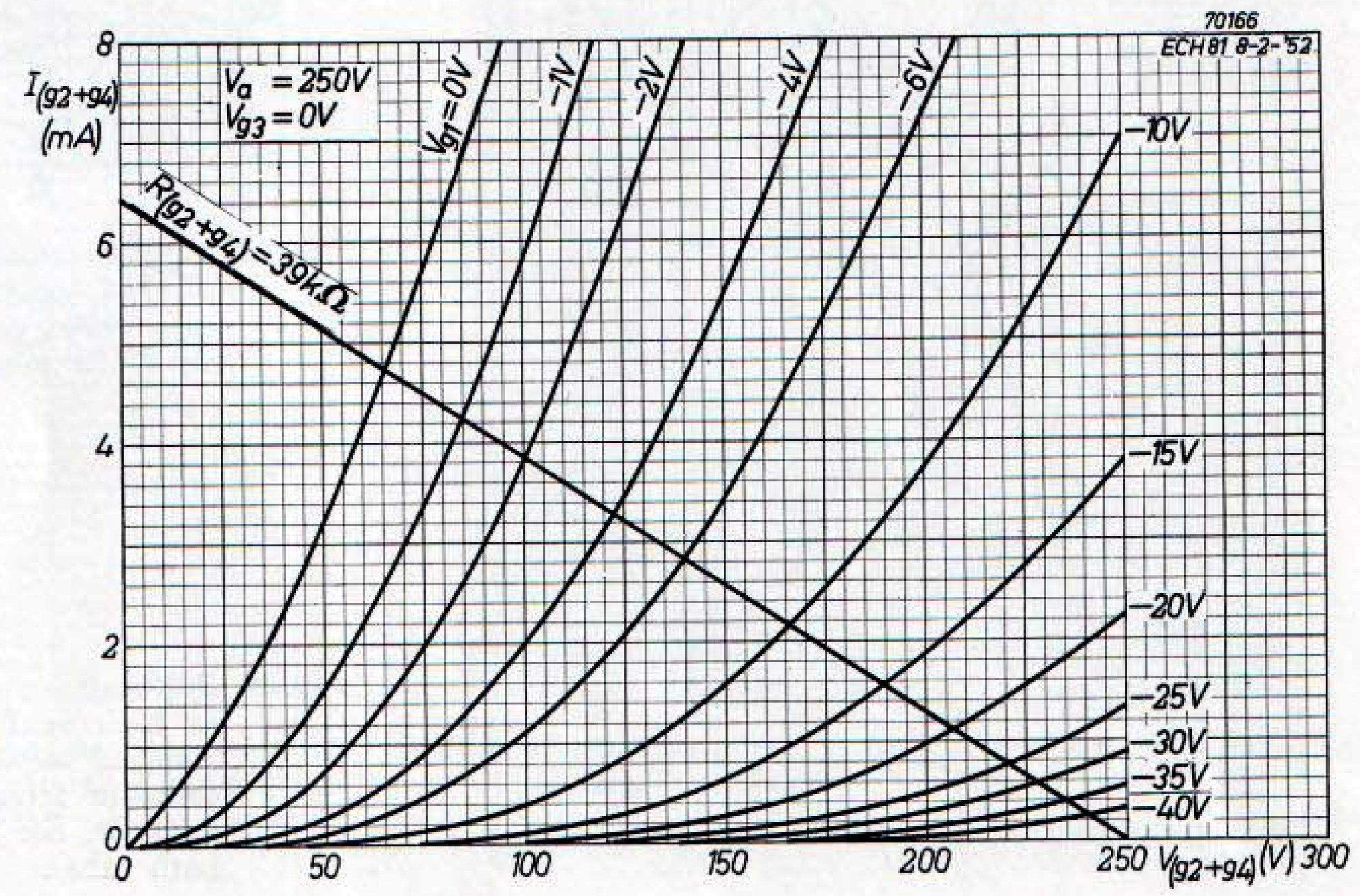


Fig. 35. **Performance of the heptode section of the ECH 81 as H.F. or I.F. amplifier, plotted against the control-grid voltage.**

Fig. 36. **Screen-grid current of the heptode section plotted against the screen-grid voltage, with the control-grid voltage as parameter.**



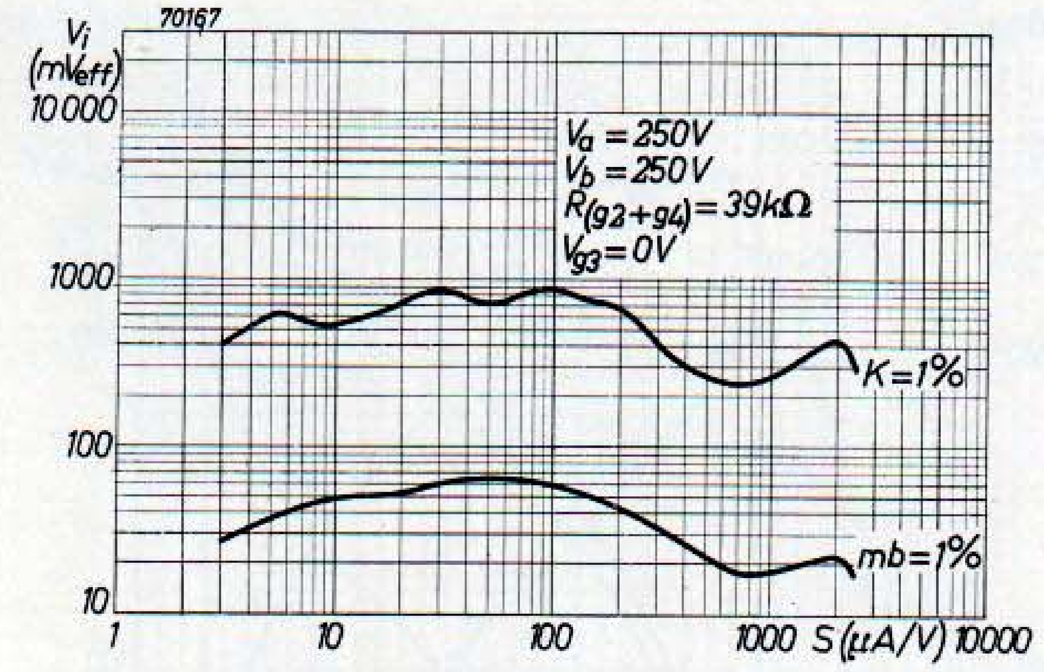


Fig. 37. Cross modulation and modulation hum of the ECH 81 (heptode section) operating as H.F. or I.F. amplifier.

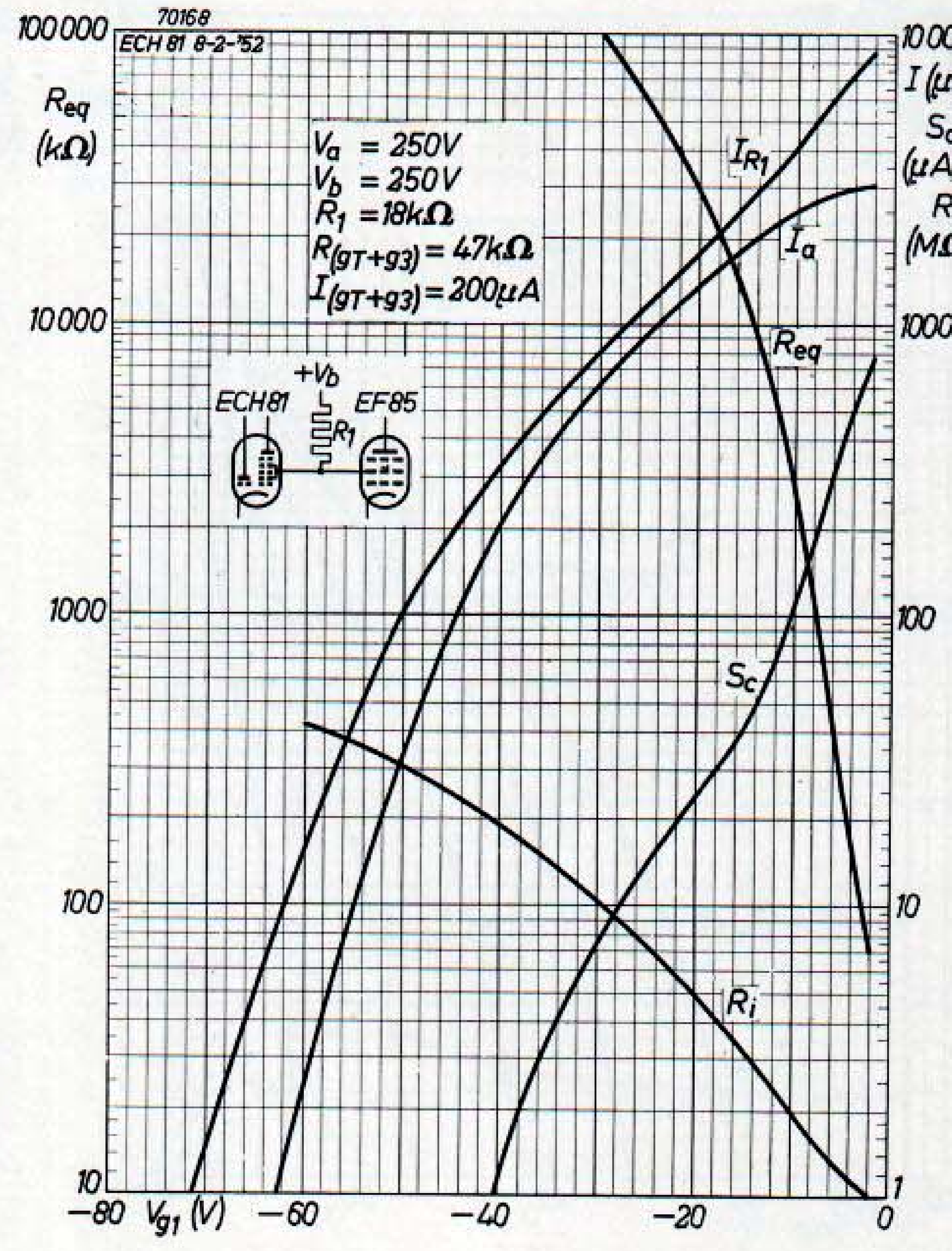
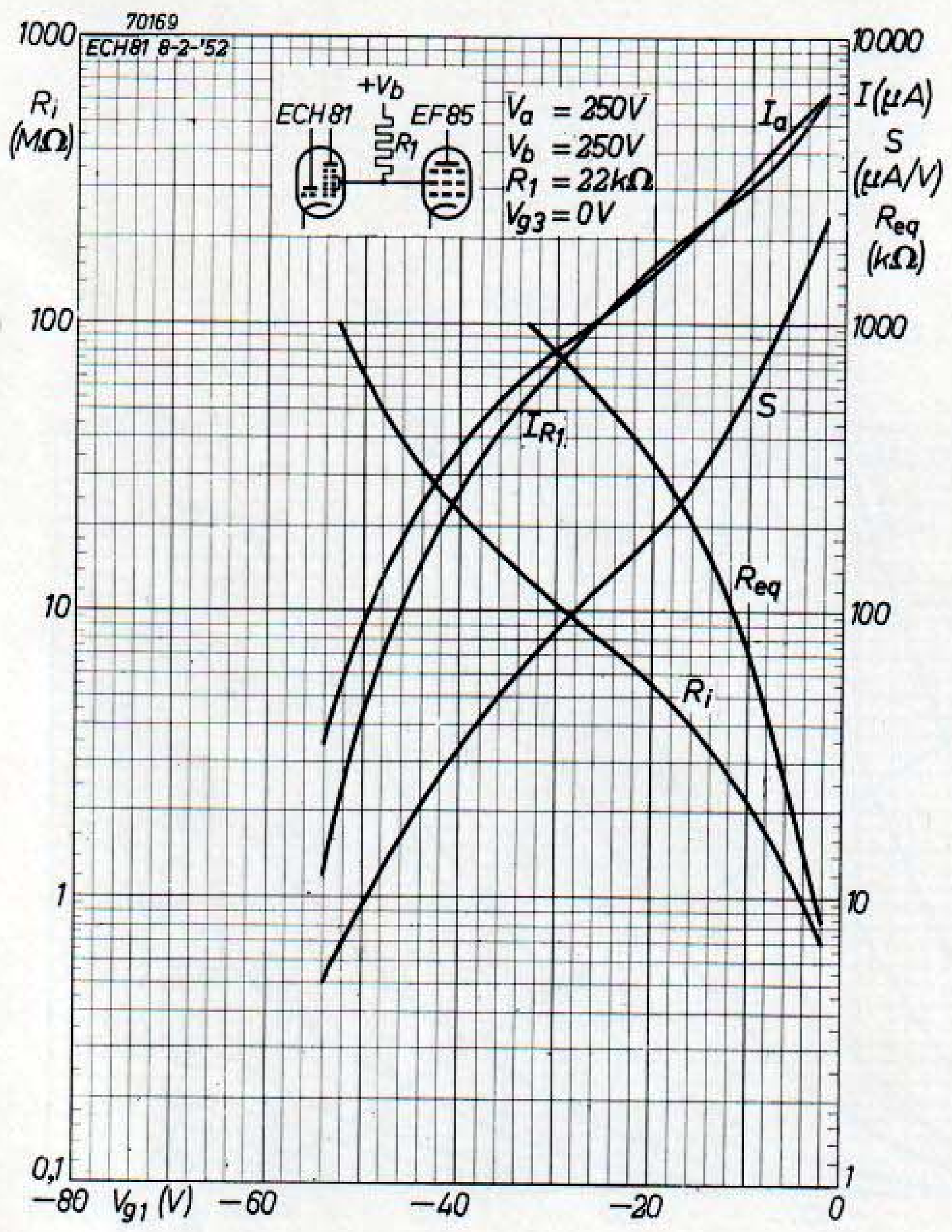


Fig. 38. Performance of the ECH 81 as frequency changer plotted against the control-grid voltage. The curves apply to the case where common screen-grid supply is used with an EF 85 pentode, the control voltage also being applied to both tubes.



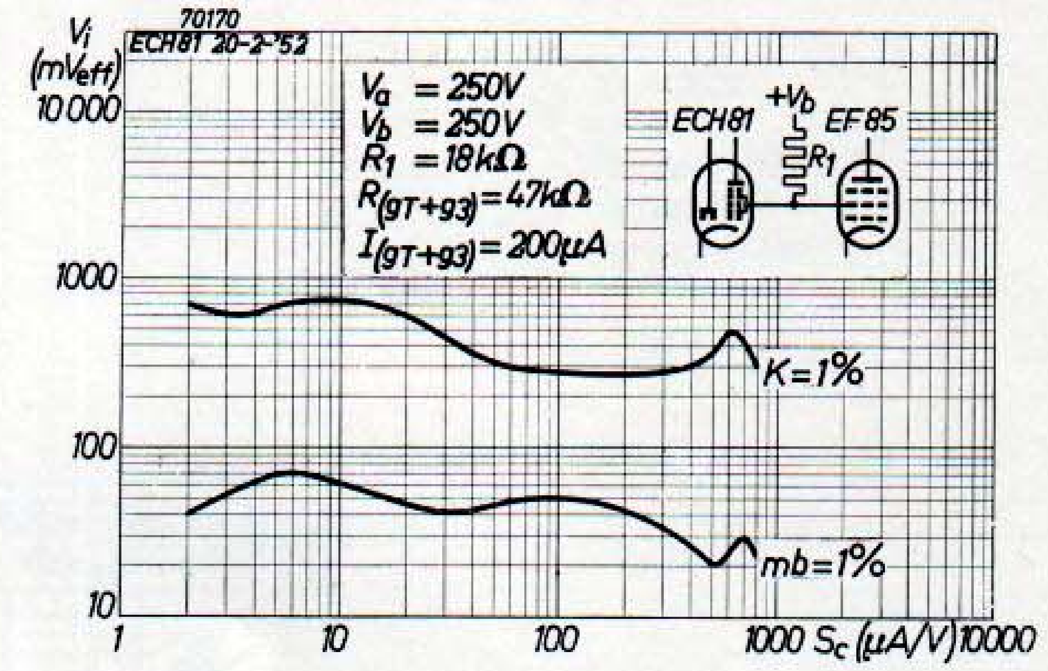


Fig. 40. Cross modulation and modulation hum of the ECH 81 operating as frequency changer, for the case where common screen-grid supply is used with an EF 85 pentode.

Fig. 39. Performance of the heptode section of the ECH 81 as H.F. or I.F. amplifier plotted against the control-grid voltage. The curves apply in the case where common screen-grid supply is used with an EF 85 pentode, the control voltage also being applied to both tubes.

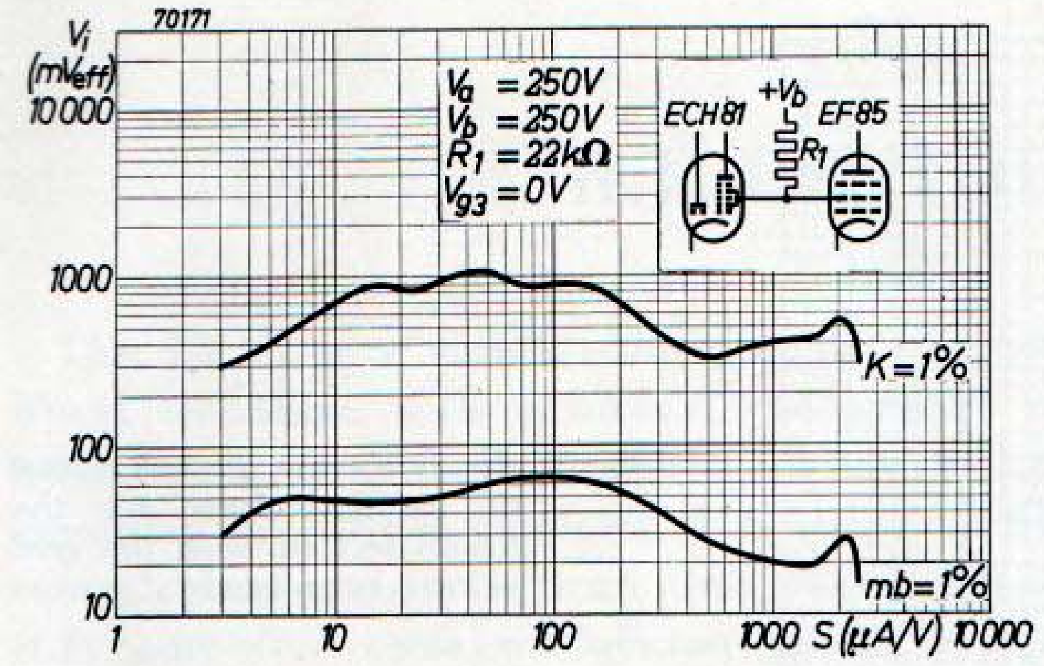


Fig. 41. Cross modulation and modulation hum of the ECH 81 (heptode section) operating as H.F. or I.F. amplifier, for the case where common screen-grid supply is used with an EF 85 pentode.

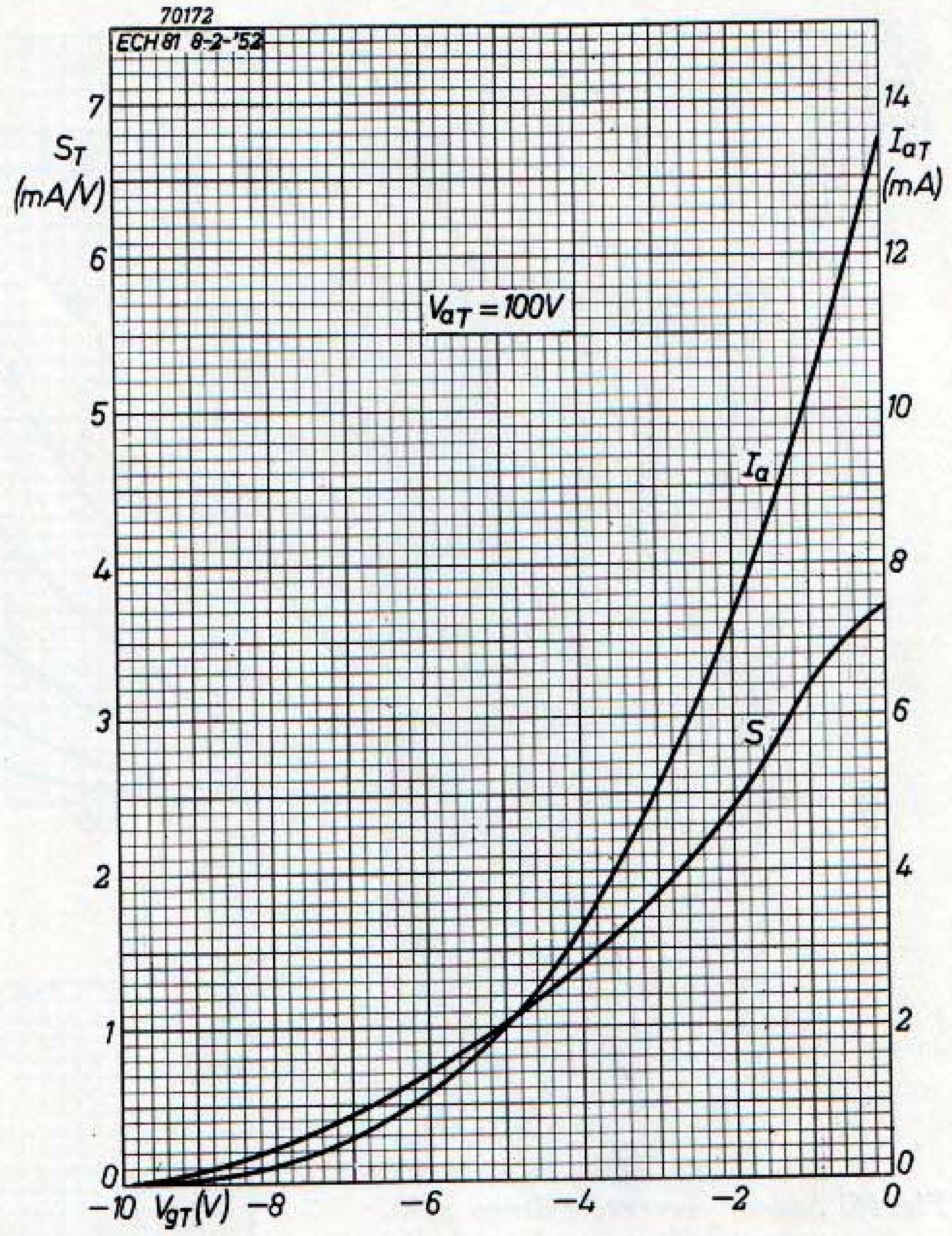


Fig. 42. Anode current and mutual conductance of the triode section plotted against the grid voltage.

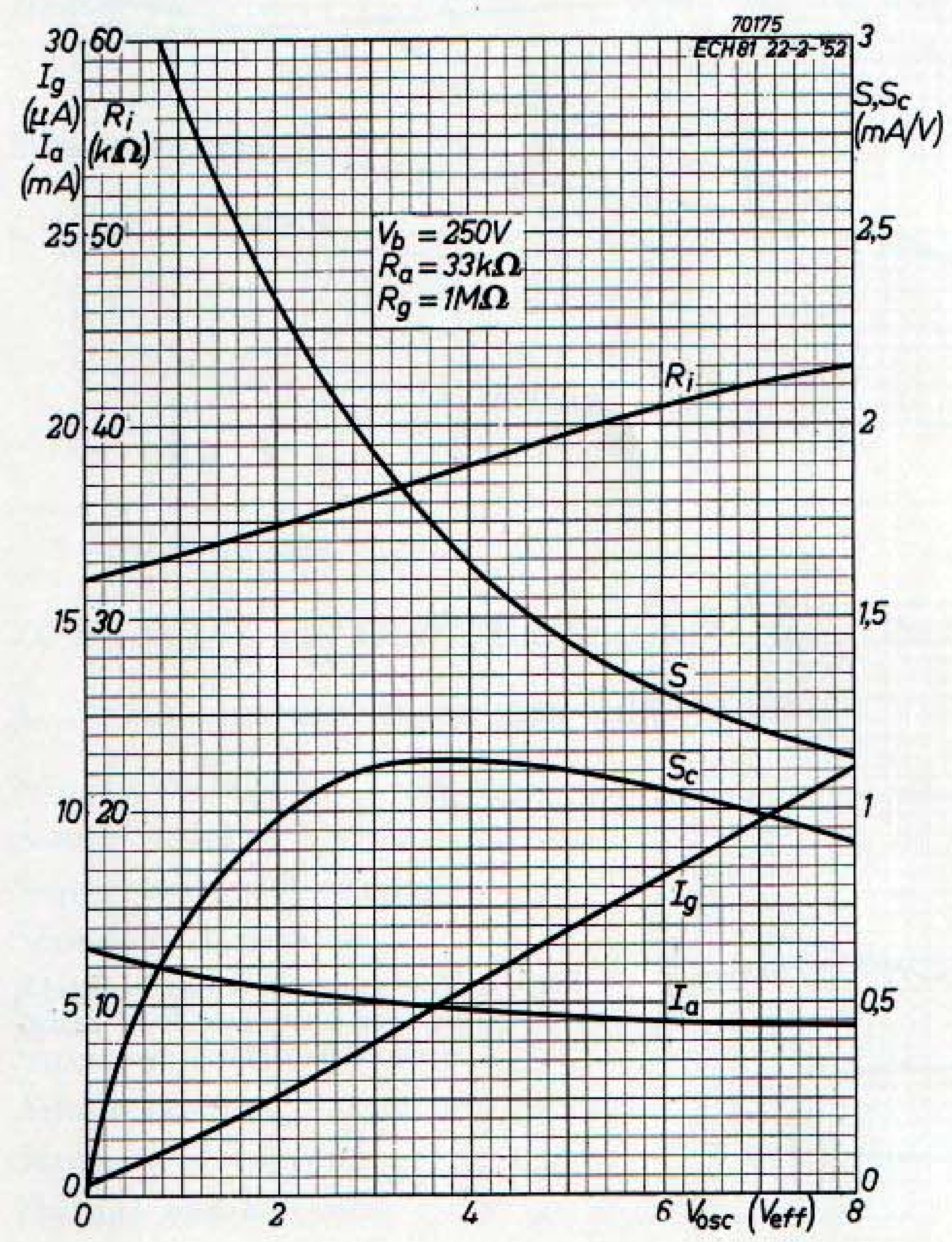


Fig. 43. Performance curves for the triode section operating as frequency changer. *S* is the effective mutual conductance for a signal of 100 mV at intermediate frequency.

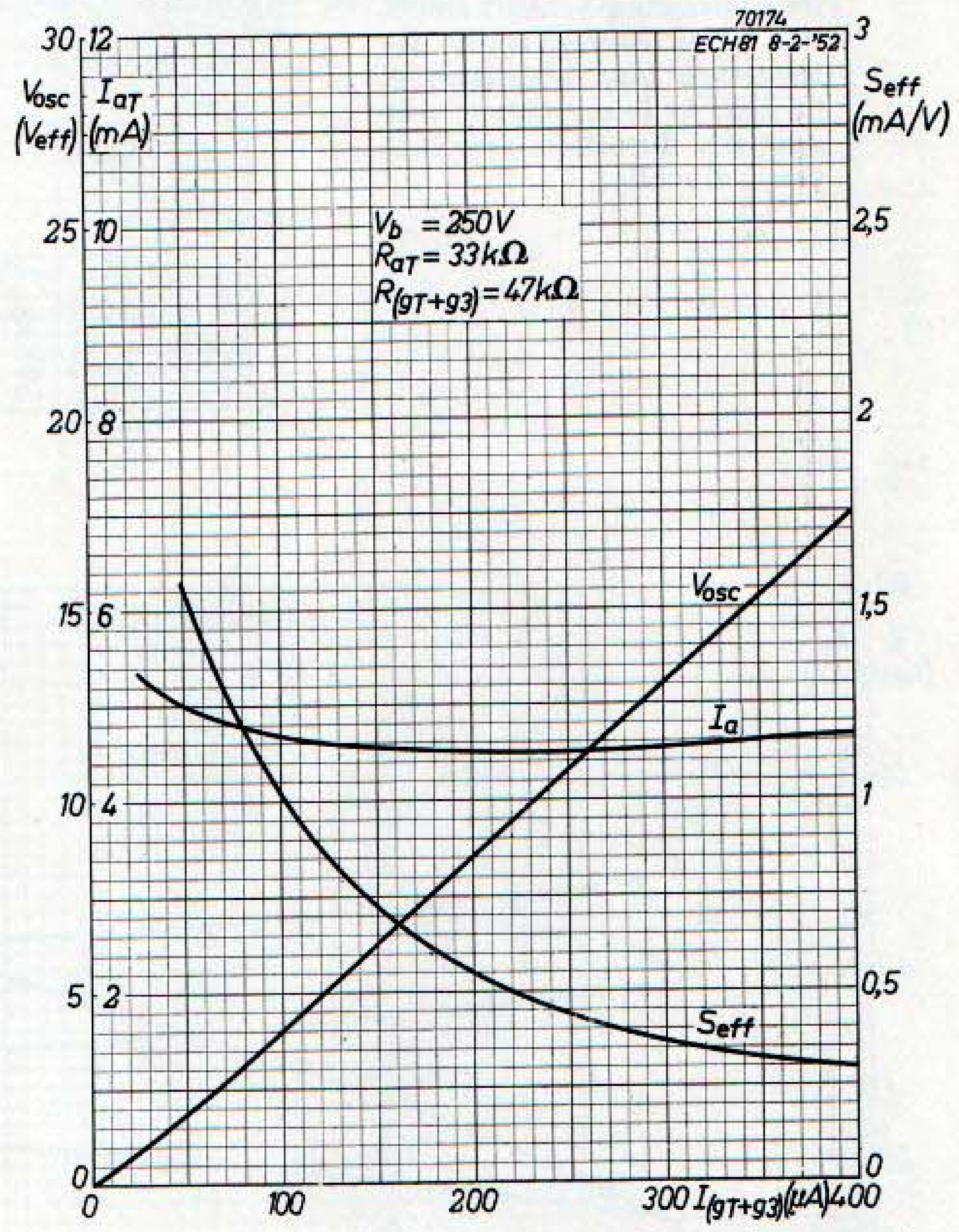


Fig. 44. Performance curves for the triode section operating as local oscillator.

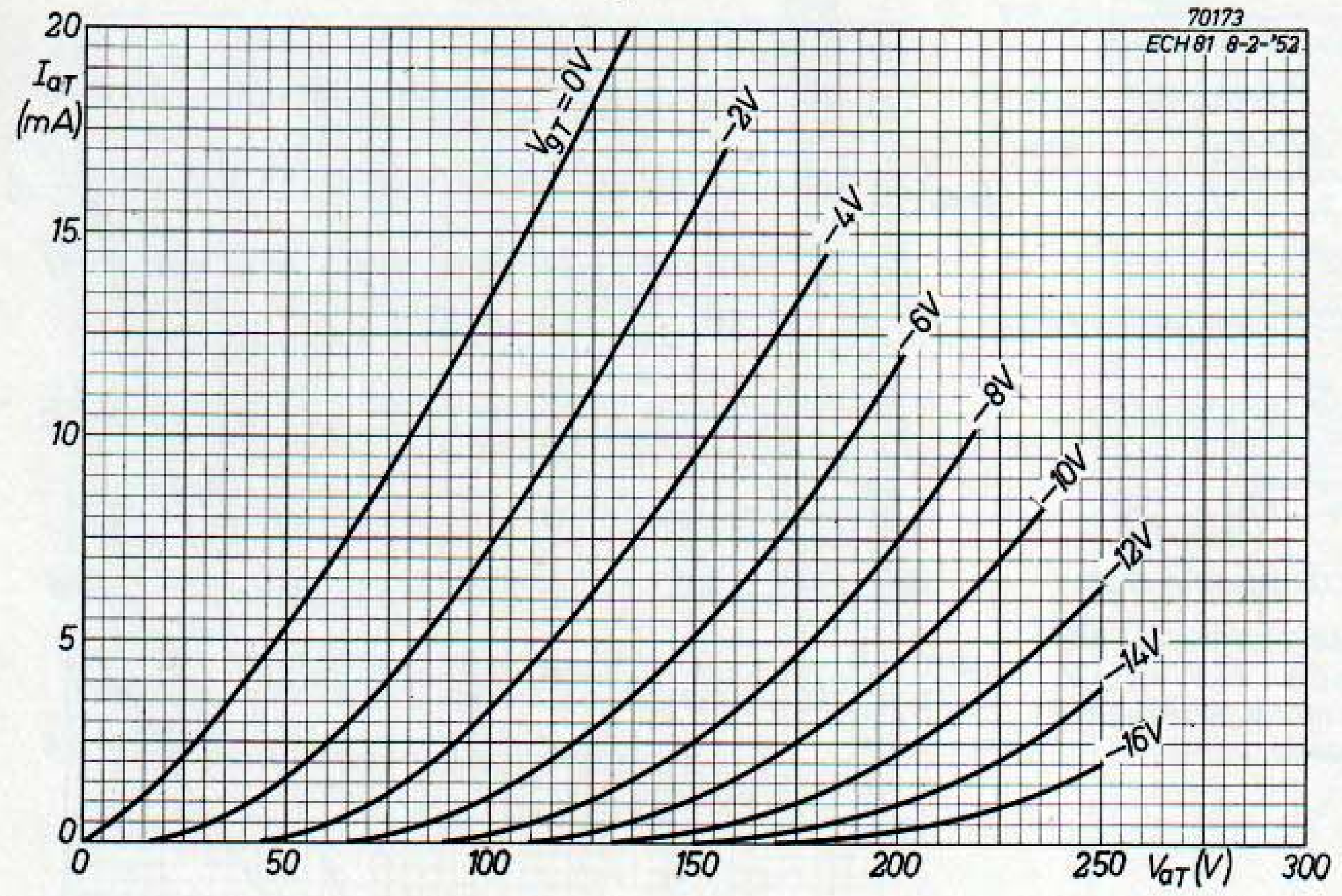


Fig. 45. **Anode current plotted against the anode voltage for the triode section, with the grid voltage as parameter.**

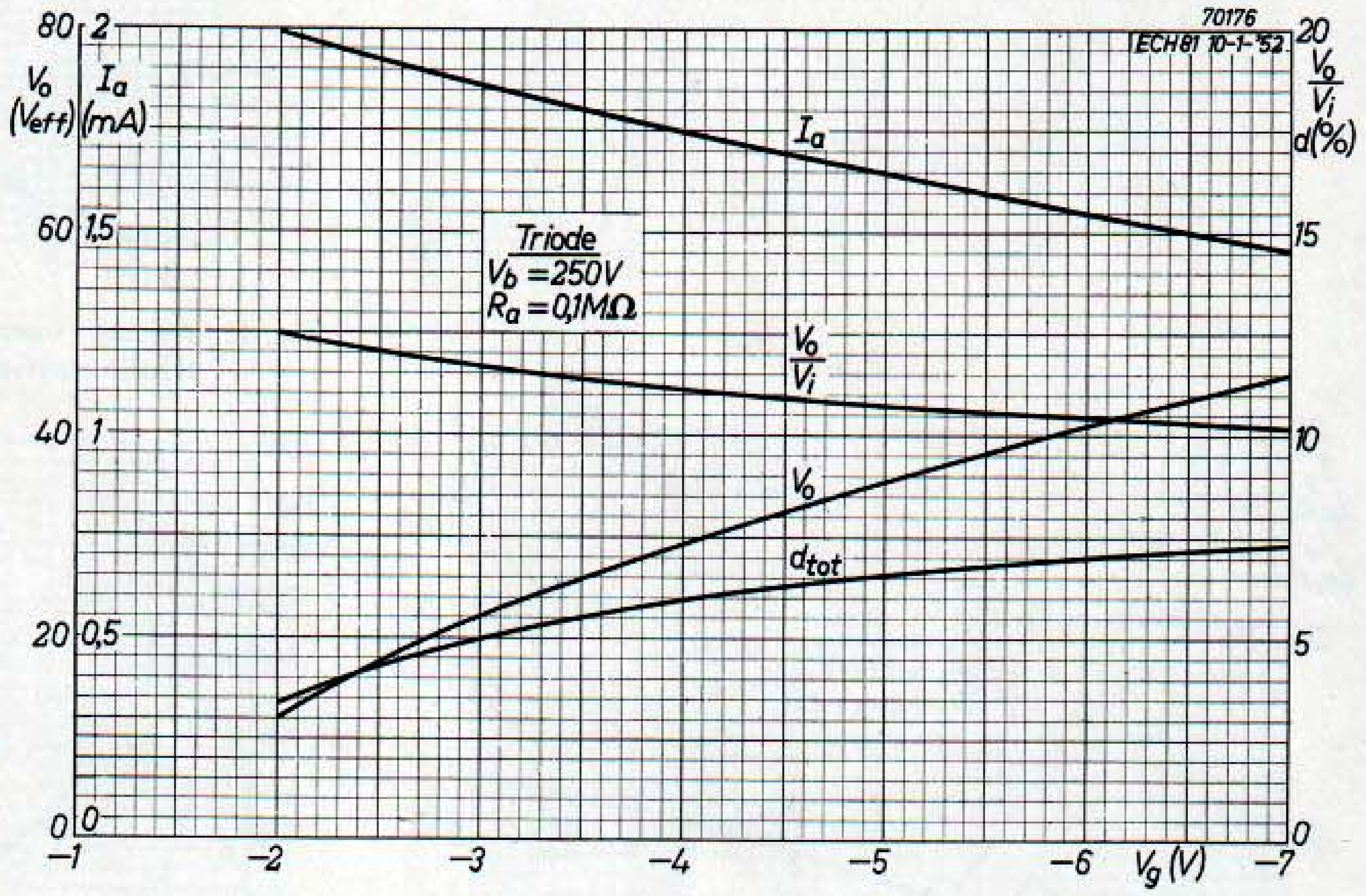


Fig. 46. **Anode current, voltage gain, output voltage and total distortion plotted against the grid bias for the triode section operating as A.F. amplifier. The curves apply for an anode load resistance of 0.1 MΩ. At lower output voltages the distortion decreases proportionally.**

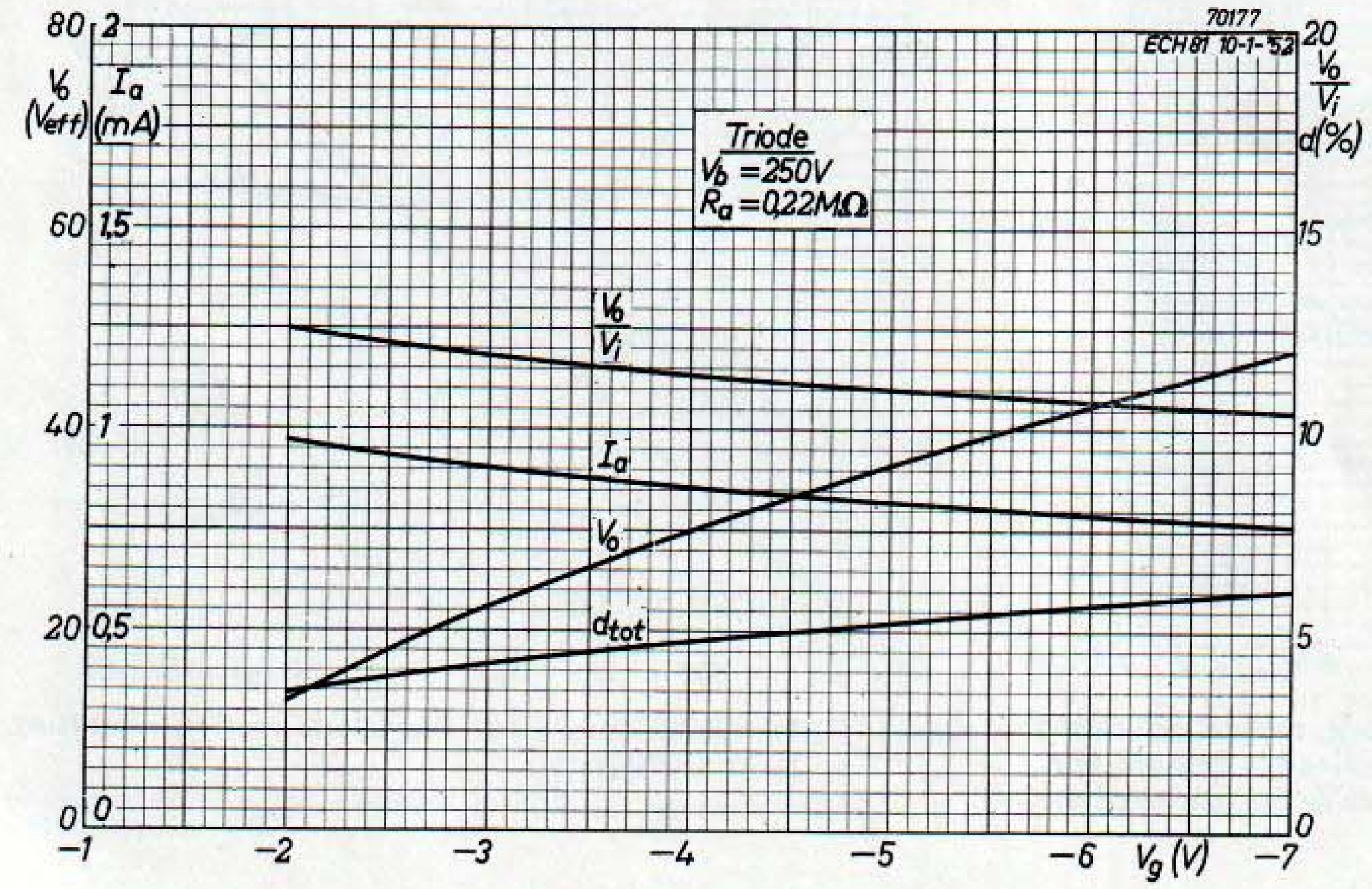


Fig. 47. **The same curves as in fig. 46, but for an anode load resistance of 0.22 MΩ.**

R.F. PENTODE EF 85 (UF 85)

The EF 85 is a variable-mu pentode in 9-pin Noval technique with a mutual conductance of 6.0 mA/V. It is specially designed for use as I.F. amplifier in AM/FM receivers. The shape of the control characteristic in such that when used as H.F. amplifier cross modulation might be experienced. The control characteristics of the ECH 81 as frequency changer and those of the EF 85 as I.F. amplifier with common screen-grid supply are adapted to each other.

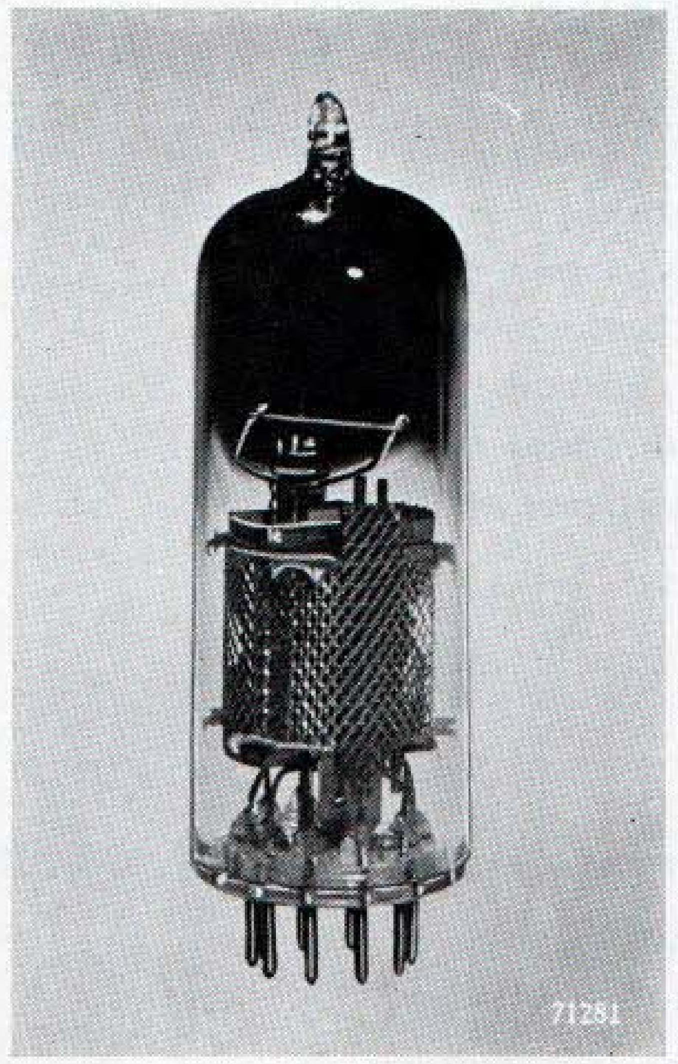


Fig. 48. The R.F. pentode EF 85.

TECHNICAL DATA [8])

HEATER DATA

Heating: indirect by A.C. or D.C.;
EF 85 for series and parallel supply,
UF 85 for series supply.

Heater voltage	EF 85	V_f	=	6.3 V
	UF 85	V_f	=	19 V
Heater current	EF 85	I_f	=	0.3 A
	UF 85	I_f	=	0.1 A

Mounting position: any

CAPACITANCES

C_{g1} = 7.2 pF
C_a = 3.7 pF
C_{ag1} < 0.007 pF
C_{g1f} < 0.15 pF

BASE CONNECTIONS AND DIMENSIONS (in mm)

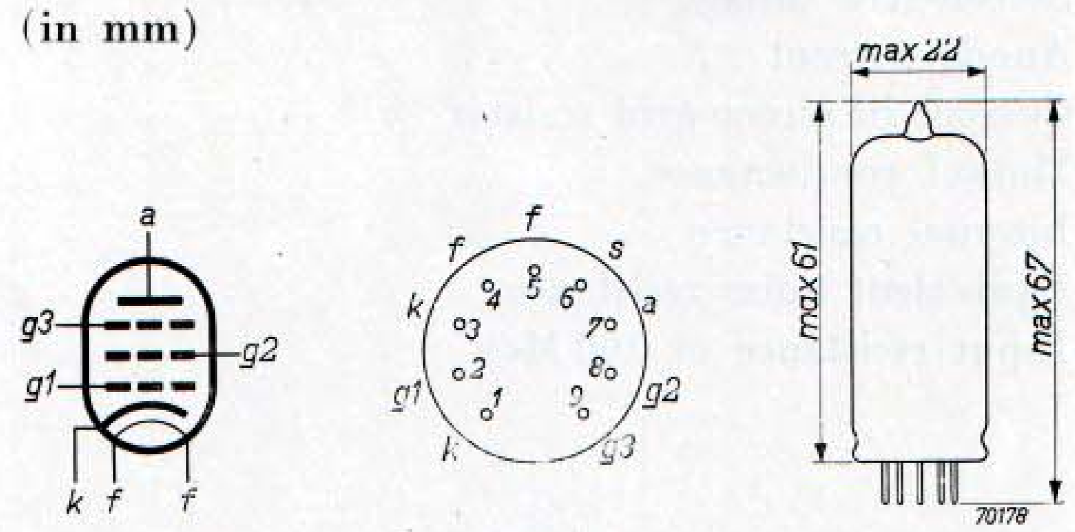


Fig. 49.

[8]) Provisional data.

OPERATING CHARACTERISTICS AS H.F. OR I.F. AMPLIFIER

A. With separate screen-grid supply

Supply voltage	V_b =	250		V
Anode voltage	V_a =	250		V
Suppressor-grid voltage	V_{g3} =	0		V
Screen-grid resistor	R_{g2} =	60		kΩ
Grid bias	V_{g1} =	−2	−35	V
Screen-grid voltage	V_{g2} =	100		V
Anode current	I_a =	10	—	mA
Screen-grid current	I_{g2} =	2.5	—	mA
Mutual conductance	S =	6000	60	μA/V
Internal resistance	R_i =	0.5	>5	MΩ
Equivalent noise resistance	R_{eq} =	1.5		kΩ
Input resistance at 100 Mc/s	r_{g1} =	2.25		kΩ

B. Common screen-grid supply with ECH 81 (ECH 81 as frequency changer)

Supply voltage	V_b	=	250	V
Anode voltage	V_a	=	250	V
Suppressor-grid voltage	V_{g3}	=	0	V
Screen-grid resistor	R_{g2}	=	18	kΩ
Grid bias	V_{g1}	=	—2	—33 V
Screen-grid voltage	V_{g2}	=	97	V
Anode current	I_a	=	10	— mA
Current in screen-grid resistor		=	8.5	— mA
Mutual conductance	S	=	6000	60 μA/V
Internal resistance	R_i	=	0.5	>5 MΩ
Equivalent noise resistance	R_{eq}	=	1.5	kΩ
Input resistance at 100 Mc/s	r_{g1}	=	2.25	kΩ

C. Common screen-grid supply with ECH 81 (ECH 81 as H.F. or I.F. amplifier)

Supply voltage	V_b	=	250	V
Anode voltage	V_a	=	250	V
Suppressor-grid voltage	V_{g3}	=	0	V
Screen-grid resistor	R_{g2}	=	22	kΩ
Grid bias	V_{g1}	=	—2	—35 V
Screen-grid voltage	V_{g2}	=	105	V
Anode current	I_a	=	10	— mA
Current in screen-grid resistor		=	6.6	— mA
Mutual conductance	S	=	6000	60 μA/V
Internal resistance	R_i	=	0.5	>5 MΩ
Equivalent noise resistance	R_{eq}	=	1.5	kΩ
Input resistance at 100 Mc/s	r_{g1}	=	2.25	kΩ

LIMITING VALUES

Anode voltage at zero anode current	V_{ao}	= max.	550 V
Anode voltage	V_a	= max.	250 V
Screen-grid voltage at zero screen-grid current	V_{g2o}	= max.	550 V
Screen-grid voltage	V_{g2}	= max.	250 V
Voltage between heater and cathode	V_{fk}	= max.	150 V
Control-grid voltage for $I_{g1} = +0.3\ \mu A$	V_{g1}	= max.	—1.3 V
Cathode current	I_k	= max.	15 mA
Anode dissipation	W_a	= max.	2.5 W
Screen-grid dissipation	W_{g2}	= max.	0.65 W
External resistance between control grid and cathode	R_{g1}	= max.	3 MΩ [9])
External resistance between heater and cathode	R_{fk}	= max.	20 kΩ

[9]) In circuits in which the tube operates at maximum ratings it is advisable to keep R_{g1} as small as possible.

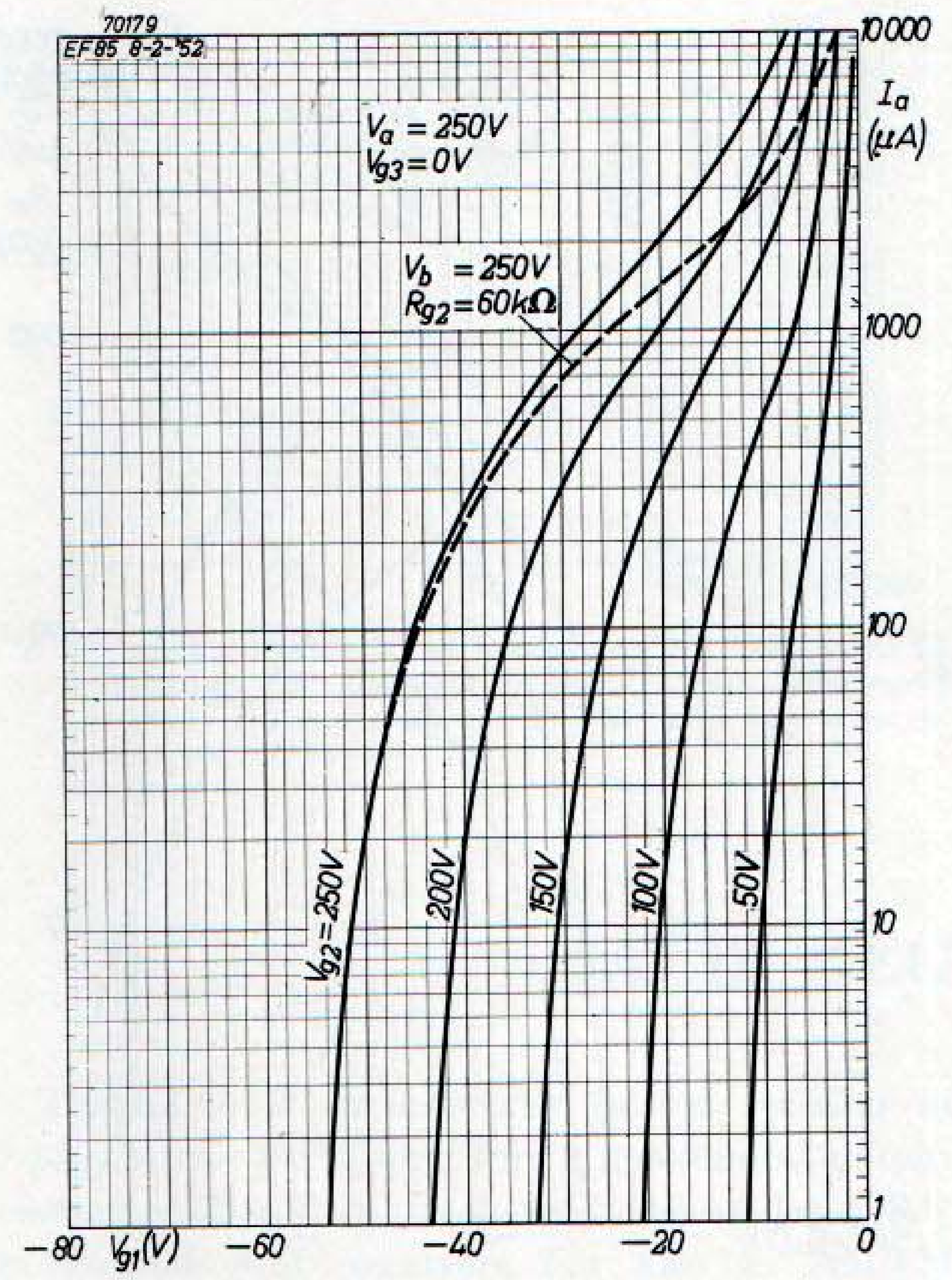


Fig. 50. **Anode current plotted against the control-grid voltage with the screen-grid voltage as parameter.**

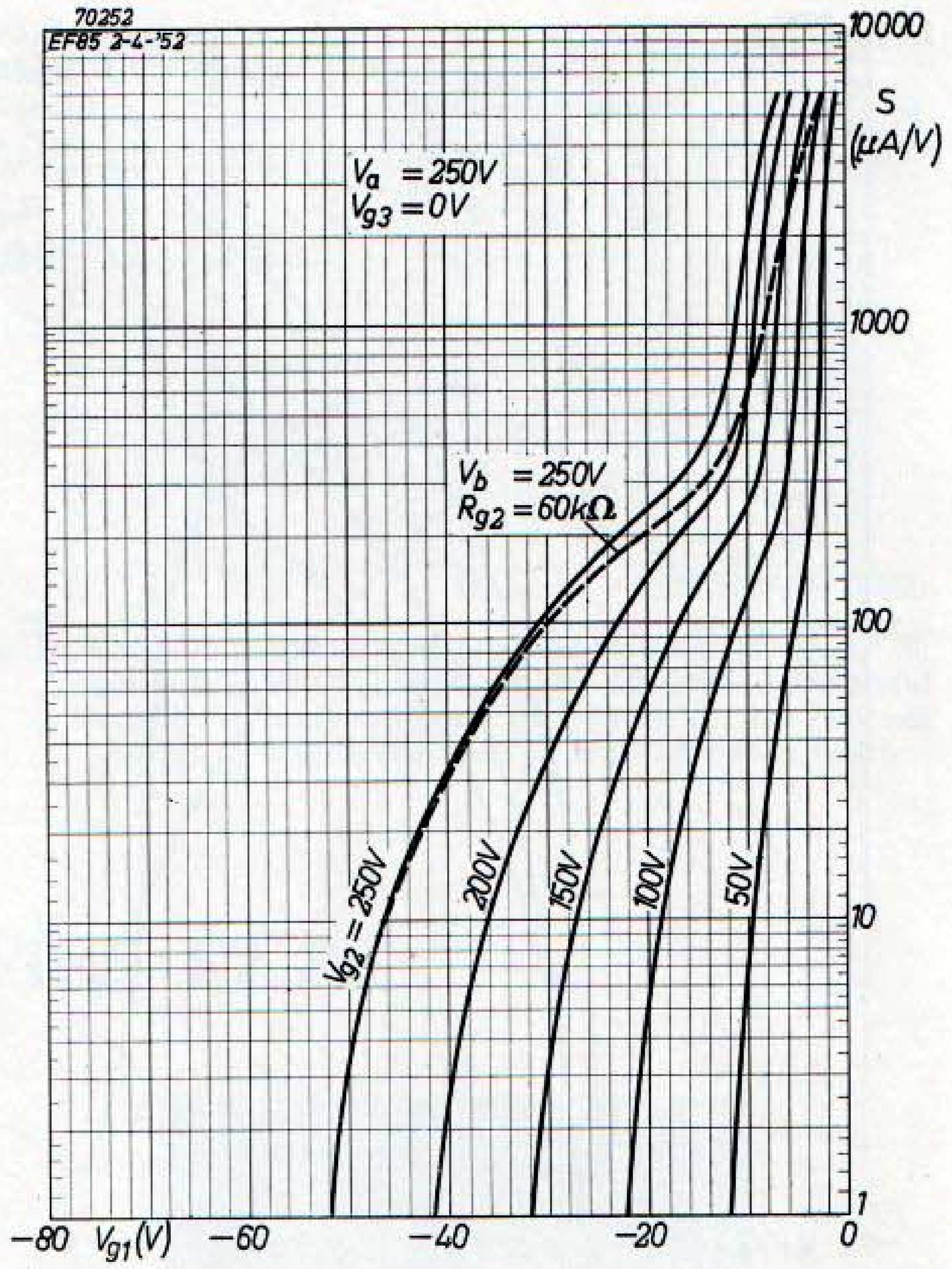


Fig. 51. **Mutual conductance plotted against the control-grid voltage with the screen-grid voltage as parameter.**

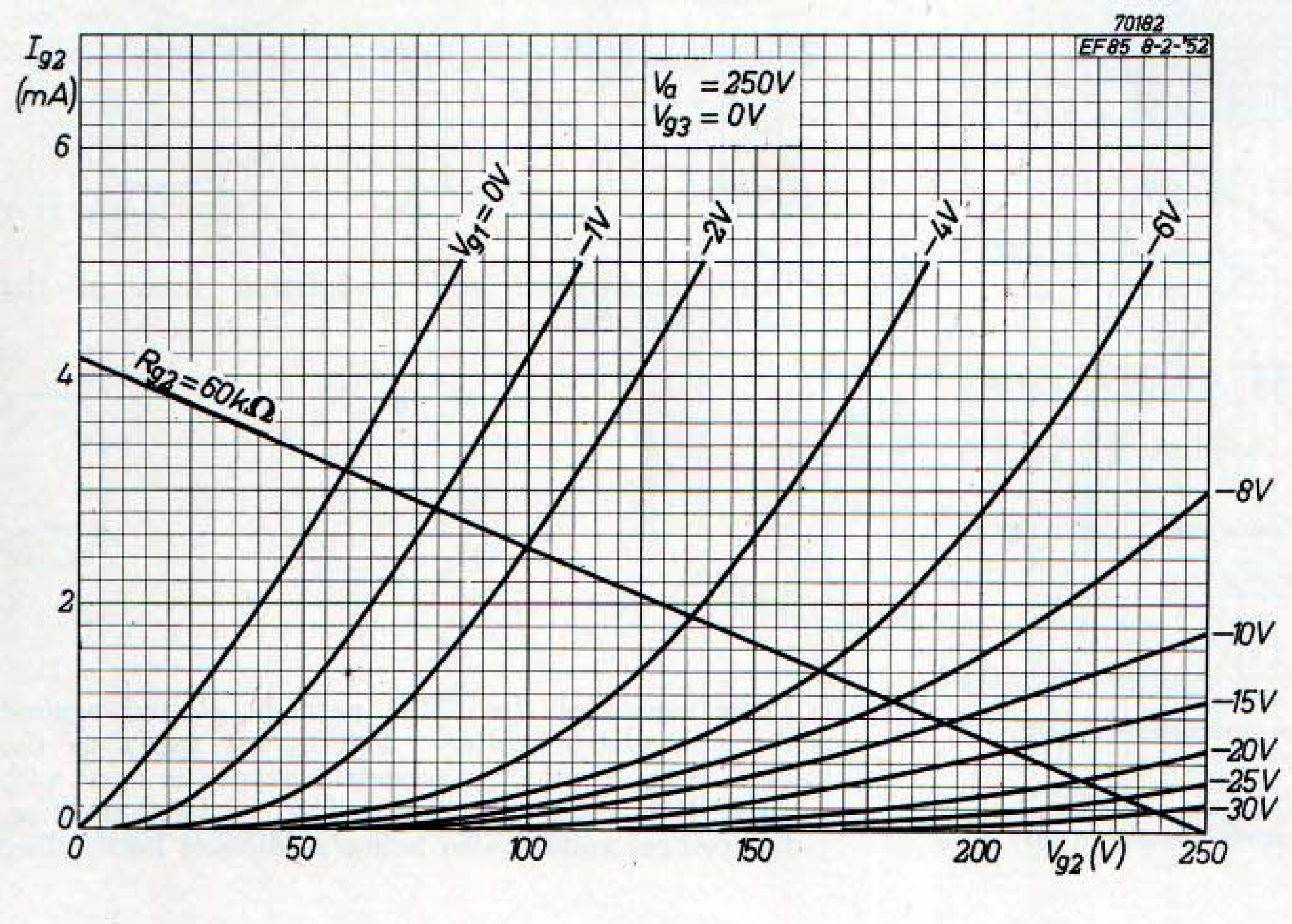


Fig. 52. **Screen-grid current plotted against the screen-grid voltage with the control-grid voltage as parameter.**

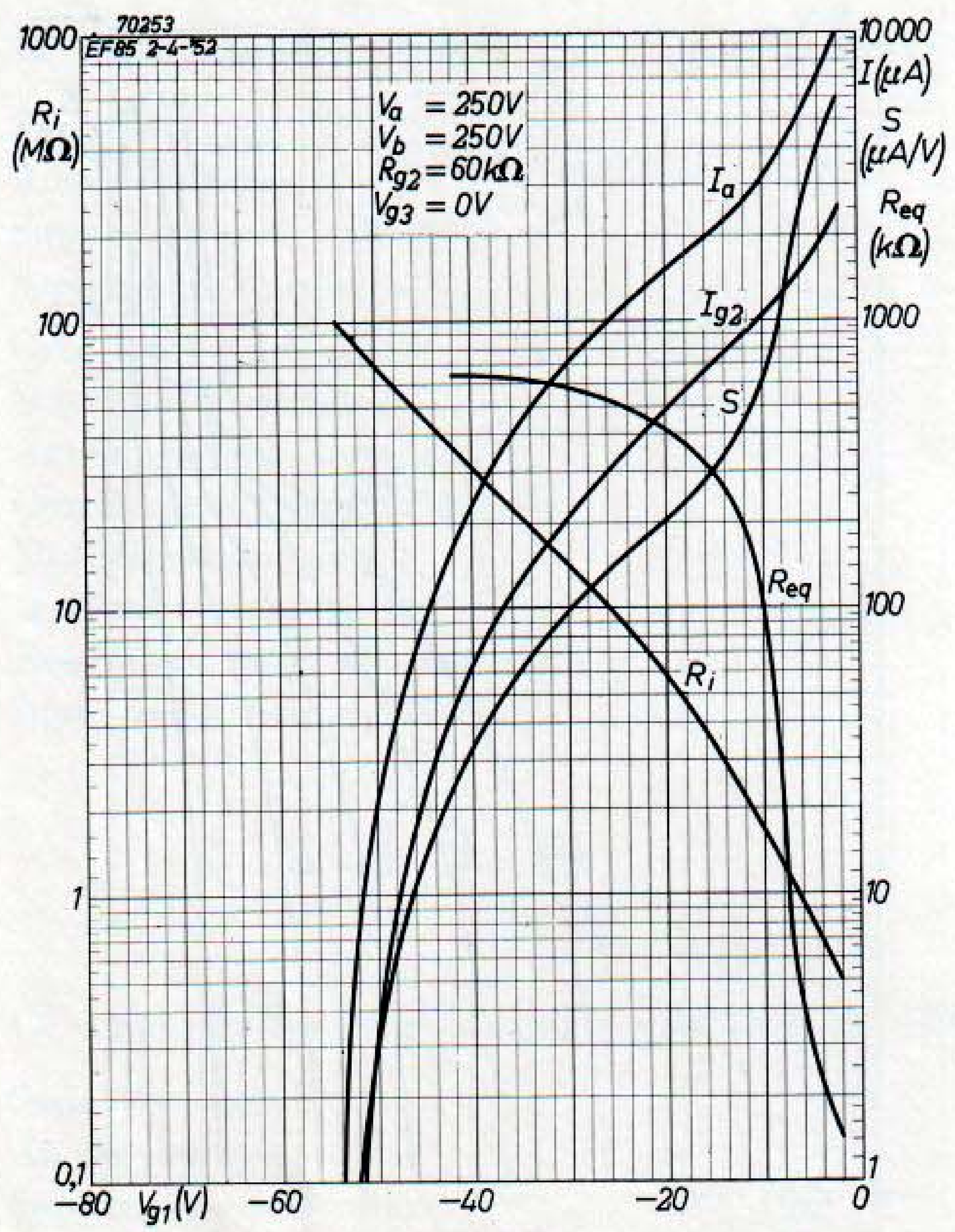


Fig. 53. Performance of the EF 85 pentode plotted against the control grid voltage.

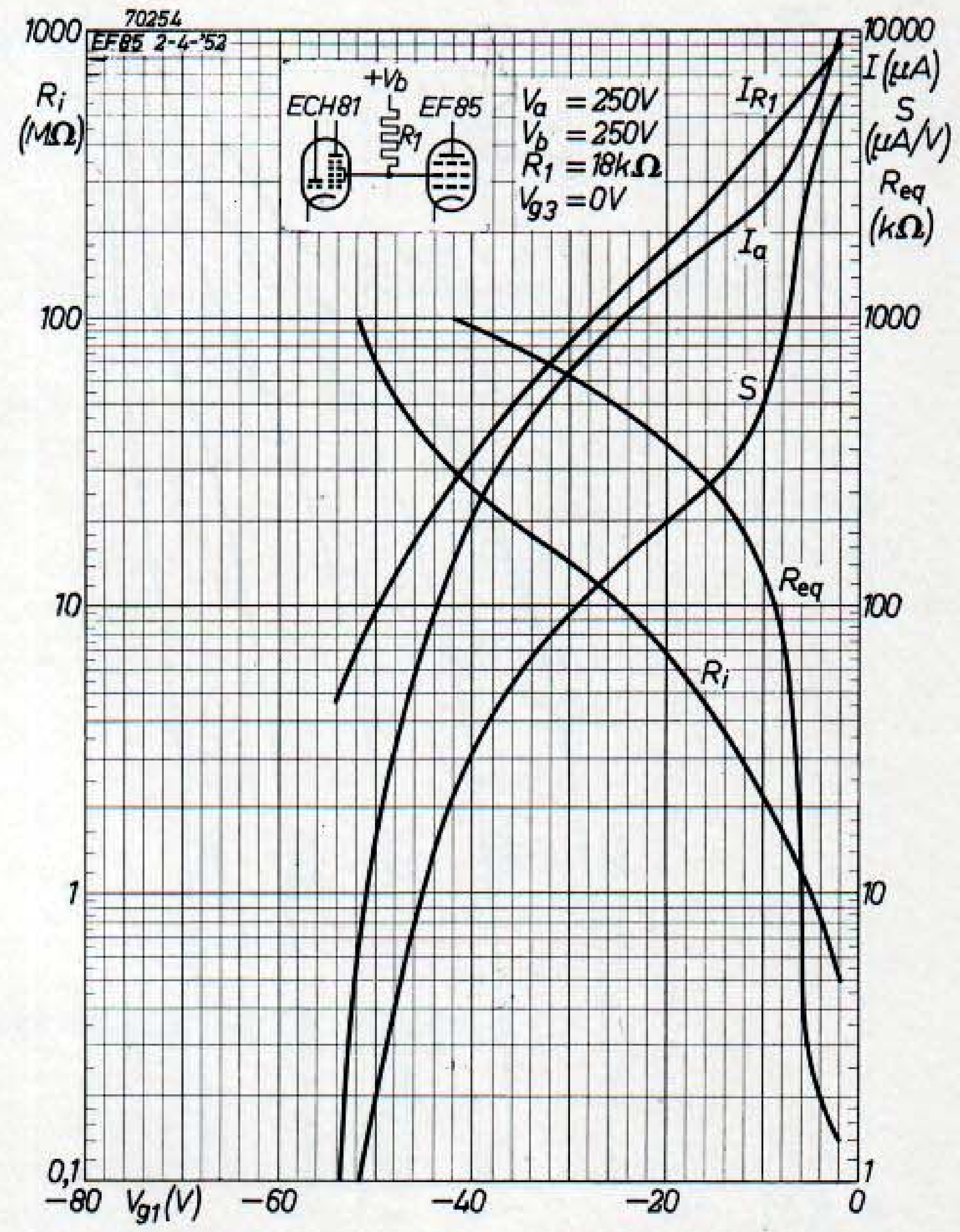
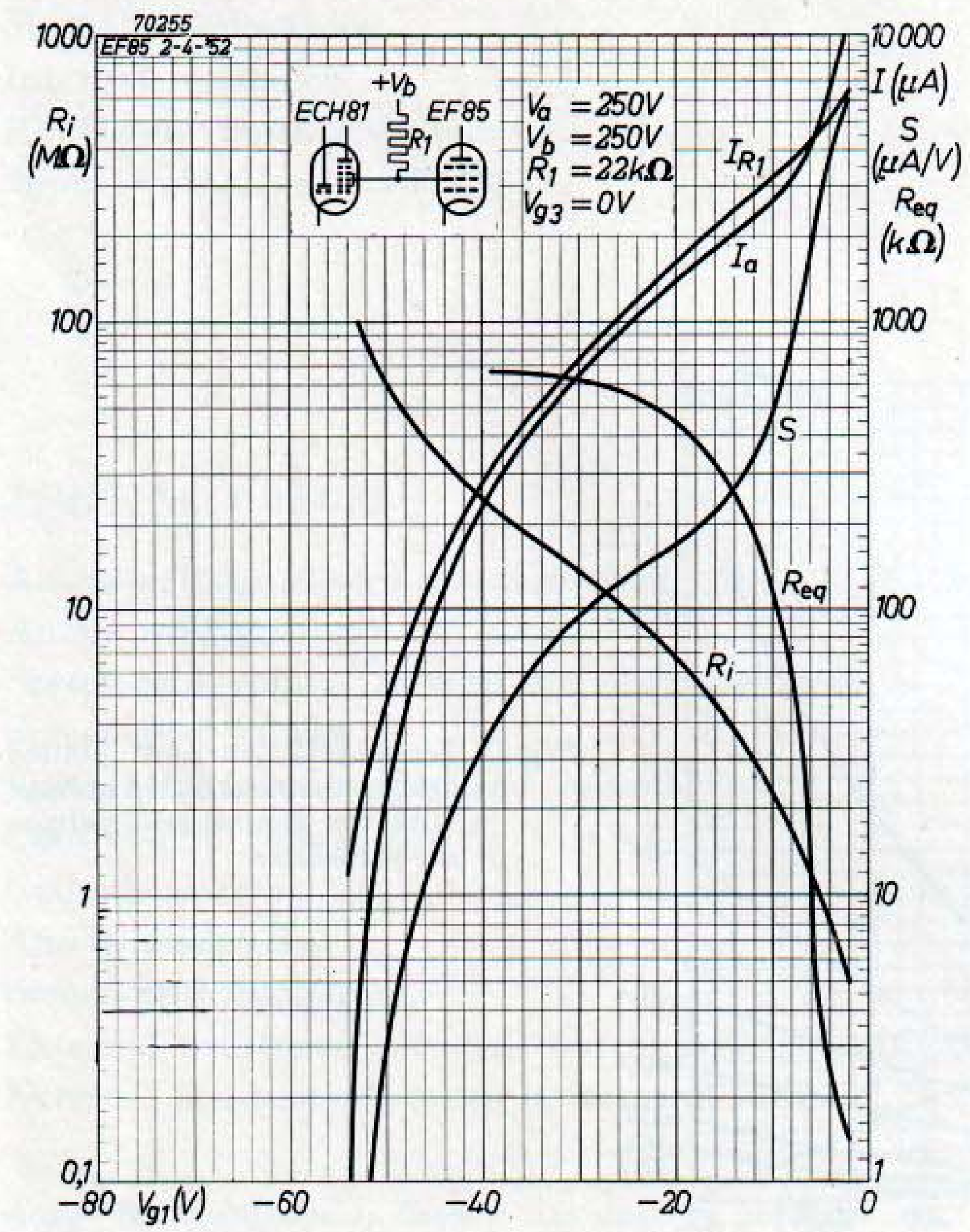


Fig. 54. Performance of the EF 85 pentode plotted against the control-grid voltage. The curves apply to the case where common screen-grid supply is used with an ECH 81 tube operating as frequency changer, the control voltage also being applied to both tubes.



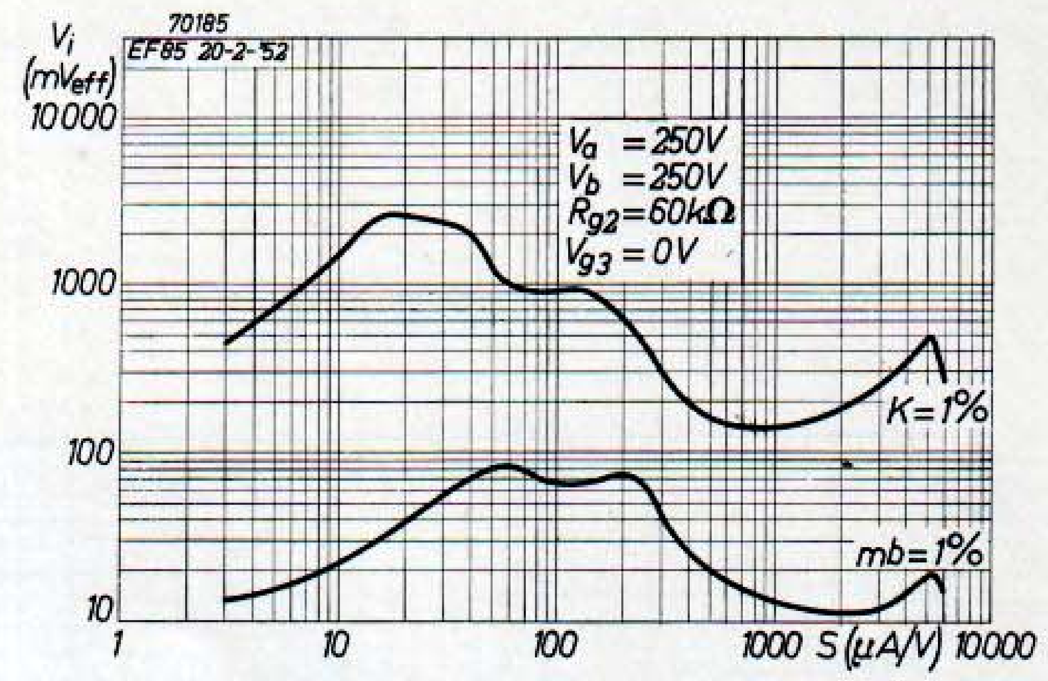


Fig. 56. Cross modulation and modulation hum of the EF 85 pentode.

Fig. 55. Performance of the EF 85 pentode plotted against the control-grid voltage. The curves apply to the case where common screen-grid supply is used with an ECH 81 tube operating as H.F. or I.F. amplifier, the control voltage also being applied to both tubes.

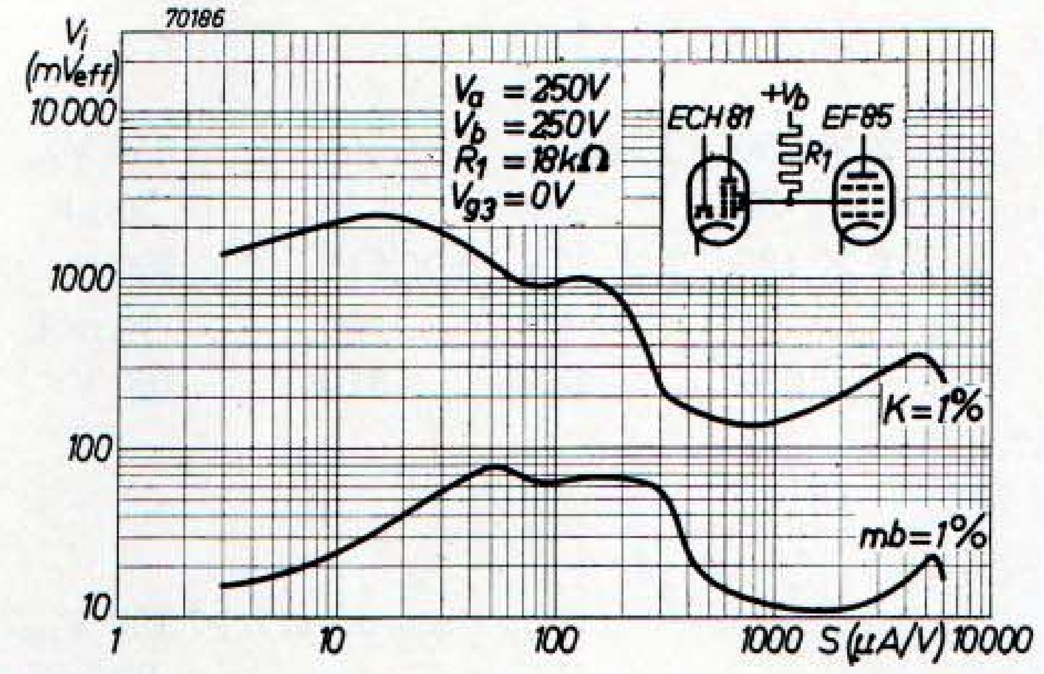


Fig. 57. Cross modulation and modulation hum of the EF 85 pentode, for the case where common screen-grid supply is used with an ECH 81 tube operating as frequency changer.

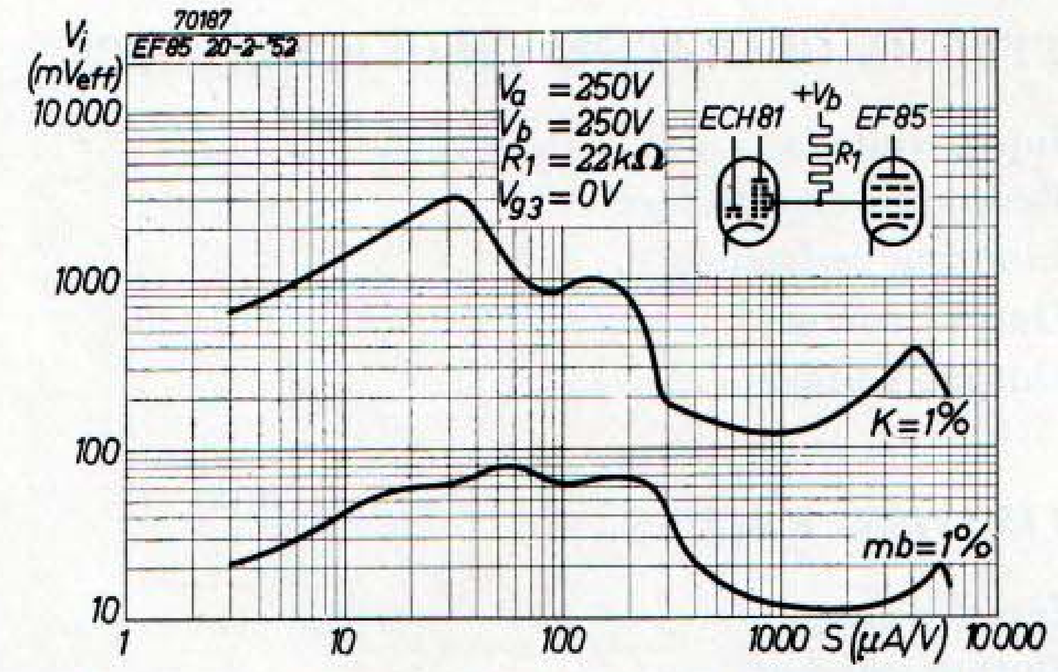


Fig. 58. Cross modulation and modulation hum of the EF 85 pentode, for the case where common screen-grid supply is used with an ECH 81 tube the heptode section of which operates as H.F. or I.F. amplifier.

MAINS RECTIFIER EZ 80

The EZ 80 is an indirectly heated rectifier in 9-pin Noval technique for a maximum output current of 90 mA. It can therefore be used not only in normal A.M. receivers but also in AM/FM receivers, the H.T. drain of which is usually somewhat greater. The insulation between heater and cathode is such that a peak voltage of 500 V is permissible between these electrodes. The heating-up time of the EZ 80 is about 15 sec. In a normal receiver with the receiving tubes ECH 42, EF 41, EBC 41 and EL 41 the voltage across the reservoir capacitor does not increase to more than 5% above its final value. Electrolytic capacitors having a low working voltage can therefore be used.

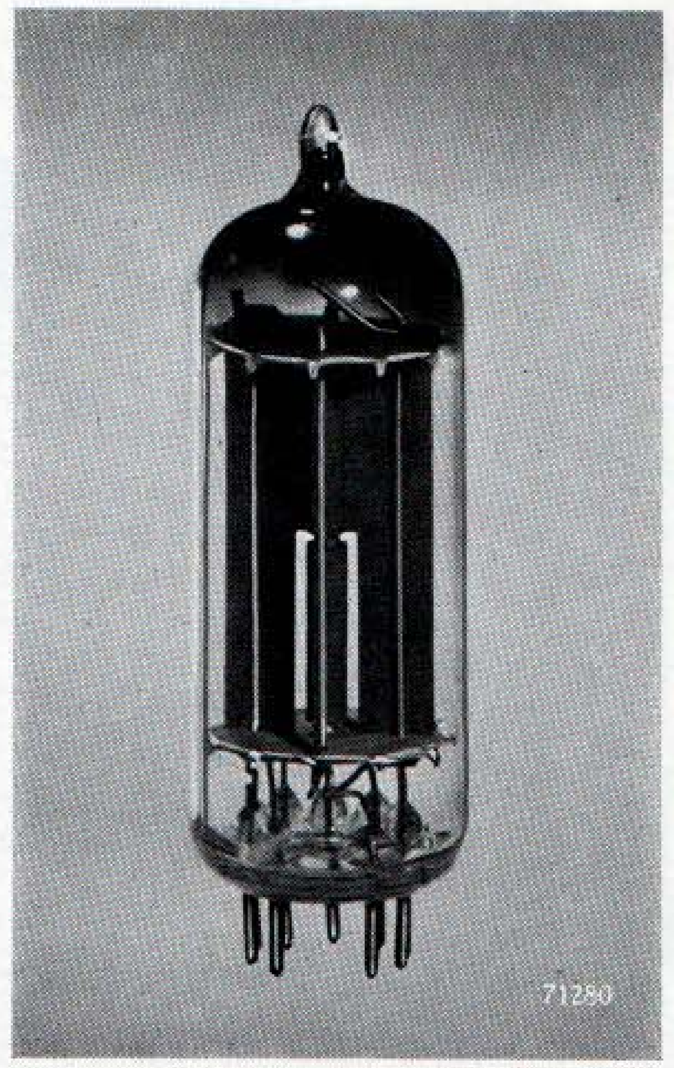


Fig. 59. The mains rectifier EZ 80.

BASE CONNECTIONS AND DIMENSIONS
(in mm)

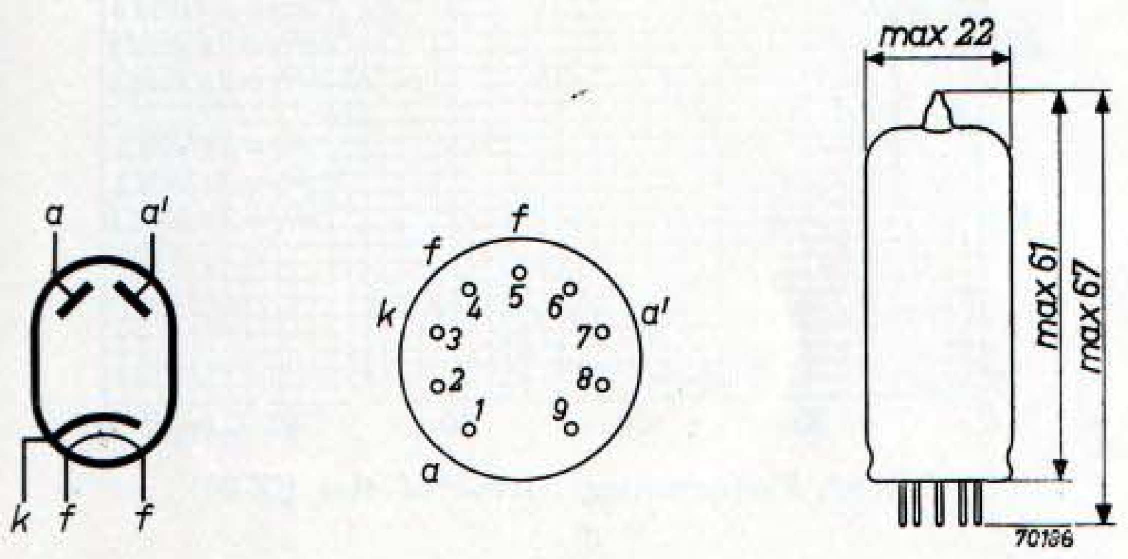


Fig. 60.

TECHNICAL DATA [10])

HEATER DATA

Heating: indirect by A.C. or D.C.; parallel supply.

Heater voltage	V_f	=	6.3 V
Heater current	I_f	=	0.6 A

Mounting position: any

[10]) Provisional data.

TYPICAL OPERATING CHARACTERISTICS

Input voltage	V_{tr}	=	2 × 250	2 × 275	2 × 300	2 × 350 V_{rms}
Reservoir capacitance	C_{filt}	=	50	50	50	50 μF
Limiting resistance	R_t	=	2 × 125	2 × 175	2 × 215	2 × 300 Ω
Output current	I_o	=	90	90	90	90 mA
Output voltage	V_o	=	265	285	310	360 V

LIMITING VALUES

Input voltage	V_{tr}	= max.	2 × 350 V_{rms}
Output current	I_o	= max.	90 mA
Peak anode current (each anode)	I_{ap}	= max.	270 mA
Peak voltage between heater and cathode	V_{fkp}	= max.	500 V

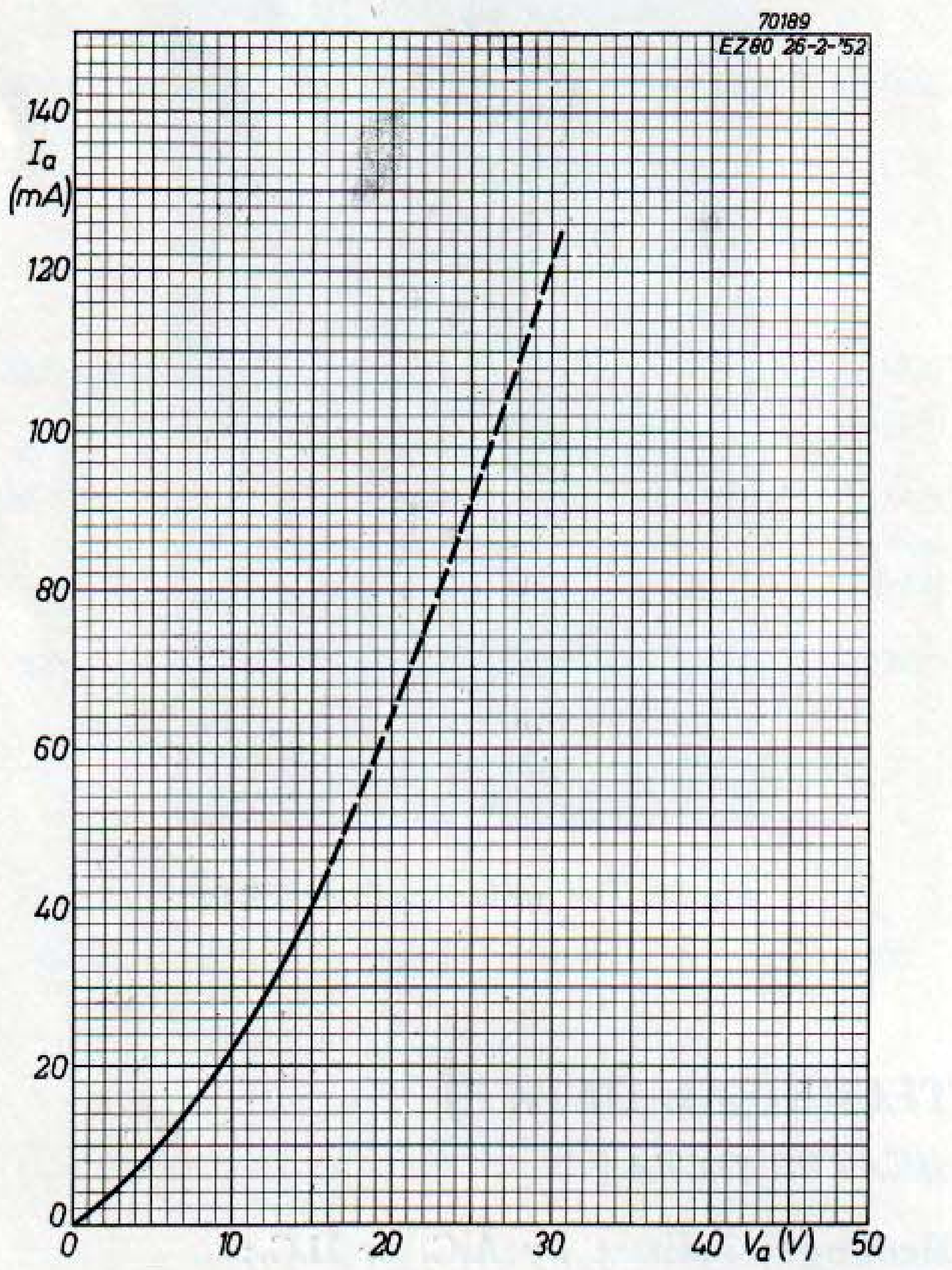


Fig. 61. Anode current of each anode plotted against anode voltage.

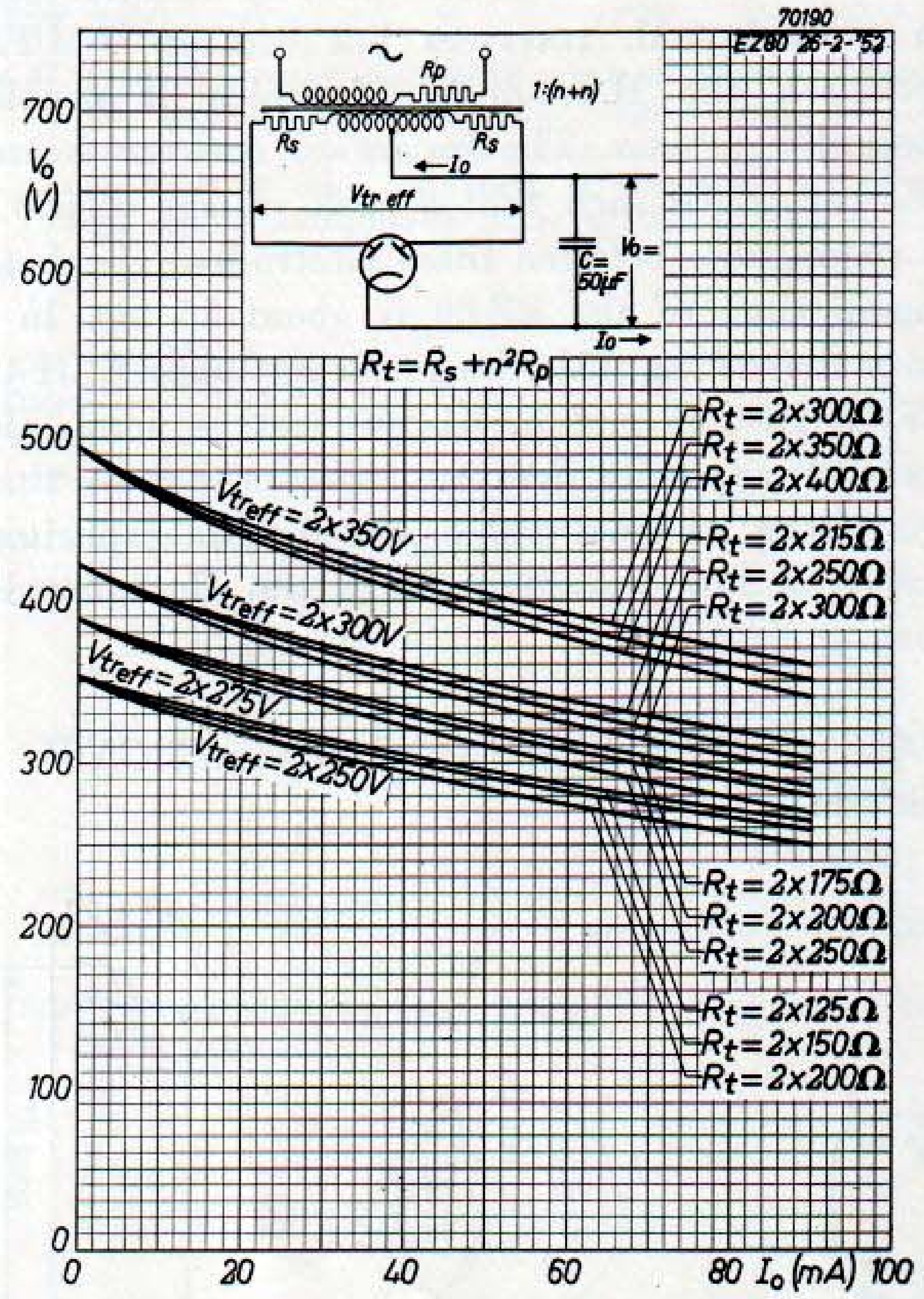


Fig. 62. Performance curves of the EZ 80.

CIRCUIT DESCRIPTIONS

DESCRIPTION OF A 5-TUBE AM/FM RECEIVER WITH TWO ECH 81 TUBES IN THE FRONT END AND CROSSWISE DISTRIBUTION OF FUNCTIONS FOR LOW RADIATION

INTRODUCTION

With the exception of the EC 92, this receiver employs the entire range of new tubes previously described. The tube layout and the functions performed at F.M. and A.M. reception respectively are given below.

Tube type	*Functions at F.M.*	*Functions at A.M.*
ECH 81 (I)	heptode as H.F. amplifier; triode not used (can be used as second A.F. amplifier).	heptode not used; triode as local oscillator.
ECH 81 (II)	triode as self-oscillating additive mixer; heptode as 1st I.F. amplifier.	triode not used; heptode as frequency changer.
EF 85	2nd I.F. amplifier.	I.F. amplifier.
EABC 80	two diodes as ratio detector; triode as A.F. amplifier; one diode not used.	one diode as detector; triode as A.F. amplifier; two diodes not used.
EL 41	output tube.	output tube.
EZ 80	mains rectifier.	mains rectifier.

It will be noticed that the functions in the front end are distributed crosswise, that is to say, the heptode section of the first ECH 81 is used as H.F. amplifier and the triode section of the second ECH 81 as self-oscillating additive mixer at F.M. reception. At A.M. the triode section of the first ECH 81 serves as local oscillator. Compared with the case where at F.M. the H.F. amplifier and the frequency changer are contained in one envelope (heptode and triode section of the ECH 81 (I)), the distribution of functions indicated here has the advantage that the capacitive coupling between the frequency changer and the aerial input circuit can be kept low, thus reducing radiation of the local oscillator voltage. In this receiver the radiation voltage measured at the aerial terminals (matched to a 75 Ω feeder) is about 2 mV, whereas when the triode section of the first ECH 81 tube is used as frequency changer the radiation voltage reaching the input circuit via capacitances between the tube sections is about 30 mV, also measured at the aerial terminals.

It is obvious that in order to keep radiation low attention must be paid to the wiring and the layout to avoid excessive stray capacitances between the frequency changer and the input circuit.

The circuit diagram of the complete receiver is given in fig. 65 *) The wave-range switch is drawn in the position for F.M. reception, the signal-frequency range being 88—100 Mc/s and the I.F. 10.7 Mc/s. The other positions of the switch are for the conventional short-wave, medium-wave and long-wave A.M. ranges respectively, operating with an intermediate frequency of 452 kc/s.

At F.M. the input signal required at the aerial terminals for 50 mW output is about 7 μV, for a frequency sweep of 2 × 15 kc/s. In the medium-wave range at A.M. the sensitivity is approx. 3 μV, also for 50 mW output and in this case for a modulation depth of 30%.

CIRCUIT DESCRIPTION

The operation of the receiver with A.M. is quite straightforward and calls for no special comment. The description is therefore almost entirely confined to the F.M. circuitry.

1. The H.F. stage

For calculating the gain of this stage it is first of all necessary to know the transfer impedance of the tuned anode circuit L_{11} (see fig. 65). This circuit is loaded by the input of the self-oscillating mixer (frequency changer), the H.F. signal being applied to a tap on the feedback coil L_{13}. The load can be represented by a resistor of 1 kΩ and

*) See fold-out on page 55.

a capacitor of 30 pF connected in parallel. It will be clear that this load influences the transfer impedance of the H.F. circuit and thus the gain of the H.F. stage.

When the frequency changer input is connected directly to the top of the H.F. circuit the total capacitance is increased, so that the capacitance in series with the tuning capacitor (5 — 25 pF) must have a comparatively high value to cover the required frequency range of 88 to 100 Mc/s. The use of a tap on the H.F. circuit has the advantage that the H.F. gain is increased, whilst it is easier to cover the required frequency range with the tuning capacitor of 5 — 25 pF. The various circuit constants are given in the table below as a function of the tapping ratio, for a signal frequency of 94 Mc/s.

Tapping ratio of L_{11}	0.3	0.45	0.5	1.0
Total capacitance of H.F. circuit	40	45	50	70 pF
Impedance of H.F. circuit	3.7	3.3	3.0	2.1 kΩ
Damping by frequency changer input	11	5	4	1 kΩ
H.F. circuit impedance, including extra damping	2.8	2.0	1.7	0.68 kΩ
Transfer impedance	0.85	0.90	0.85	0.68 kΩ

Although the optimum tapping ratio would be 0.45, for practical reasons a tap of 0.5 on L_{11} is used in the circuit of fig. 65, so that the gain of the stage measured between the control grid and the input of the frequency changer becomes $0.85 \times 2.4 = 2.1$, the mutual conductance of the heptode section of the ECH 81 being 2.4 mA/V. The gain measured between control grid and anode is 4.2.

As indicated above, the tuning range of the H.F. circuit is from 88 to 100 Mc/s, this range being adjusted at the low end with the series trimmer of 30 pF and at the high end with the parallel trimmer, which also has a maximum capacitance of 30 pF. The bandwidth (—3 db points) of the H.F. circuit is 2 Mc/s and the total capacitance varies from 44 to 57 pF within the frequency range.

The control-grid circuit of the H.F. stage is fixed tuned, the bandwidth is 12 Mc/s with the aerial disconnected (resonant frequency 94 Mc/s) and the total capacitance 12 pF. At resonance the circuit impedance is 4 kΩ and with an input impedance of the tube of 1.5 kΩ this gives an effective impedance of 1.1 kΩ. Assuming the input circuit to be matched to a feeder having a characteristic impedance of 75 Ω, the ratio between the signal voltage at the control grid and the e.m.f. in the feeder for optimum power transfer would be:

$$\tfrac{1}{2}\sqrt{\frac{1100}{75}} = \frac{3.8}{2} = 1.9,$$

and this would correspond to a transformer ratio of 1 : 3.8. Owing to positive feedback occurring in this stage via the impedance between anode and control grid, the transformer ratio can be chosen higher [11]).

At low frequencies the impedance between anode and control grid of the heptode section can be represented by a positive capacitance, but when the frequency is increased, as a result of transit time effects and self-inductance of electrode leads, the capacitance decreases, until, at a given frequency, it becomes zero. At still higher frequencies the coupling between anode and control grid can be represented by a negative capacitance. When the transit time in the tube is negligibly small, the response curve is distorted asymmetrically, but when the phase angle between the signal voltage at the control grid and the alternating anode current is 90°, which is the case with the heptode at a frequency of 100 Mc/s, the distortion is symmetrical. With a negative feedback capacitance the feedback is then positive over the entire frequency range, so that the gain is increased. This increase in gain can be taken into account as an increase of the impedance of the input circuit. At a frequency of about 100 Mc/s the capacitance between anode and control grid of the heptode is —0.14 pF and this results in an increase of circuit impedance from 1.1 to 1.8 kΩ. The transformer ratio between the feeder and the grid circuit for optimum power transfer should then be $\sqrt{\frac{1800}{75}} = 4.9$.

Since the gain of the H.F. stage is 2.1 the voltage gain between the feeder input and the input of the mixer becomes $4.9 \times 2.1 = 10$.

It will be clear that the feedback decreases with the gain of the tube, thus when the mutual conductance is reduced as a result of the A.G.C. applied to the first and third grids of the heptode. Combined control on g_1 and g_3 is applied to obtain a rapid variation of the gain. The input damping also depends upon the mutual conductance of the heptode, the damping decreasing with decreasing mutual conductance. In fig. 66 the impedances of

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[11]) *H. H. van Abbe, B. G. Dammers, J. Haantjes* and *A. G. W. Uitjens*, New Trends in AM/FM Receiver Design, Electr. Appl. Bull. *12*, p. 209, 1952 (No. 12).

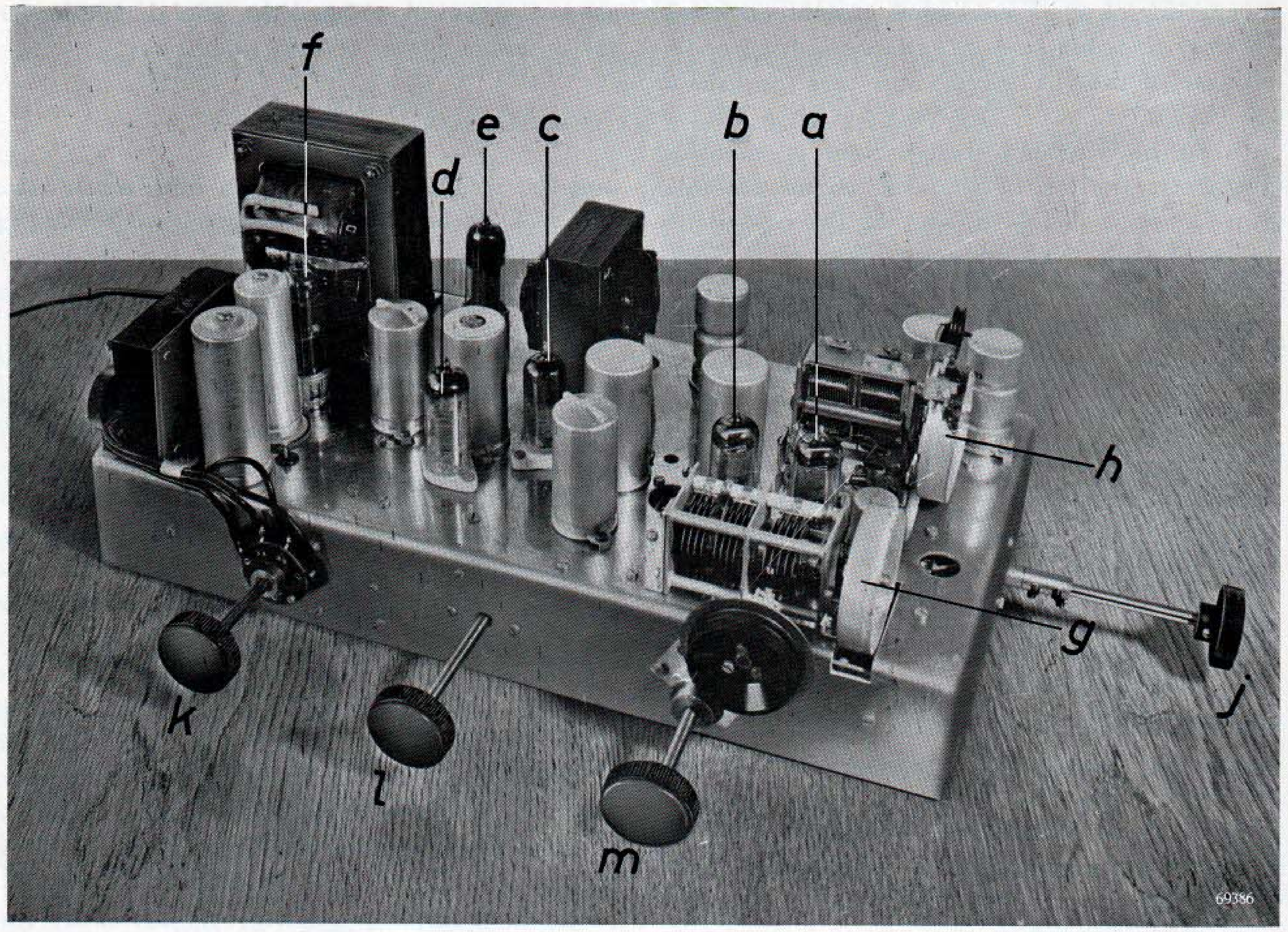


Fig. 63. Top view of an experimental AM/FM receiver with five tubes (plus rectifier). The first and second ECH 81 tubes are marked *a* and *b* respectively. The I.F. tube EF 85 is denoted by *c* and the EABC 80 by *d*. Finally, *e* and *f* indicate respectively the output pentode EL 41 and the mains rectifier. Two separate twin capacitors are used, *g* serving for the F.M. range and *h* for the A.M. ranges.
The following controls can be seen: *j* = wave-range switch, *k* = combined volume control and mains switch, *l* = bass response control (in this receiver the triode section of the first ECH 81 tube was used as second A.F. voltage amplifier, combined with a circuit for boosting the bass response) and *m* the tuning control for both variable capacitors.

the grid circuit without feedback Z_g and with feedback Z_g' are plotted against the mutual conductance for a frequency of 94 Mc/s, this being the frequency to which the grid circuit is tuned. In fig. 67 the ratio between the signal voltage at the control grid and the e.m.f. in the feeder is given as a function of frequency with the mutual conductance as parameter, for the case where the anode circuit is tuned to 94 Mc/s. Since the input damping decreases with the mutual conductance, when A.G.C. is applied the gain in the aerial circuit is increased, whilst, as a result of decreasing feedback the influence of the anode circuit upon the frequency response is reduced. The response of the grid circuit without feedback is almost flat.

2. The frequency changer

In this receiver a self-oscillating additive mixer circuit with the triode section of the second ECH 81 tube is used. As is the case with the H.F. circuit preceding the frequency changer, the oscillator circuit has been so arranged that one side of the tuning capacitor can be earthed. The oscillator is therefore anode tuned, the anode being parallel fed via the primary L_{14} of the I.F. transformer. Since the impedance of the oscillator circuit for the intermediate frequency is very low, the capacitor of 27 pF serves at the same time as tuning capacitor for the primary of the I.F. transformer and as coupling capacitor for the oscillator circuit. The I.F. is 10.7 Mc/s, so that the oscillator frequency must be varied from 98.7 to 110.7 Mc/s.

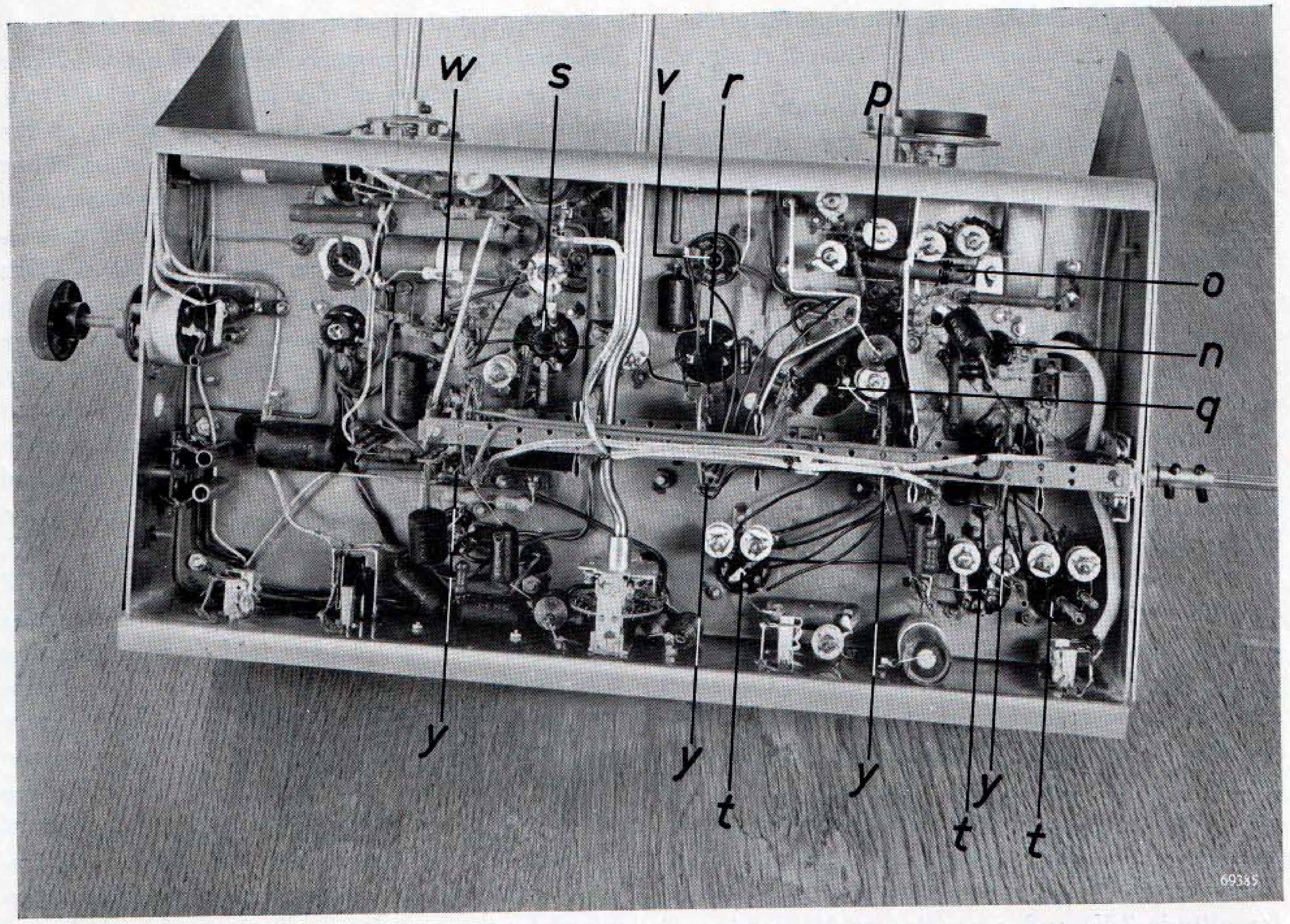


Fig. 64 Bottom view of the receiver shown in fig. 63. The switch sections are indicated by *y* and the input and oscillator circuits for A.M. by *t*. When, as in the circuit of fig. 65, the triode section of the first ECH 81 tube is not used as second A.F. voltage amplifier, the number of switch contacts is reduced. The input circuit for F.M. reception is denoted by *n*, the tuned anode circuit of the H.F. tube and the oscillator coils by *o* and *p* respectively. The two I.F. transformers for F.M. and the discriminator are marked *q*, *r* and *s* respectively.
Finally *v*, and *w* indicate the first and second I.F. transformers for A.M., whilst the tone control for high notes can be seen on the left.

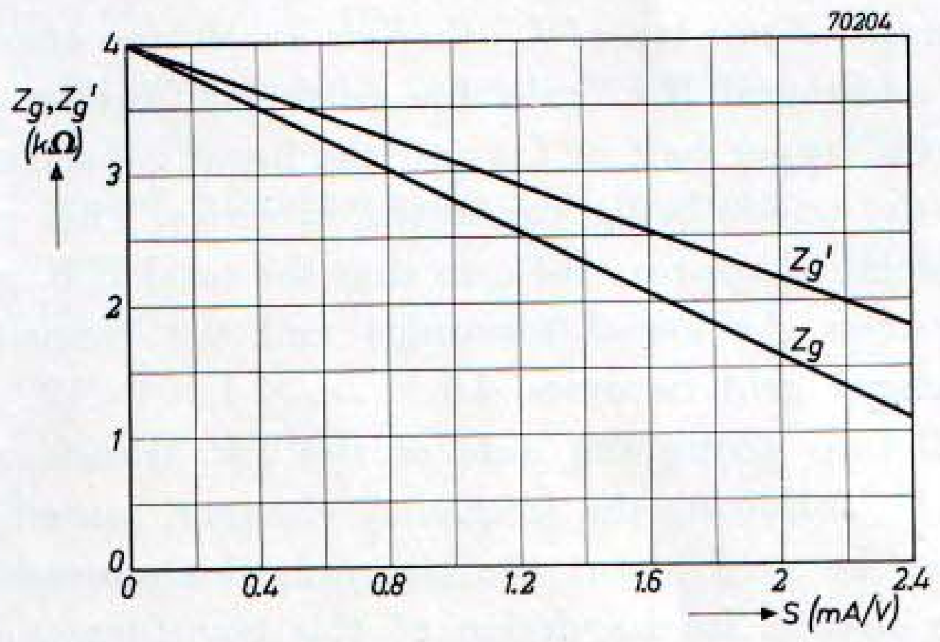


Fig. 66. Impedance of the grid circuit of the H.F. tube without feedback (Z_g) and with feedback (Z'_g) plotted against the mutual conductance for a frequency of 94 Mc/s (resonant frequency of input circuit).

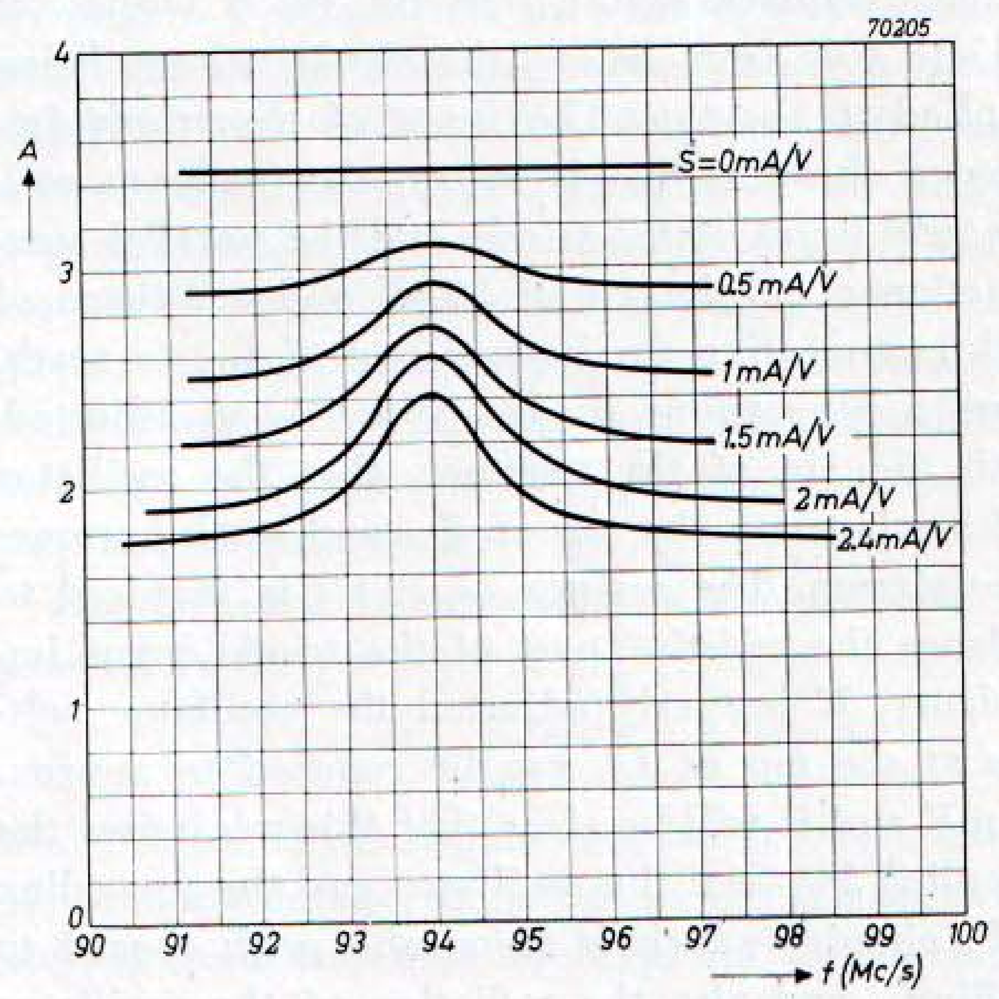


Fig. 67. Response of the input circuit, with the mutual conductance of the heptode as parameter.

The data of the oscillator circuit are as follows:

Tuning capacitance		5—25 pF
Series capacitance	approx.	30 pF
Parallel capacitance	approx.	20 pF
Impedance of tuned circuit (with feedback coil)	approx.	1.8 kΩ
Impedance of tuned circuit (including all extra damping)	approx.	1.2 kΩ

When the circuit oscillates the alternating voltage at the grid of the triode is 5 V and at the anode 6.5 V. The ratio of the grid and anode alternating voltages is usually expressed as a factor t, the modulus of which in this case is $5/6.5 = 0.75$. Disregarding tube capacitance and stray self-inductance, this figure determines the required transformer ratio between the oscillator coil L_{12} and the feedback coil (upper half of L_{13}). There is, however, additional feedback caused by the anode-to-grid capacitance of the triode and the stray self-inductance as measured at the top of L_{13}. In practice, therefore, the transformer ratio of the coils can be chosen somewhat smaller than 0.75.

In normal operation the direct current flowing in the grid leak of 22 kΩ is approx. 250 μA, which corresponds to an r.m.s. oscillator voltage of 5 V (amplitude 7 V) and a positive grid excursion of 1 to 2 V. Under these conditions the anode current is 5.8 mA and the effective mutual conductance 1.2 mA/V. This satisfies the oscillatory condition, according to which the product of effective mutual conductance, anode impedance and transformer ratio must be equal to unity.

The feedback coil L_{13} in fig. 65 is tapped at 0.55 to 0.60 from below, the signal voltage being applied to the tap. The input of the triode frequency changer, that is to say, the feedback coil, the grid input of the triode and the parallel combination of a trimmer of 30 pF and a resistor of 10 kΩ connecting the bottom end of L_{13} to earth, form a Wheatstone bridge, which is so adjusted, with the aid of the trimmer, that the oscillator voltage between the tap on L_{13} and earth becomes a minimum. The resistor of 10 kΩ is required to balance the resistive part of the triode input impedance. If properly adjusted the oscillator voltage at the tap of L_{13} can be reduced to approx. 50 mV and it will be clear that this minimizes the coupling between the oscillator and the preceding H.F. circuit (which is favourable with regard to pulling), and also the radiation of the oscillator voltage into the aerial.

As indicated above, provided the frequency changer input is properly balanced the oscillator voltage at the tap of L_{11} is approx. 50 mV, the same voltage being present at the anode of the heptode H.F. amplifier. The amount of oscillator voltage reaching the H.F. input is now determined by the potentiometer formed by the anode-to-control-grid capacitance and the input circuit. This potentiometer reduces the oscillator voltage by a factor of approx. 25, giving 2 mV oscillator voltage at the control grid of the H.F. stage. This, however, is a calculated value and does not take into account the effect of additional stray coupling. An oscillator voltage of 10 mV has actually been measured at the control grid, so that the radiation voltage at the aerial terminals becomes approx. 2 mV, corresponding to a power of $4 \times 10^{-6}/75 = 0.05\ \mu W$ when the aerial impedance is 75 Ω. This figure is far below the requirements laid down in existing anti-interference regulations and leaves adequate margin for tolerances occurring in wiring capacitance. This favourable result is largely due to the fact that the frequency changer and the H.F. tube are in separate envelopes. If the triode section of the first ECH 81 tube should be used as the frequency changer then the radiation would be determined by the capacitances between the triode and the control grid of the heptode. It can easily be shown that in this case the radiation voltage at the aerial terminals would be 15 times greater (30 mV), corresponding to a 225-fold increase in radiated power.

Returning now to the frequency changer circuit, it is to be pointed out that since the H.F. signal is applied to a tap of L_{13} there is a welcome amount of additional H.F. gain due to the self-inductance of the upper half of L_{13} and the input capacitance of the triode being connected in series. This gain amount to approx. 20%, so that the total H.F. gain between the aerial terminals and the frequency changer grid becomes $4.9 \times 2.1 \times 1.20 = 12$.

Before giving the data of the I.F. transformer $L_{14}L_{15}$ following the frequency changer, something must be said about the damping introduced by the circuit. In the design of this transformer the quality factors obtainable and the minimum permissible tuning capacitances form the limiting factors. It will be clear that the primary of the I.F. transformer $L_{14}L_{15}$ is damped by the effective internal resistance of the triode, which is reduced by the negative feedback occurring via the potentiometer formed by the anode-to-control grid capacitance and the impedance between grid and earth, the latter being capacitive for the intermediate frequency. In order to reduce the damping caused by the negative feedback the grid capacitor (120 pF) has been given the highest permissible value consistent with adequate safety against squegging. The total parallel damping due to the effects mentioned above amounts to 15 kΩ. The quality factor of the primary L_{14} of the I.F. transformer is also influenced by the tuned oscillator circuit, which is effectively in series with it. This results in an additional parallel damping of 24 kΩ. The data of the I.F. transformer $L_{14}L_{15}$ are given below.

Primary L_{14}	
Total tuning capacitance (of which 4 pF coil capacitance and 5 pF tube and tube-holder capacitance)	36 pF
Impedance at resonant frequency of 10.7 Mc/s ($Q = 85$)	35.5 kΩ
Parallel damping caused by frequency changer tube	15 kΩ
Parallel damping caused by oscillator circuit	24 kΩ
Effective primary circuit impedance Z_1	7.3 kΩ
Effective quality factor of primary Q_1	17.6
Secondary L_{15}	
Total tuning capacitance (of which 4 pF coil capacitance, 5 pF switch and wiring capacitance and 6 pF tube and tube-holder capacitance)	30 pF
Impedance at resonant frequency of 10.7 Mc/s ($Q = 100$)	50 kΩ
Parallel damping caused by switch and wiring	300 kΩ
Parallel damping caused by heptode input	150 kΩ
Effective secondary circuit impedance Z_2	33.5 kΩ
Effective quality factor of secondary Q_2	67
Primary and secondary $L_{14}L_{15}$	
Coupling KQ ($Q = \sqrt{Q_1 \cdot Q_2}$)	1
Transfer impedance $Z_t = \frac{KQ}{1 + (KQ)^2} \cdot \sqrt{Z_1 Z_2}$	7.8 kΩ
Output impedance $Z_o = \frac{Z_2}{1 + (KQ)^2}$	17 kΩ
Bandwidth at —3 db points	350 kc/s

Since the conversion conductance of the mixer triode is 1.2 mA/V, the conversion gain between the grid of the triode and the heptode would be $S_c \cdot Z_t = 1.2 \times 7.8 = 9.4$. This figure does not, however, take into account the feedback caused by the capacitance between the anode of the heptode and the anode of the triode. It would be possible to neutralize this feedback, but in production a much better consistency of the gain can be obtained by turning the feedback to advantage, i.e. by making it positive and decreasing the input impedance of the I.F. transformer following the heptode, so that stability is ensured, whilst the loss of gain caused by the reduction of input impedance is compensated by the remaining amount of positive feedback. This will be discussed at greater length in the following paragraphs.

3. The 1st I.F. stage

In an I.F. stage in which feedback occurs via the capacitance between anode and control grid, the response curve is distorted asymmetrically, because the current fed back to the input circuit is 90° out of phase with the alternating anode voltage, the impedance of the capacitance between anode and control grid being normally high compared with the impedance in the control-grid circuit. If, however, the feedback is not applied directly to the control grid, but to the primary of an I.F. transformer, the secondary of which is connected to the control grid, there will be an additional phase shift of 90° in the I.F. transformer, assuming that the signal frequency corresponds to the resonant frequency. The feedback then causes a symmetrical distortion of the response curve. These conditions apply to the circuit of fig. 65, where there is an interelectrode feedback capacitance of 0.22 pF between the anode of the heptode (primary L_{23} of second I.F. transformer) and the anode of the frequency changer triode (primary L_{14} of first I.F. transformer). The impedance of this capacitance is large compared with the input impedance of the first I.F. transformer.

The feedback at resonance is conveniently expressed by the factor:

$$p^2 = \omega \cdot C_{aHaT} \cdot S \cdot Z_i \cdot Z_t,\ ^{12})$$

where C_{aHaT} is the capacitance between the anode of the heptode and the anode of the triode, S the mutual conductance of the heptode, Z_i the input

[12]) See the article quoted in footnote 11).

impedance of the second I.F. transformer $L_{23}L_{24}$ and Z_t the transfer impedance of the first I.F. transformer $L_{14}L_{15}$ (both at resonance). It can be shown that the transfer impedance Z_t is apparently changed according to the formula:

$$Z_t' = \frac{Z_t}{1-p^2}.$$

It depends upon the sign of the factor p^2 whether Z_t' is greater or smaller than Z_t, i.e. whether the feedback is positive or negative. The factor p^2 is positive (positive feedback) when the secondary voltage of the first I.F. transformer leads 90° with respect to the primary input current, whilst it is negative (negative feedback) when there is a phase lag of 90°. It will be clear that the conversion gain is proportional to Z_t'.

As already indicated, the feedback can be compensated by applying neutralization, but in that case the factor p^2 is zero only for one given value of C_{aHaT}. When the tube is replaced by another having a slightly different capacitance C_{aHaT}, the resulting feedback either increases or decreases the gain, depending on whether the capacitance has become greater or smaller. The difference in gain is then determined by the absolute tolerances of the capacitance between the anode of the heptode and the anode of the triode, and the variation in gain is much larger than in the case where positive feedback is used intentionally, the variation then being determined by the relative tolerances in capacitance.

The standard deviation of the capacitance C_{aHaT} (0.220 pF) is ± 0.015 pF, i.e. the capacitance lies between these limits with two-thirds of all tubes. It may be calculated that with a second I.F. transformer having identical high-impedance primary and secondary circuits, and with neutralization of the feedback capacitance for an average tube, the variation in gain is between −19% and +30% when tubes having the standard deviation in capacitance are used without readjusting the neutralization. Without neutralization and with positive feedback the variation in gain resulting from the replacement of the triode-heptode is kept between −9% and +10%. This is a much smaller variation, whilst the circuit is simpler because components for neutralization are not required.

When positive feedback is used it is necessary to keep the input impedance of the second I.F. transformer $L_{23}L_{24}$ below a value where the stability of the stage might be impaired by the normal tolerances in the feedback capacitance C_{aHaT}. This is determined by the magnitude of the factor p^2 and in this receiver amounts to 0.57, at which value the total gain is the same as that which could be obtained in a circuit with neutralization. From the formula given for p^2 it may be calculated that the input impedance Z_i of the second I.F. transmust then be 2 kΩ, the transfer impedance Z_t of the first I.F. transformer being 7.8 kΩ, the mutual conductance of the heptode 2.4 mA/V and the capacitance C_{aHaT} 0.22 pF. The I.F. is 10.7 Mc/s and it is assumed that the two I.F. transformers are correctly tuned. When in the case of positive feedback the connections to the secondary L_{15} of the first I.F. transformer are reversed, the feedback becomes negative. It is, however, very easy to distinguish between positive and negative feedback, because the difference in gain is quite considerable.

With the feedback described above the effective transfer impedance of the first I.F. transformer becomes;

$$Z_t' = \frac{7.8}{1-0.57} = 18.2 \text{ k}\Omega,$$

which, when the conversion conductance of the frequency changer is 1.2 mA/V, gives a conversion gain between the grid of the triode and the control grid of the heptode of 1.2 × 18.2 = 22. Since the H.F. gain between the aerial terminals and the grid of the frequency changer triode is 12, the total gain is 12 × 22 = 264.

The shape of the response curve is changed by the feedback, and this change can be calculated by multiplying the original response curve of Z_t by the factor:

$$\frac{Z_t'}{Z_t} = \frac{1}{1 + j\omega C_{aHaT}\, S\, Z_i\, Z_t},$$

in which complex values, dependent upon the frequency, have to be substituted for Z_i and Z_t.

The characteristic data of the second I.F. transformer $L_{23}L_{24}$ are determined by the required input impedance with regard to feedback and by the secondary circuit impedance obtainable. The data are given below.

Primary L_{23}

Total tuning capacitance	115 pF
Impedance at resonant frequency of 10.7 Mc/s ($Q = 71$)	9.3 kΩ
Extra damping resistance	18 kΩ

Effective primary circuit impedance Z_1	6.1 kΩ
Effective quality factor of primary Q_1	46

Secondary L_{24}

Total tuning capacitante (of which 4 pF coil capacitance, 6 pF switch and wiring capacitance and 8 pF tube and tube-holder capacitance)	30 pF
Impedance at resonant frequency of 10.7 Mc/s (Q = 100)	50 kΩ
Parallel damping caused by switch and wiring	250 kΩ
Input resistance of EF 85 tube	80 kΩ
Effective secondary circuit impedance Z_2	27.5 kΩ
Effective quality factor of secondary Q_2	55

Primary and secondary $L_{23}L_{24}$

Coupling KQ $(Q = \sqrt{Q_1 \cdot Q_2})$	1.4
Transfer impedance Z_t	6 kΩ
Input impedance $Z_i = \frac{Z_1}{1+(KQ)^2}$	2 kΩ
Output impedance $Z_o = \frac{Z_2}{1+(KQ)^2}$	9 kΩ
Bandwidth at —3 db points	450 kc/s
Bandwidth at 0 db points	310 kc/s
Relative depth of dip with respect to peak of response	6 %

The mutual conductance of the heptode section of the second ECH 81 is 2.4 mA/V, so that the gain between the control grids of the EF 85 and heptode becomes $2.4 \times 6 = 14.4$. The total gain between the aerial terminals and the control grid of the EF 85 is therefore $264 \times 14.4 = 3800$.

A few remarks remain to be made about the operation of the heptode I.F. amplifier.

The feedback in this tube caused by the capacitance between the anode and the control grid has not been discussed so far. This feedback, however, is so small that it does not result in any change in gain or frequency response. A fixed bias of about 2 V is applied to the control grid. With A.M. reception the third grid is switched over to the grid of the local oscillator for A.M. (triode section of first ECH 81 tube). Simultaneously the anode supply of the frequency changer triode for F.M. is switched off and the screen-grid dropping resistance of the heptode reduced to compensate for the increase in screen-grid current. The H.F. signal is applied via conventional aerial circuits to the heptode, the A.G.C. then also being applied to this grid.

4. The second I.F. stage

In this stage the variable-mu pentode EF 85 is used. The mutual conductance of this tube is 6.0 mA/V and the capacitance between anode and control grid <0.007 pF. The input impedance of the discriminator in the anode circuit is 13.5 kΩ and this gives for the stage gain $5.5 \times 13.5 = 74$, the mutual conductance being slightly reduced from 6.0 mA/V to 5.5 mA/V by the non-bypassed cathode resistor of 18 Ω. The total gain between the aerial terminals and the primary of the discriminator is therefore $3800 \times 74 = 280{,}000$.

Since the EF 85 is a high-slope pentode attention must be paid to the stability. At F.M. and with the I.F. transformers used in the circuit diagram of fig. 65 (data of the discriminator will be given later) there is an adequate safety margin against instability. The feedback is determined by the factor $p^2 = \omega\, C_{ag}\, S\, Z_a\, Z_g$, in which C_{ag} is the capacitance between anode and control grid (<0.007 pF), S the mutual conductance (5.5 mA/V), Z_a the input impedance of the discriminator (13.5 kΩ) and Z_g the output impedance of the I.F. transformer in the grid circuit (9 kΩ). At centre frequency (10.7 Mc/s) therefore, the factor p^2 has the value 0.30, the critical value with regard to instability being 0.90.

An important point in the design of this stage is the variation in input capacitance of the tube caused by the automatic gain control. Also replacement of the tube will give rise to a deviation of the capacitance shunted across the secondary L_{24} of the I.F. transformer, because there is a certain spread in input capacitance between individual tubes. These two effects result in detuning of the secondary L_{24} of the I.F. transformer, so that the response curve measured at the primary L_{23} is changed and the positive feedback used in the preceding stage (heptode section of second ECH 81) is unfavourably influenced. A considerable detuning of the secondary may then lead to inadmissible distortion of the total response curve of the receiver and, in extreme cases, to instability. [13])

[13]) In the Addendum on p. 55 alternative data are given for the I.F. transformers $L_{14}L_{15}$ and $L_{23}L_{24}$, with which stability is ensured under all conditions of detuning.

In the circuit of fig. 65 the variation in input capacitance that might be caused by replacement of the tube is reduced by using automatic grid bias and a non-bypassed cathode resistor of 18 Ω. Moreover, the A.G.C. voltage is applied to the suppressor grid and not to the control grid, which, in combination with the non-bypassed cathode resistor, reduces the variation in input capacitance caused by the A.G.C. The suppressor grid is positively biased, thus providing for a delay in the automatic gain control of all tubes.

The means employed to avoid excessive input capacitance variations give rise to secondary effects. Owing to the presence of a non-bypassed cathode resistor of 18 Ω the mutual conductance of the tube is reduced from 6.0 mA/V to 5.5 mA/V. Moreover, the fact that the impedance of the cathode by-pass capacitor is not infinitely small results in a negative component of input resistance, which might lead to instability if the capacitance is not chosen sufficiently large. With the mica capacitor of 10,000 pF used in the circuit of fig. 65 the negative component of input resistance due to this effect is approx. —250 kΩ. The non-bypassed cathode resistor of 18 Ω, which is effectively in series with the capacitance between control grid and cathode, results in a positive component of input resistance, so that the total input resistance becomes positive. For the intermediate frequency with A.M. additional by-pass must by provided, which is done by means of a rolled paper capacitor of 0.1 μF.

With A.M. reception the A.G.C. can be applied to the control grid, the suppressor grid then also being used for the delay. To ensure stability, however, the control grid must be connected to a tap at 0.3 on the secondary of the I.F. transformer. Theoretically, the same result could be obtained by tapping the anode circuit, but the damping across the F.M. discriminator would thereby be increased.

The anode circuit of the EF 85 has been so arranged that no switching over is required for the I.F. circuits. With F.M. reception the primary L_{27} of the I.F. transformer for A.M. is used as a choke, through which the anode is parallel fed. The capacitor of 115 pF serves at the same time as coupling capacitor for the F.M. discriminator $L_{29}L_{30}L_{31}$ and as tuning capacitor with A.M. reception. With A.M. reception the primary of the discriminator is in series with the I.F. circuit, but this has only a negligible effect upon the tuning or the quality factor because at 452 kc/s the impedance of L_{29} is very small.

In order to facilitate measurement of the freqeuncy response of the receiver a resistor of 0.47 MΩ is connected to the primary of the discriminator. Between the terminal P and the receiver chassis a germanium diode, a capacitor of about 100 pF and a voltmeter can be connected in parallel, the meter then giving an indication of the I.F. voltage across L_{29}. This method prevents detuning of the discriminator, which would occur when an R.F. voltmeter is connected directly across the primary. The characteristic data of the discriminator are given below; constructional details are given under the heading "Component values".

Primary L_{29}

Total tuning capacitance	30 pF
Quality factor (without extra damping)	75
Effective quality factor in circuit Q_1	42
Effective primary circuit impedance Z_1	21 kΩ

Secondary L_{31}

Total tuning capacitance	40 pF
Quality factor (without extra damping)	115
Effective quality factor in circuit Q_2	25
Effective secondary circuit impedance Z_2	9.4 kΩ

Total discriminator

Coupling KQ ($Q = \sqrt{Q_1Q_2}$)	0.75
Input impedance Z_i	13.5 kΩ
Bandwidth at —3 db points	490 kc/s
Transformer ratio between L_{29} and L_{30}	5.9

The discriminator curve of the ratio detector is determined, among others, by the ratio of the voltages across L_{31} and L_{30}, which in this case is 2.9, by the transformer ratio between L_{29} and L_{30}, which is 5.9, and the coupling between L_{29} and L_{31} ($KQ = 0.75$). With a discriminator transformer according to the data given above good linearity and reasonable sensitivity are obtained. The output voltage in mV across the load may be expressed by the formula:

$$V_o = D\,V_i\,\triangle f,$$

where D is a constant, in this case 0.6, V_i is the I.F. input in volts across L_{29}, and $\triangle f$ the frequency deviation in kc/s. With an I.F. input voltage of 1 V and a frequency deviation of 15 kc/s the A.F. output voltage across the total load is therefore 9 mV.

5. Detection, A.G.C. and A.F. amplification

In this receiver a ratio-detector circuit operating with the diodes d_2 and d_3 (see base diagram) of the EABC 80 is used. The remaining diode d_1, having a higher internal resistance, is used for A.M. detection. It is well known that for a favourable limiting action of the ratio detector it is necessary that the internal resistances of the diodes (d_2 and d_3) do not differ greatly. In the design of the EABC 80 special care has been taken to obtain identical characteristics for small currents, the ratio between the internal resistances being smaller than 1.5. Moreover, in the circuit a non-by-passed resistor of 47 Ω is connected in series with the tertiary coil L_{30}, which partly compensates for unequal internal resistances. This resistor is followed by a de-emphasis network (39 kΩ and 2200 pF), after which the detected A.F. voltage is applied to a volume control of 0.5 MΩ, followed by a continuously adjustable tone-control circuit for the high notes. The switching over to A.M. detection will be clear from the circuit diagram. The A.M. diode (d_1) is connected to a tap of 0.7 on the secondary of the I.F. transformer $L_{27}L_{28}$.

For 50 mW A.F. output a signal of 18 mV is required at the grid of the EABC 80. With a frequency sweep of 2 × 15 kc/s this corresponds to an I.F. signal at the primary of the discriminator of approx. 2.0 V. Since the total gain between the aerial terminals (75 Ω) and the primary of the discriminator is 280,000, the sensitivity of the receiver with F.M. reception is approx. 7 μV. It may easily de calculated that with A.M. reception a sensitivity of 3 μV is reached.

With F.M. reception the control voltage for the A.G.C. is obtained from the limiter (27 kΩ, 10 μF) and applied to the suppressor grid of the EF 85 via a resistor of 1 MΩ. The suppressor grid is positively biased via a potentiometer across the H.T. supply (56 kΩ and 22 kΩ) and a series resistor of 5.6 MΩ. This results in a delay of the control; the A.G.C. curve is given in fig. 68. The correct potentials at zero signal for the grids of the preceding tubes are obtained by means of a potentiometer circuit between the suppressor grid of the EF 85 and a bias source of approx. —7 V in the power supply unit.

With A.M. reception the control voltage is derived from the detector diode, the suppressor grid of the EF 85 then also being used for the delay.

The A.F. section of the receiver is entirely conventional. It has already been indicated that for 50 mW output a signal voltage of 18 mV is required at the grid of the EABC 80 triode. This triode has a voltage gain of 50, so that the sensitivity at the control grid of the EL 41 is 0.9 V. This sensitivity depends upon the negative feedback and applies for a speech coil impedance of 5Ω. Care should be taken in the wiring around the EABC 80 to keep the capacitances between the triode and the diode sections as small as possible.

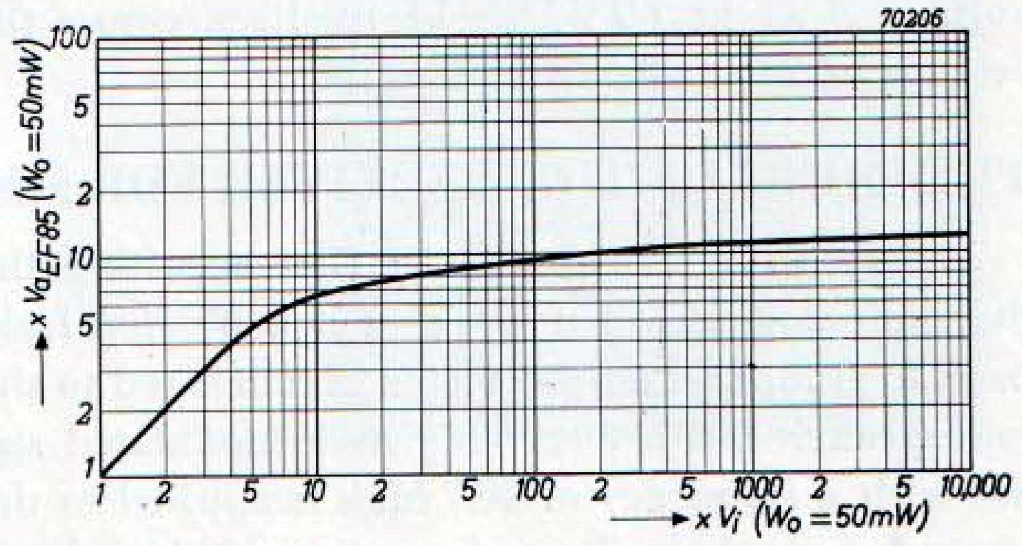


Fig. 68. A.G.C. curve when the receiver is switched for F.M. reception.

With the A.F. circuit given in fig. 65 adequate total sensitivity and sufficiently low A.F. distorcion can be obtained. It may, however, be desired to boost the bass response and this, according to the amount of bass boost required, involves some sacrifice of A.F. gain for the centre of the audio frequency range. The total sensitivity corresponding to a modulation frequency of 800 c/s would then be reduced. This can be avoided by using the triode section of the first ECH 81 tube (local oscillator with A.M. reception) as second A.F. amplifier between the EABC 80 and the EL 41 when the receiver is switched for F.M. reception [14]). The additional A.F. gain provided by this triode then permits of a bass boost of 14 db at 50 c/s, whilst a greater amount of negative feedback can be applied. A total sensitivity of about 4 μV can then be obtained at F.M. It will be clear that the use of the triode section of the first ECH 81 tube as A.F. amplifier makes the circuit more complicated.

6. Power supply

The power supply unit should give a rectified voltage of 275 V across the reservoir capacitor at a rectified current of 85 mA. In order to prevent the occurrence of excessive peak currents in the rectify-

[14]) See the article quoted in footnote 11).

ing tube the effective resistance of each half of the H.T. winding should be at least 175 Ω. This is the sum of the resistance of one half of the H.T. winding and the transformed primary resistance.

With the EZ 80 rectifying tube the maximum permissible peak voltage between cathode and heater is 500 V. This makes is possible to feed all heaters from one common winding.

The bias voltage is obtained by means of resistors in the negative supply line (60 + 23.5 Ω). The latter resistance can be obtained by connecting two resistors of 47 Ω in parallel. The total bias voltage is about 7.0 V, the bias voltage across the resistor of 23.5 Ω being 2 V.

TRIMMING OF THE RECEIVER FOR F.M.

The receiver is trimmed by first adjusting the discriminator and then working step by step from back to front. An output meter is connected to the loudspeaker and a 30% amplitude-modulated signal with a frequency of 10.7 Mc/s is applied to the control grid of the heptode section of the second ECH 81 tube. For correct adjustment at maximum limiting of the discriminator it is necessary to short-circuit the secondary L_{15} of the first I.F. transformer and to detune the primary and the secondary (L_{23} and L_{24}) of the second I.F. transformer by means of shunting capacitors of, say, 270 pF. The primary L_{29} of the discriminator is then tuned for maximum A.F. output and after that the secondary for minimum A.F. output. Then the detuning capacitor is removed from L_{23} and this coil tuned for maximum output, after which L_{24} can be dealt with in the same way. The input signal is then applied to the tap on the oscillator coil L_{13}. When the short-circuiting lead is removed from L_{15} the primary and the secondary of the first I.F. transformer $L_{14}L_{15}$ can be trimmed in turn. The total I.F. response can be corrected by retuning the secondary L_{24} of the second I.F. transformer.

Before commencing with the trimming of the oscillator and H.F. circuits the oscillator should be balanced for minimum radiation. This is done by means of the trimmer of 30 pF in series with the feedback coil L_{13}. A grid-current meter must be connected in series with the grid leak of 22 kΩ and the trimmer is so adjusted that short-circuiting of the tap on L_{13} against the chassis does not produce a variation in grid current. It is also possible to measure the oscillator voltage at the tap of L_{13} by means of a well-screened and sensitive diode voltmeter.

For trimming the oscilator and H.F. circuits use can be made of an oscillograph and a frequency-modulated signal generator having a total frequency sweep of about 0.5 Mc/s. The input terminals of the oscillograph are connected between the chassis and the point *P* terminating the resistor connected to the primary L_{29} of the discriminator. Between the point *P* and the chassis of the receiver a high-vacuum or germanium diode is connected. When the frequency-modulated signal is applied to the aerial terminals the total response curve of the receiver can be made visible on the oscillograph. The tuning capacitor for F.M. is adjusted to minimum capacitance and the signal generator at 100 Mc/s. With the trimmer of 30 pF in parallel to L_{12} the oscillator is then tuned such that the response curve appears in the centre of the cathode-ray tube screen. Thereafter the signal frequency is changed to 88 Mc/s and the tuning capacitor adjusted to maximum capacitance. The oscillator circuit is then tuned as before with the aid of the 30 pF trimmer in series with the tuning capacitor. It is then necessary to readjust the compensation (trimmer in series with L_{13}) preferably at a signal frequency of 94 Mc/s.

After adjusting the required frequency range as described above the H.F. circuits can be trimmed. The signal frequency is adjusted to 88 Mc/s and the receiver tuned such that the total response curve is in the centre of the cathode-ray tube screen. The H.F. circuit L_{11} is then trimmed to maximum height of the response curve with the aid of the 30 pF trimmer in series with the tuning capacitor. It is then necessary to check the oscillator frequency range, which might have been influenced by the trimming of the preceding H.F. circuit. After that the trimming of the H.F. circuit L_{11} can be completed by adjusting the signal frequency to 99 Mc/s and trimming for maximum height of the response curve on the oscillograph, with the aid of the trimmer in parallel to L_{11}. Finally, the aerial circuit L_2 is trimmed with the iron-dust core at a signal frequency of 94 Mc/s.

RESPONSE CURVES

In this part of the description a large number of response curves are given which have been obtained with the aid of an oscillograph and a frequency-modulated signal generator in the manner described in the previous section. The modulation frequency is 50 c/s.

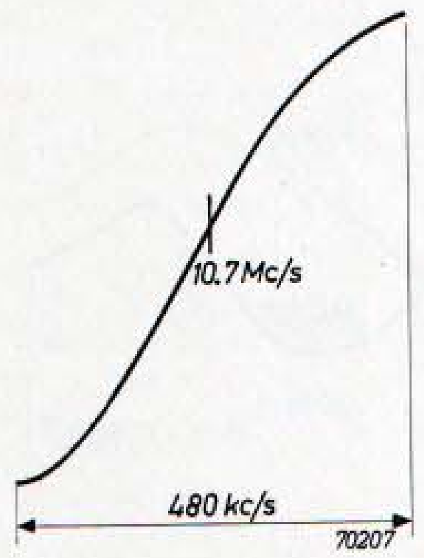
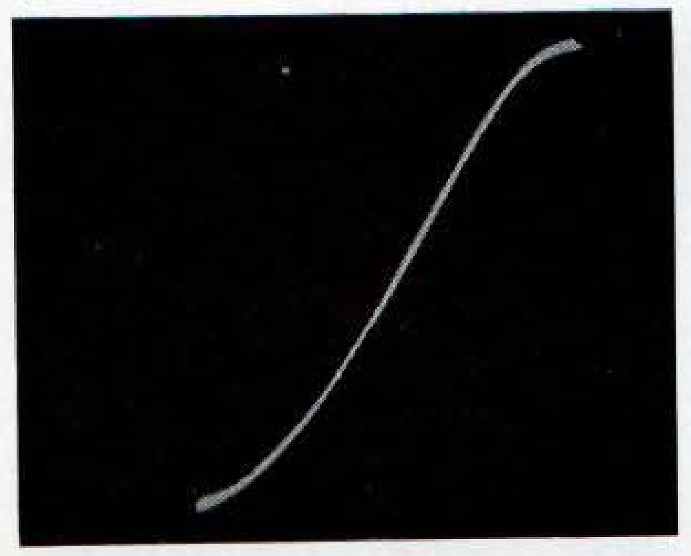


Fig. 69. Discriminator curve. Input signal applied to control grid of EF 85. Oscillograph across volume control.



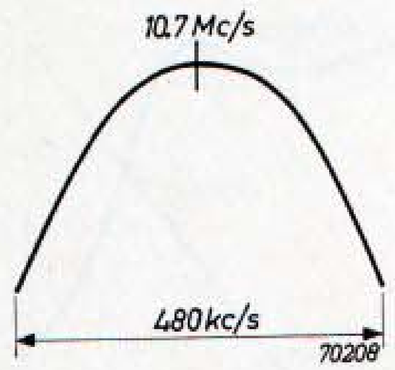
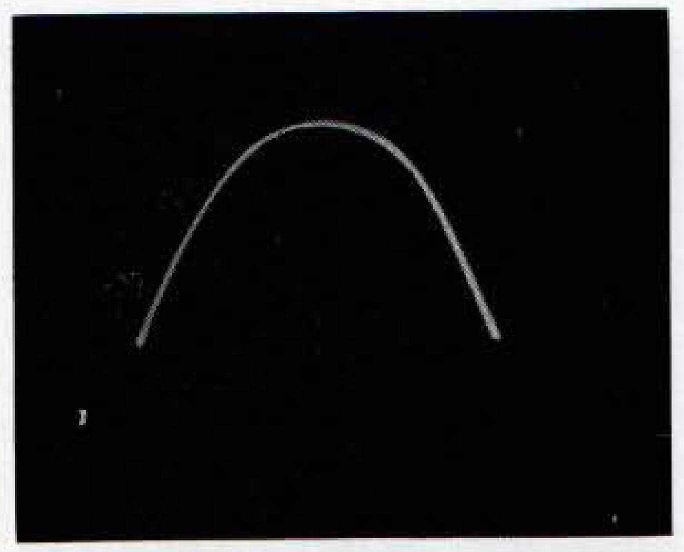


Fig. 70. Input impedance of discriminator. Input signal applied to control grid of EF 85. Oscillograph connected to point *P* on discriminator.



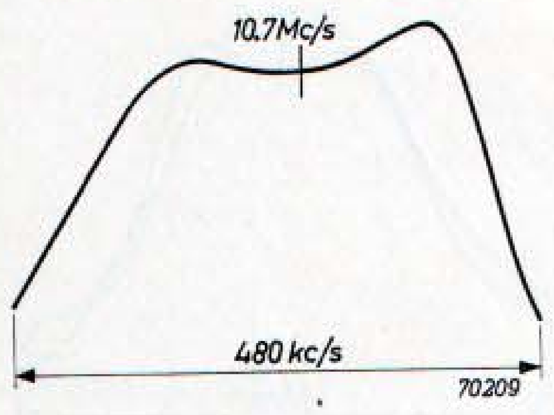
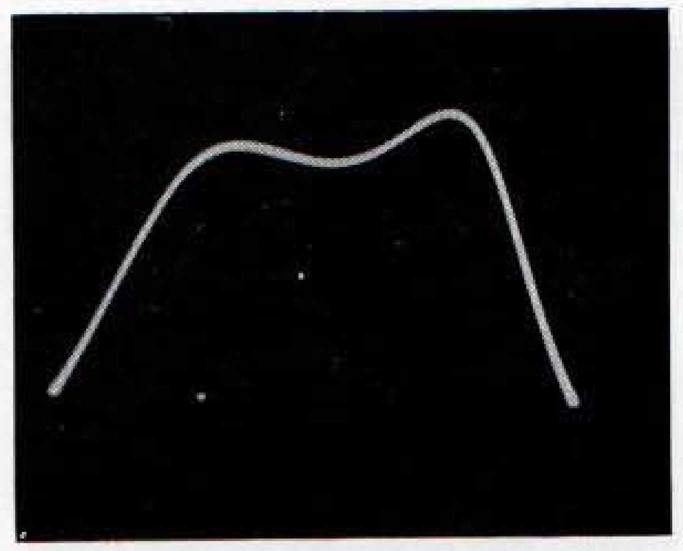


Fig. 71. Transfer impedance of second I.F. transformer $L_{23}L_{24}$. Input signal applied to control grid of heptode section of second ECH 81 tube. Oscillograph connected to point *P* on discriminator and primary L_{29} damped with 1 kΩ.



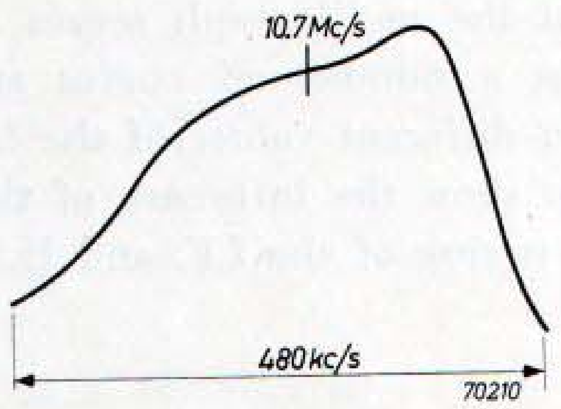
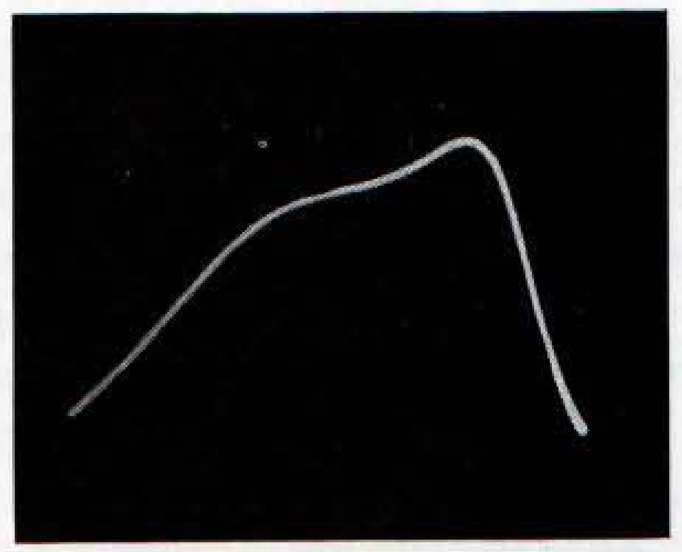


Fig. 72. Total response of second I.F. transformer and primary of discriminator. Input signal applied to control grid of heptode section of second ECH 81 tube. Oscillograph connected to point *P* on discriminator.



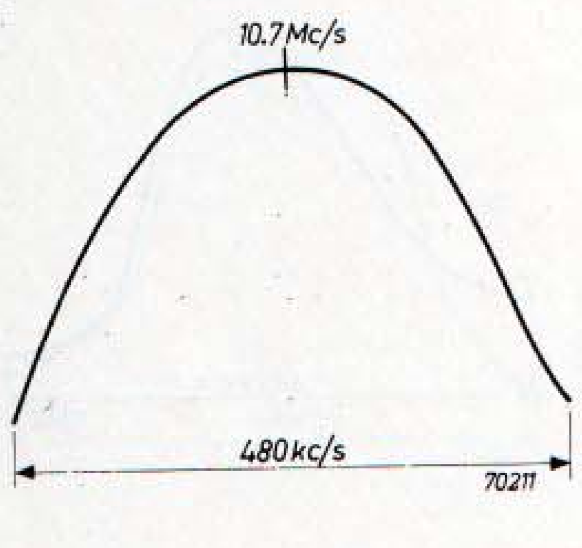
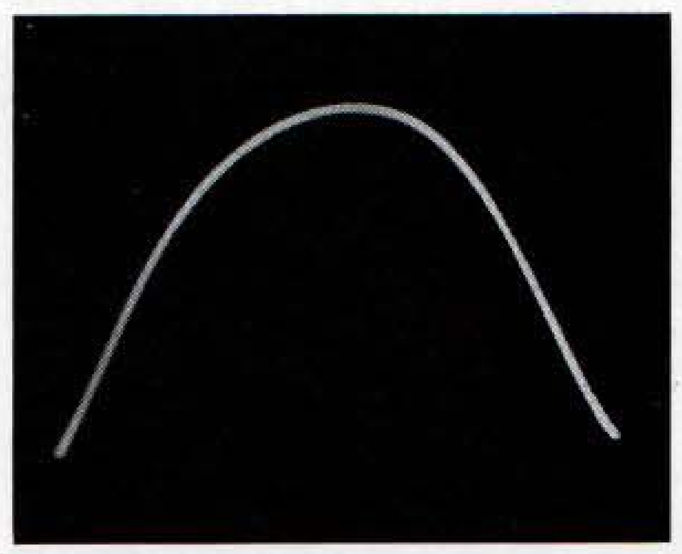
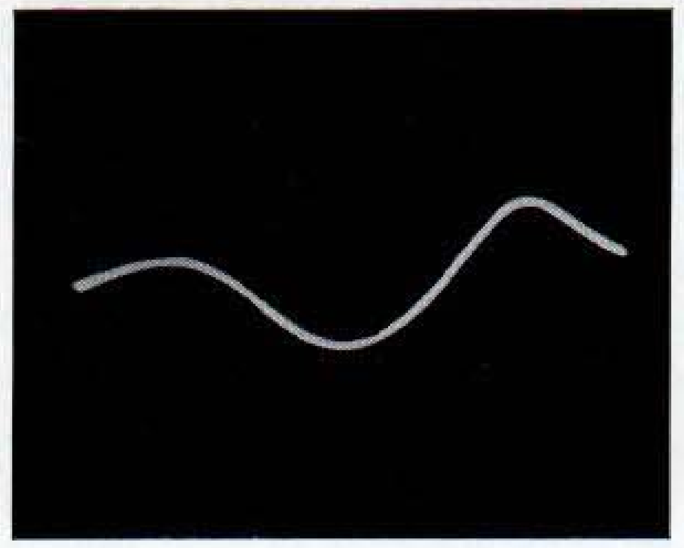


Fig. 73. Transfer impedance of first I.F. transformer $L_{14}L_{15}$. Input signal applied to tap on oscillator coil L_{13}. Oscillograph across secondary via a capacitor of 0.8 pF and a diode across its input terminals.





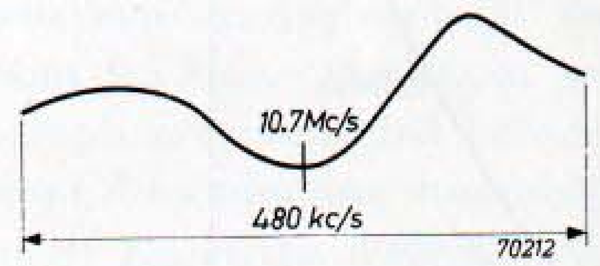
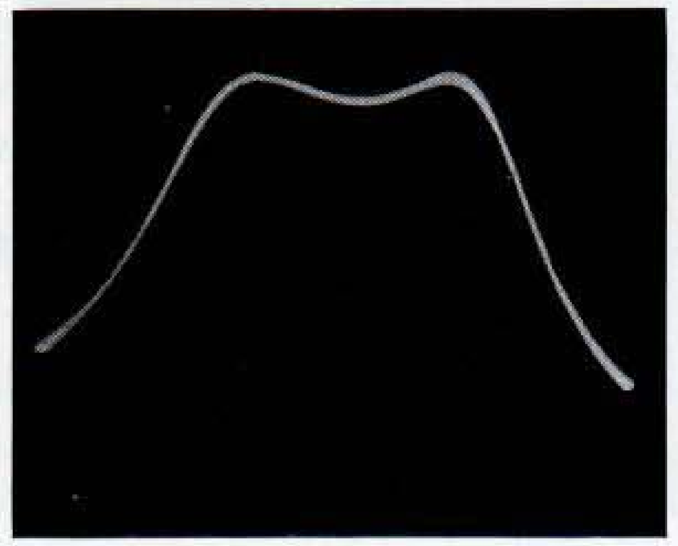


Fig. 74. Input impedance of second I.F. transformer. Input signal applied to control grid of heptode section of second ECH 81 tube. Oscillograph via a capacitor of 0.8 pF across L_{23}. Input terminals of oscillograph shunted by a diode.



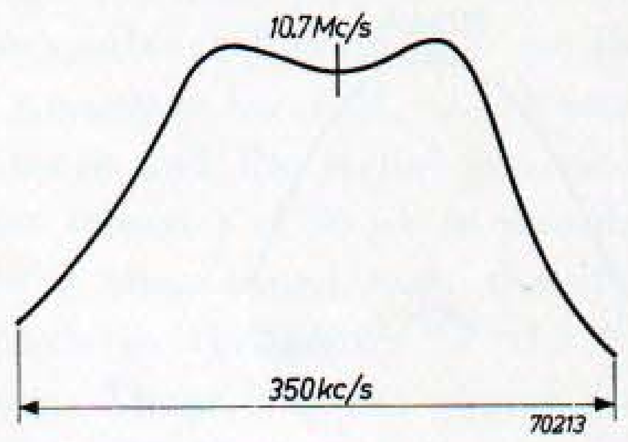
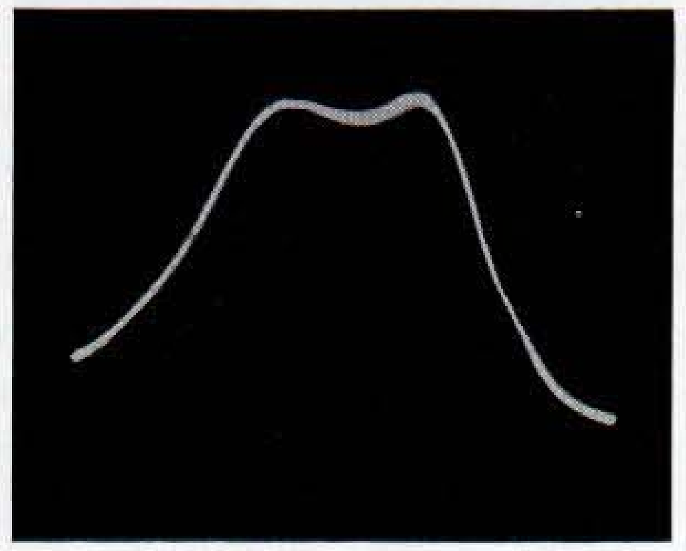


Fig. 75. Total response of first and second I.F. transformers. Input signal applied to tap on oscillator coil L_{13}. Oscillograph connected to point *P* on the discriminator. Primary of discriminator damped with 1 kΩ.



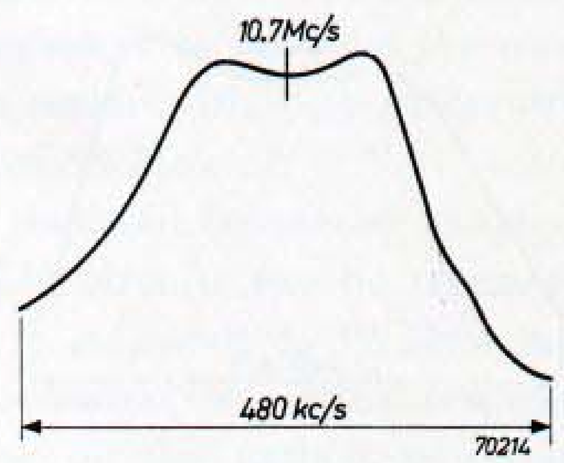
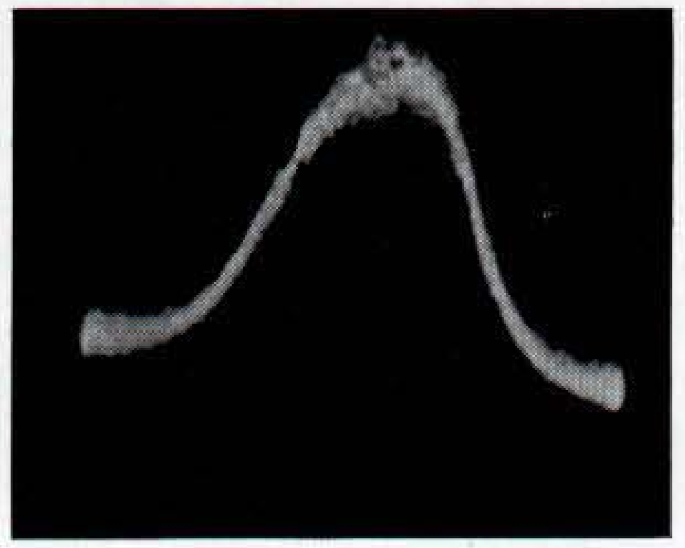


Fig. 76. Total response of first and second I.F. transformers and input of discriminator. Input signal applied to tap on oscillator coil L_{13}. Oscillograph connected to point *P* on discriminator.

The following overall response and discriminator curves have all been obtained by applying the signal to the input terminals of the receiver, the oscillograph being connected to point *P* on the discriminator. Al diode is connected between point *P* and the chassis, whilst the capacitance of the screened input lead of the oscillograph serves as charge capacitor. First a number of curves are given corresponding to different values of the input signal, in order to show the influence of the A.G.C. voltage on the tuning of the I.F. and H.F. circuits.



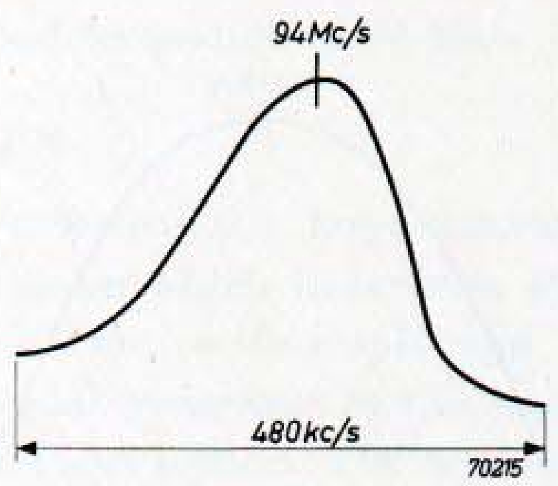


Fig. 77. Overall response at maximum sensitivity and a signal frequency of 94 Mc/s.

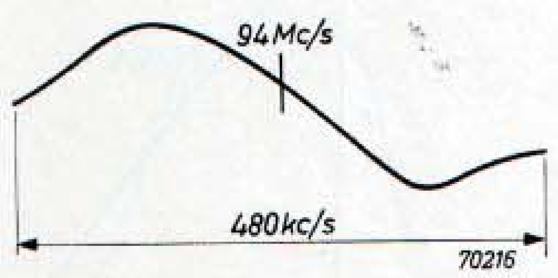
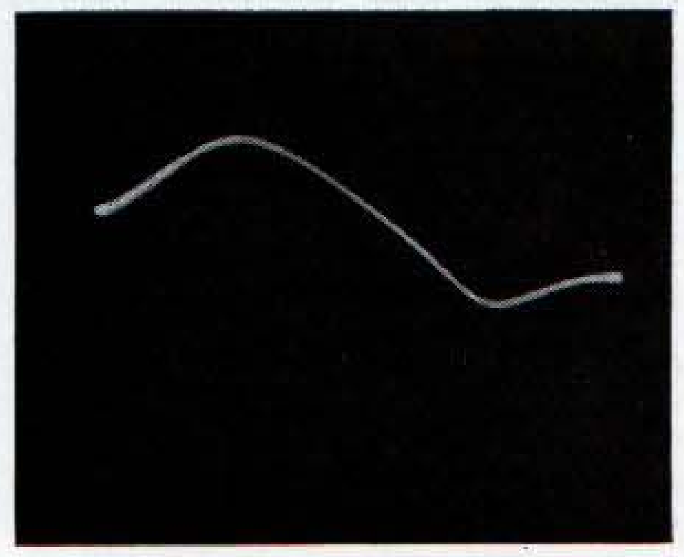


Fig. 78. Overall discriminator curve at maximum sensitivity and a signal frequency of 94 Mc/s. The frequency sweep is 480 kc/s.



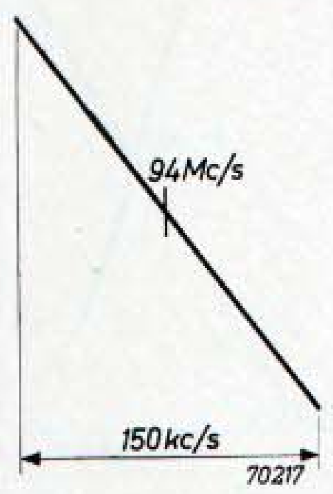
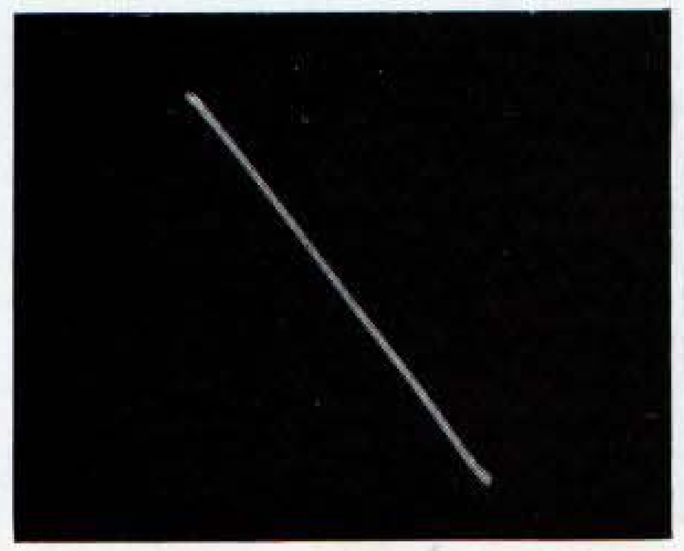


Fig. 79. The same curve as in fig. 78 but for a frequency sweep of 150 kc/s.



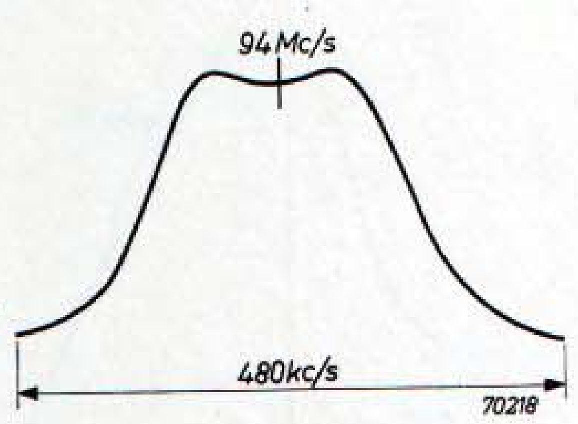
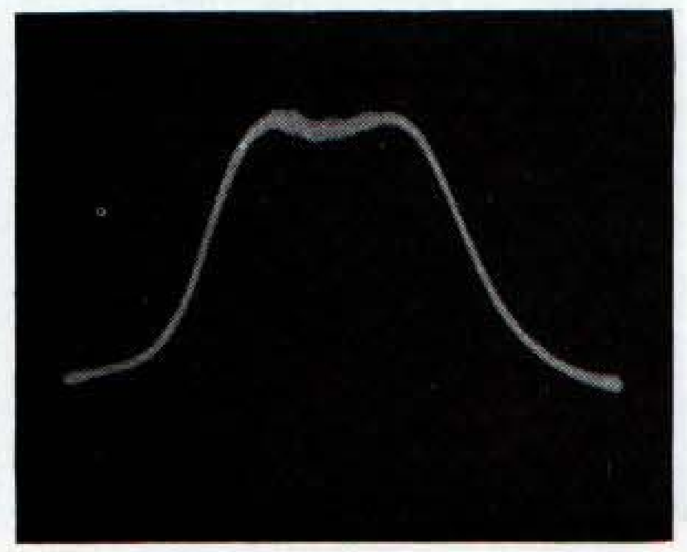


Fig. 80. Overall response curve with an input signal of 25 μV and a signal frequency of 94 Mc/s.



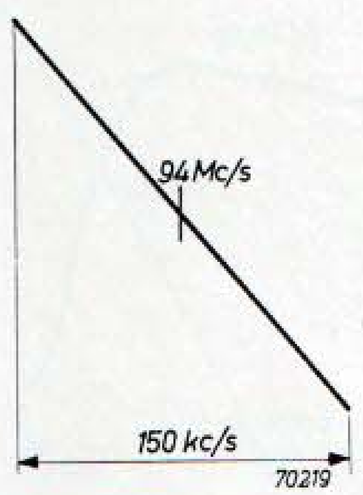
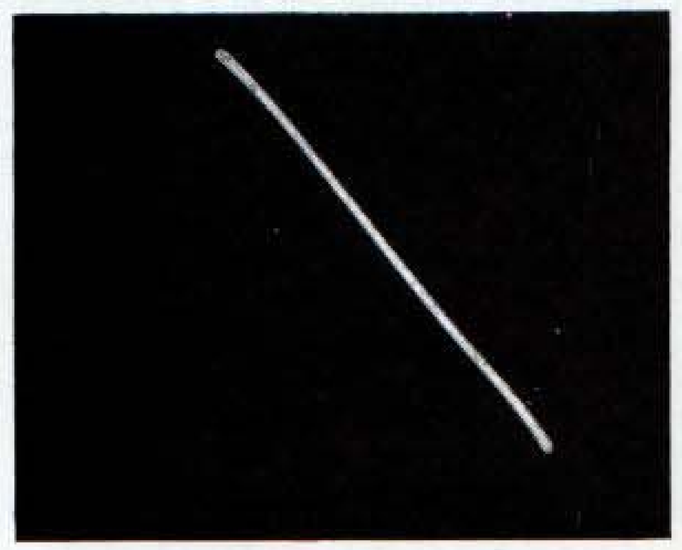


Fig. 81. Overall discriminator curve corresponding to fig. 80.



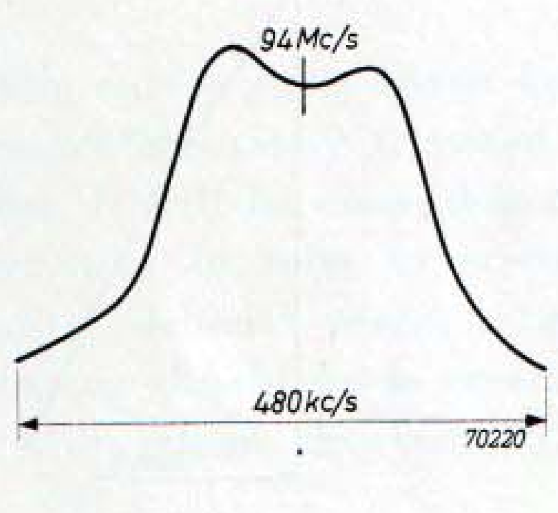
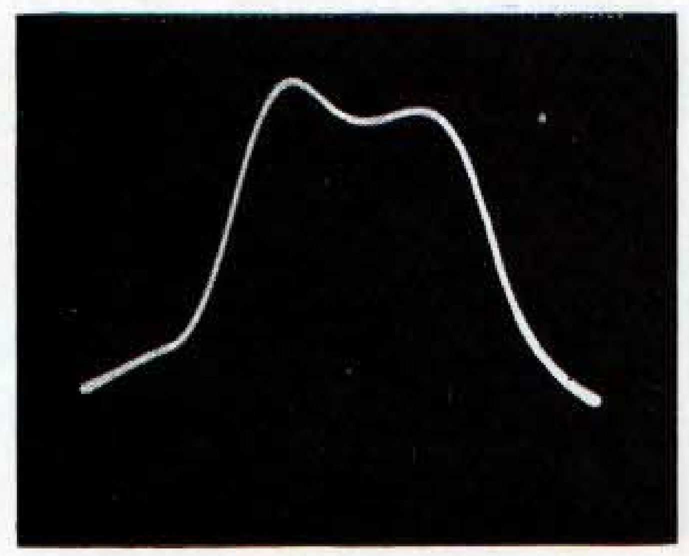


Fig. 82. Overall response curve with an input signal of 250 μV and a signal frequency of 94 Mc/s.



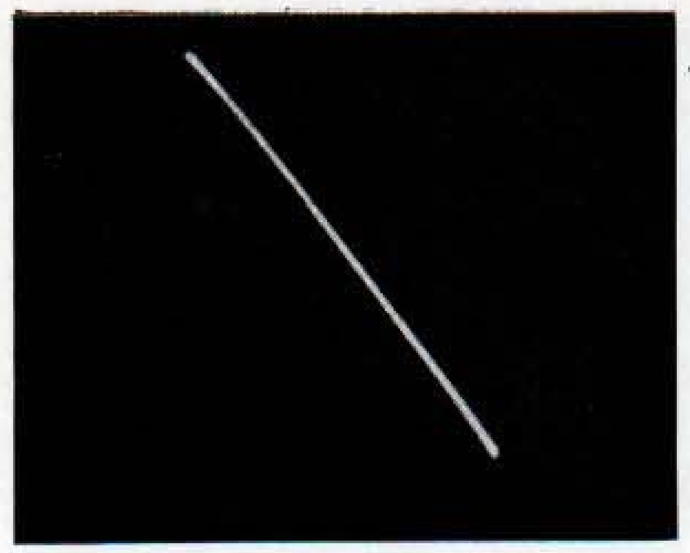
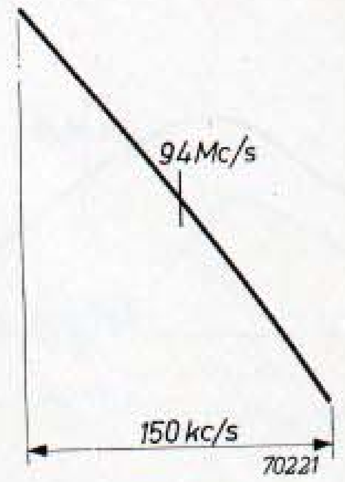


Fig. 83. Overall discriminator curve corresponding to fig. 82.



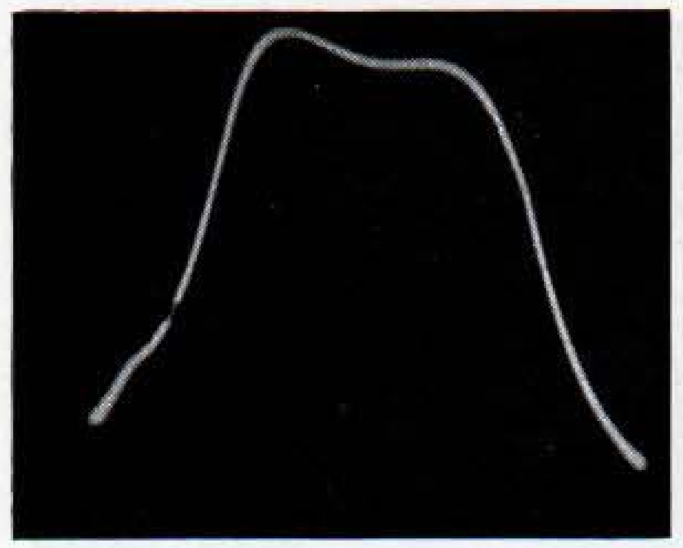


Fig. 84. Overall response curve with an input signal of 2.5 mV and a signal frequency of 94 Mc/s.

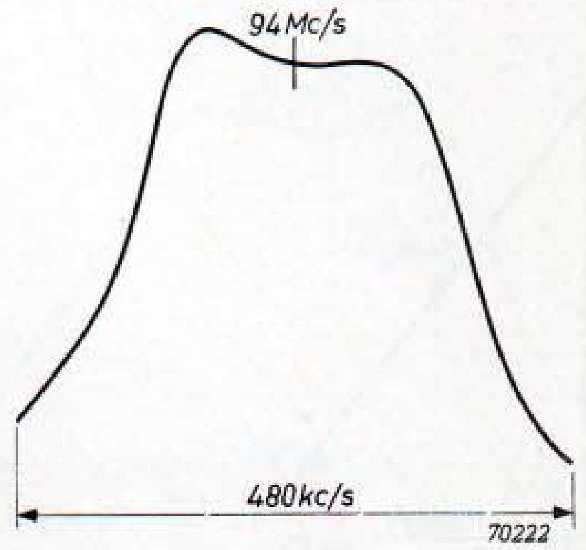
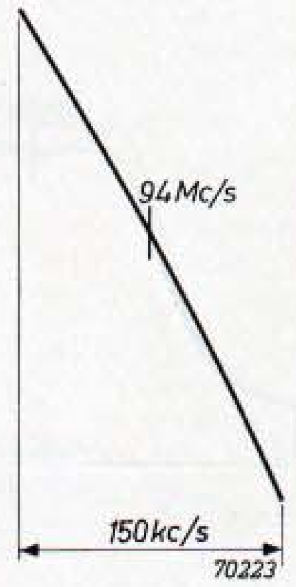


Fig. 85. Overall discriminator curve corresponding to fig. 84.



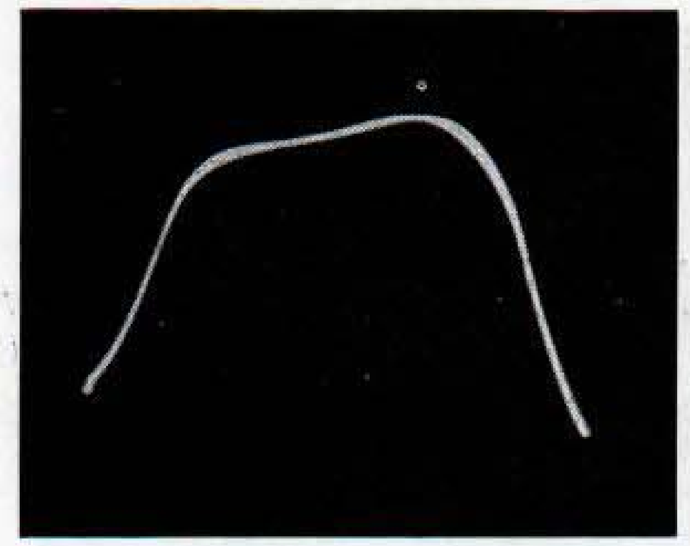
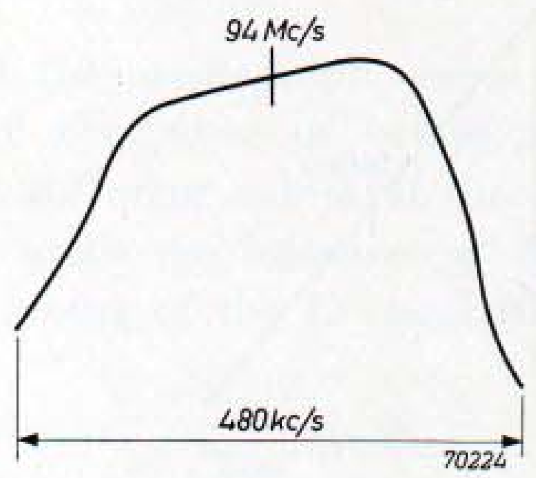


Fig. 86. Overall response curve with an input signal of 25 mV and a signal frequency of 94 Mc/s.



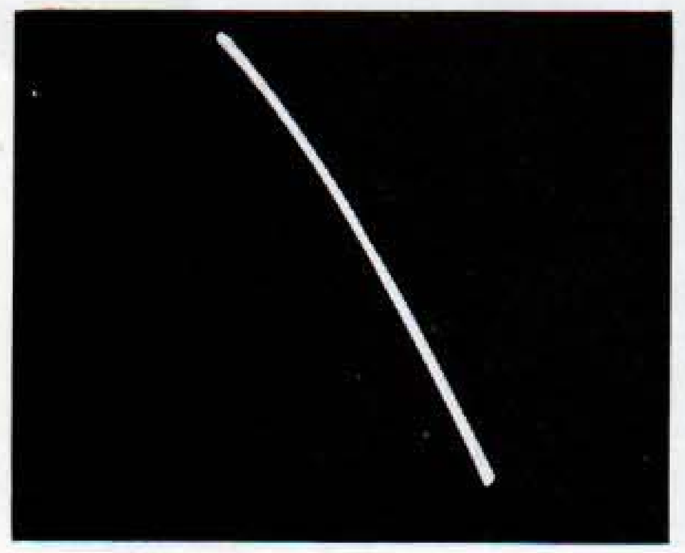
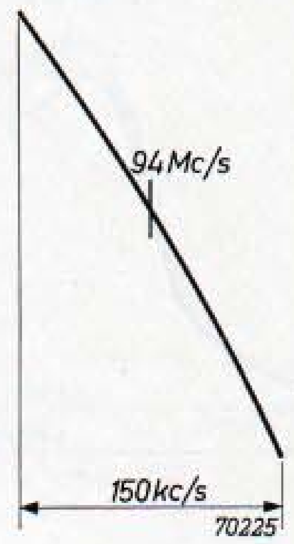


Fig. 87. Overall discriminator curve corresponding to fig. 86.



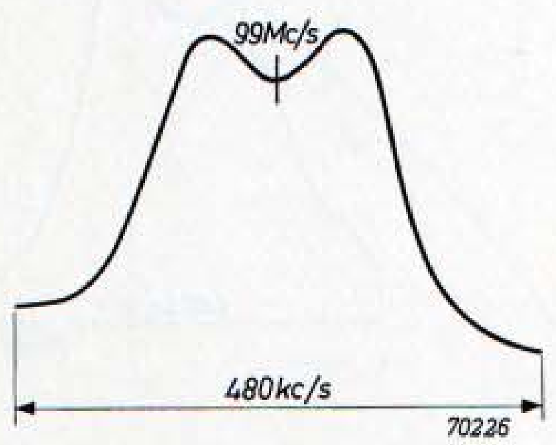
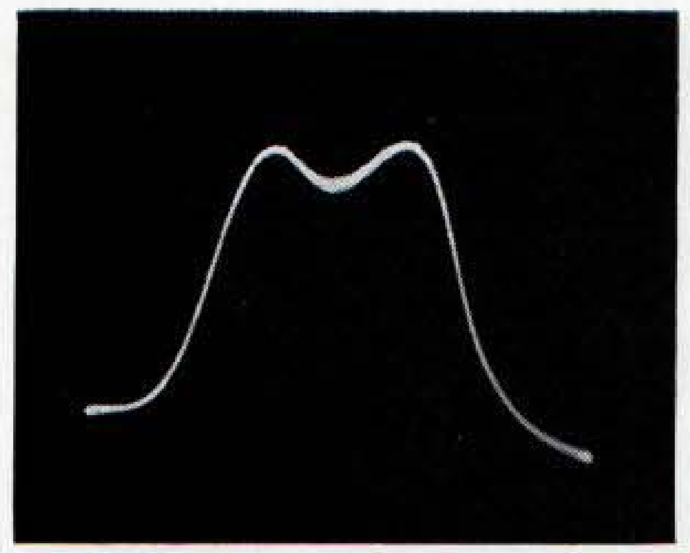


Fig. 88. Overall response curve with an input signal of 35 μV and a signal frequency of 99 Mc/s.



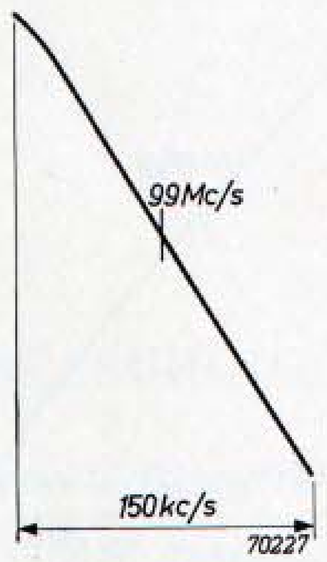
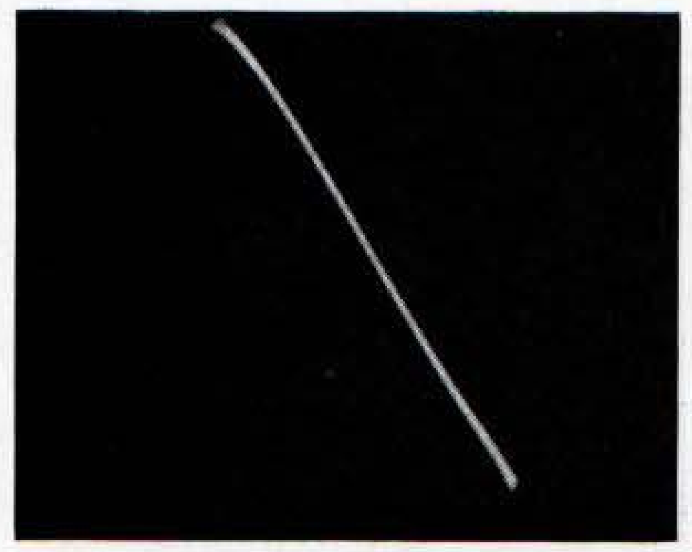


Fig. 89. Overall discriminatoı curve corresponding to fig 88.



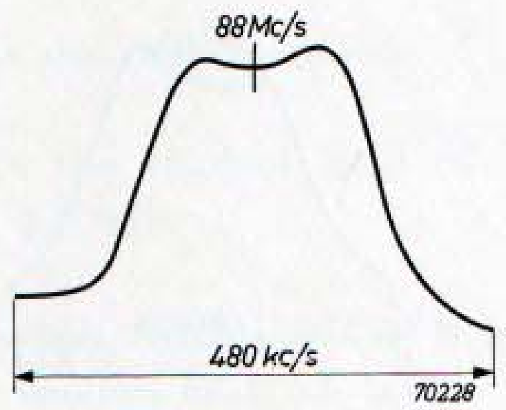
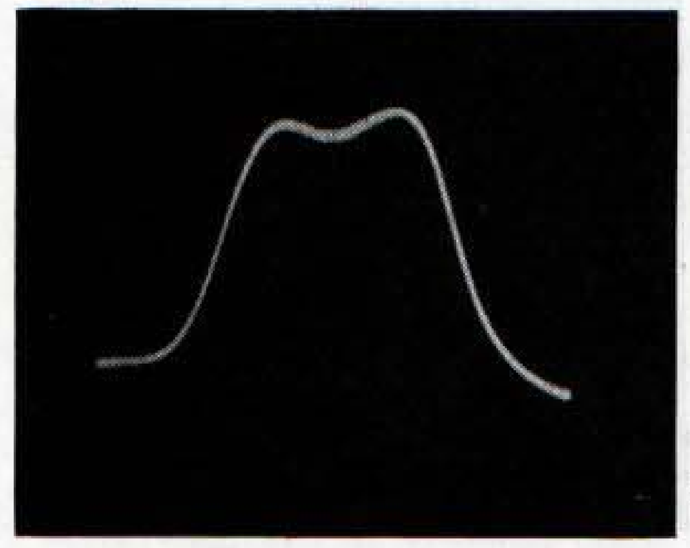


Fig. 90. Overall response curve with an input signal of 35 μV and a signal frequency of 88 Mc/s.



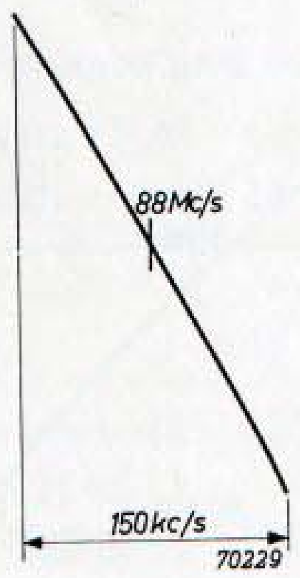
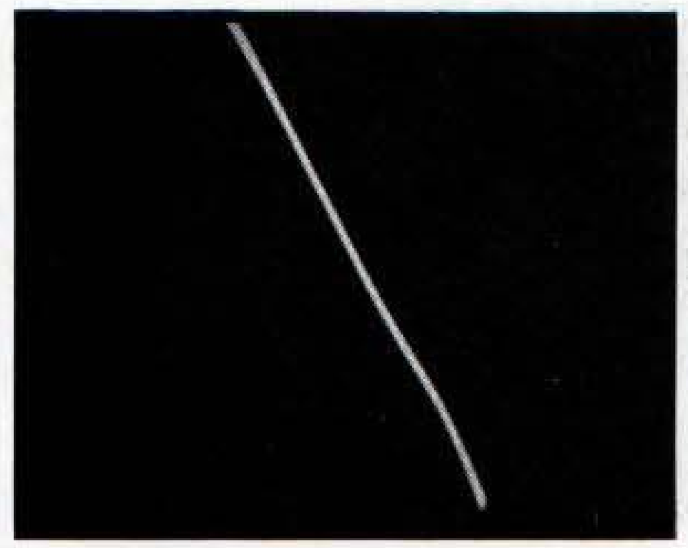


Fig. 91. Overall discriminator curve corresponding to fig 90.



The curves given above were obtained with the receiver accurately trimmed with a given set of tubes. It will be clear that owing to unavoidable tolerances in tube capacitance circuits may be slightly detuned when a tube is replaced. This detuning should be so small that it is not necessary to retrim the receiver, and this has been checked by replacing the EF 85 I.F. amplifier or one of the two ECH 81 tubes. From tests with a large number of tubes it has been found that in no case was the distortion so serious as to make retrimming necessary. A few examples of response and discriminator curves obtained in this way are given below.

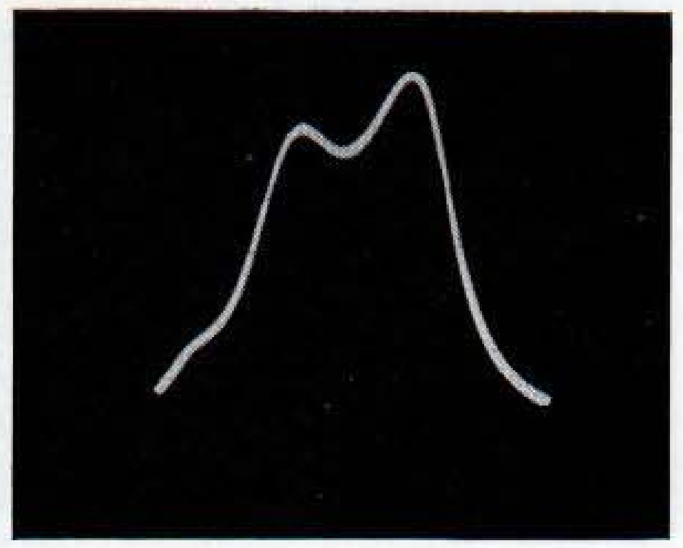
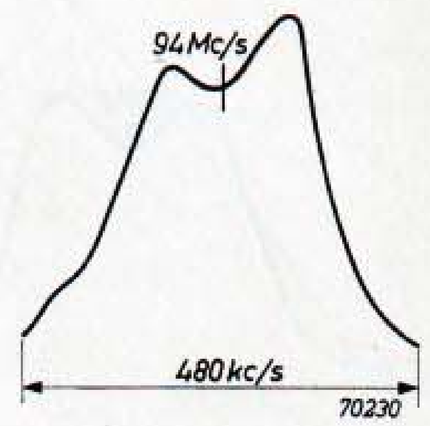


Fig. 92. Example of overall response curve obtained when the I.F. amplifier tube EF 85 is replaced.



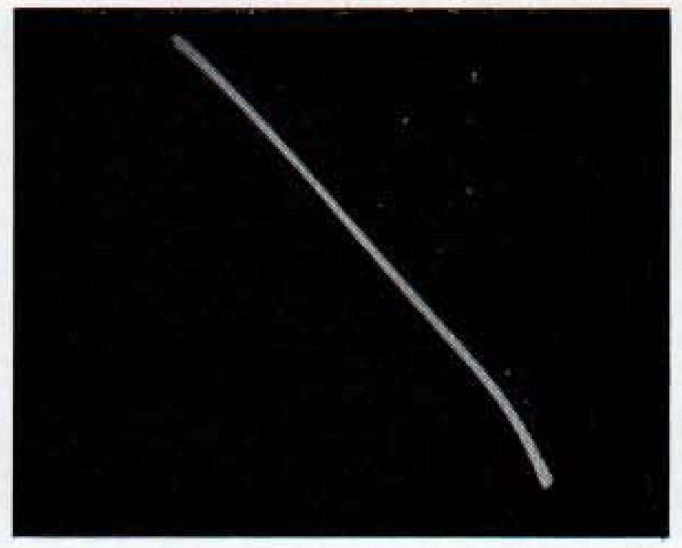
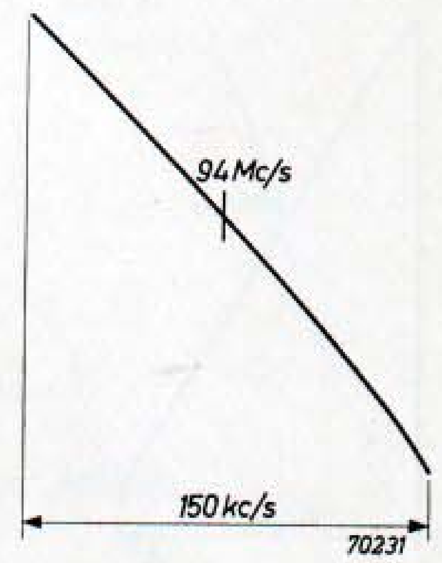


Fig. 93. Overall discriminator curve corresponding to fig92.



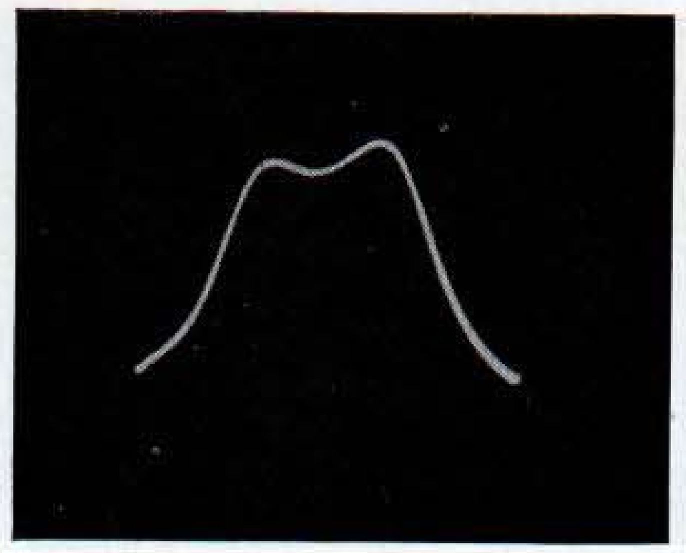
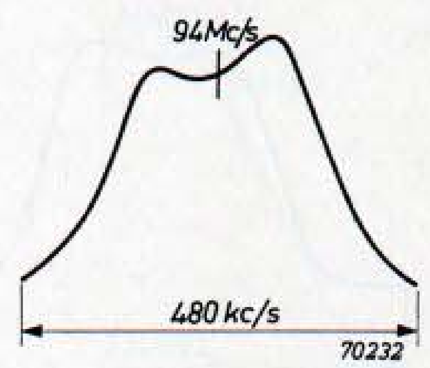


Fig. 94. Example of overall response curve obtained when the second ECH 81 tube is replaced.



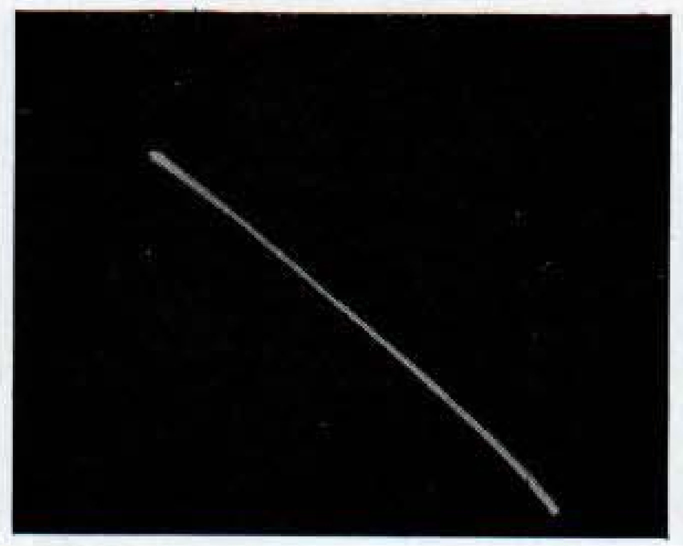
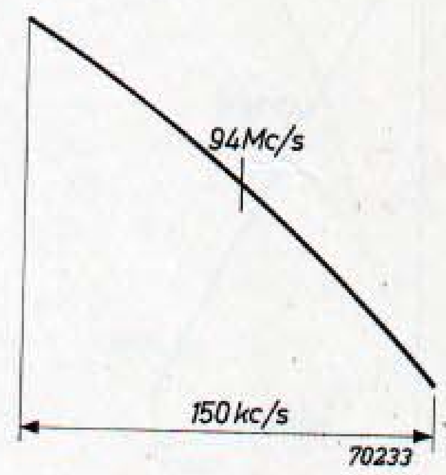


Fig. 95. Overall discriminator curve corresponding to fig. 94.



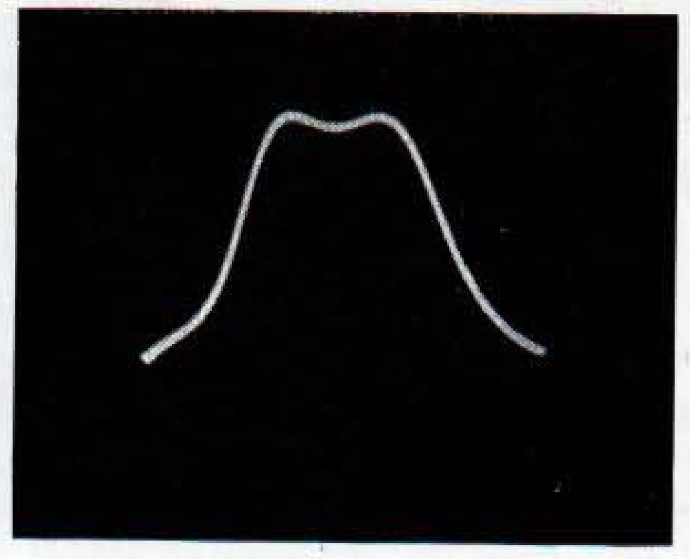
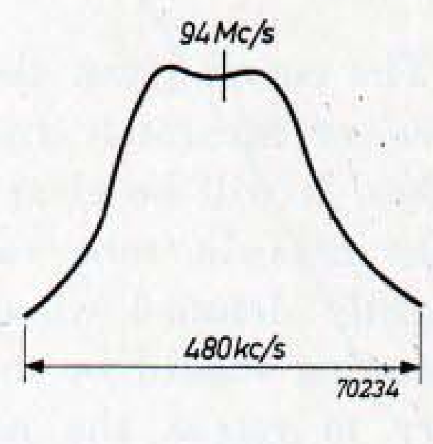


Fig. 96. Example of overall response curve obtained when the first ECH 81 tube is replaced.



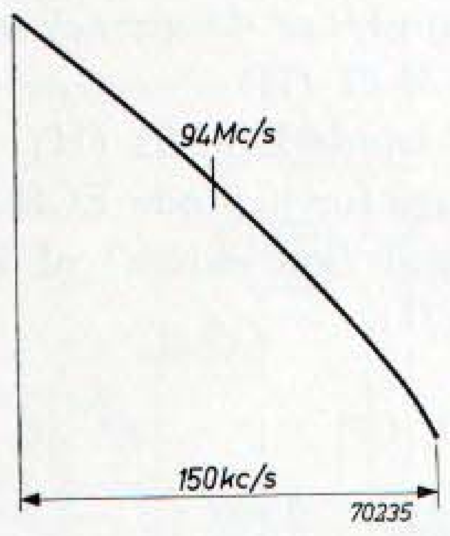
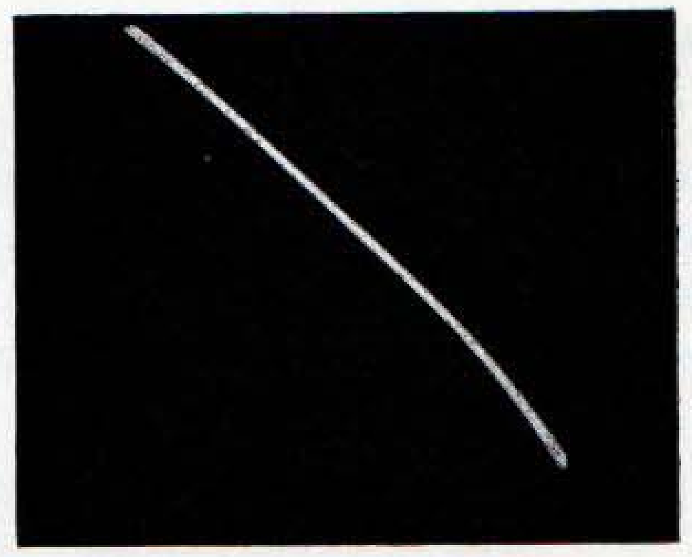


Fig. 97. **Overall discriminator curve corresponding to fig. 96.**



MEASURING RESULTS

Sensitivities with A.M. reception

(50 mW output, modulation depth 30%)

At the grid of the EABC 80	18 mV	(400 c/s)
At the detector diode	150 mV	(452 kc/s)
At the control grid of the EF 85	0.45 mV	(452 kc/s)
At the control grid of heptode section ECH 81 (II)	12 μV	(1 Mc/s)
At the aerial input approx.	3 μV	(1 Mc/s)

Sensitivities with F.M. reception

(50 mW output, frequency sweep 2 × 15 kc/s)

At the grid of the EABC 80	18 mV	(800 c/s)
At the control grid of the EF 85	27 mV	(10.7 Mc/s)
At the control grid of heptode section ECH 81 (II)	1.9 mV	(10.7 Mc/s)
At the tap on the oscillator coil L_{13}	72 μV	(94 Mc/s)
At the control grid of heptode section ECH 81 (I)	34 μV	(94 Mc/s)
At the aerial terminals	7 μV	(94 Mc/s)
	10 μV	(100 Mc/s)
	10 μV	(88 Mc/s)

Voltages and currents

With F.M. reception and zero signal (voltages with respect to chassis)

	V_a (V)	V_{g2} (V)	V_{g1} (V)	V_k (V)	I_a (mA)	I_{g2} (mA)	I_{g1} (mA)
ECH 81 (I) heptode	235	105	—2		6.5	3.7	
ECH 81 (I) triode	60				5.7		
ECH 81 (II) heptode	235	105	—2		6.5	3.7	
ECH 81 (II) triode	93				5.8		0.25
EF 85	230	110		2.1	10	2.5	
EABC 80	150		—2		0.45		
EL 41	230	250	—7.0		36	5.2	

With A.M. reception and zero signal (voltages with respect to chassis)

	V_a (V)	V_{g2} (V)	V_{g1} (V)	V_k (V)	I_a (mA)	I_{g2} (mA)	I_{g1} (mA)
ECH 81 (I) triode section	100				4.5		0.20
ECH 81 (II) heptode section	245	98	—2		3.0	6.1	
EF 85	225	105	0.1	2.1	10.4	2.6	
EABC 80	150		—2		0.45		
EL 41	230	250	—6.8		39	5.6	

COMPONENT VALUES

The values of resistors and capacitors are indicated in the circuit diagram of fig. 65. Constructional details of other components are listed below. The characteristic data of the I.F. transformers for F.M. are given in the text.

L_1L_2 — F.M. aerial coils.
Coil former with iron-dust core of 6 mm length and 6 mm diameter, type 7977.
Diameter of former 7 mm. L_2 has $4\frac{2}{3}$ turns of 0.5 mm enamelled copper wire (pitch 1.5 mm). L_1 has $1\frac{1}{3}$ turn of 0.5 mm enamelled copper wire (with midtap).
L_1 is wound between the turns of L_2.

L_3 — Booster coil for short-wave A.M. range.

L_4L_5 — Oscillator coils for short-wave A.M. range.

L_6L_7 — Oscillator coils for medium-wave A.M. range.

L_8L_9 — Oscillator coils for long-wave A.M. range.

L_{10} — R.F. choke, self-inductance approx. 10 μH.

L_{11} — H.F. tuning coil for F.M. Diameter of coil former 8 mm. Number of turns 3 (with midtap, pitch approx. 2 mm).
Wire 1 mm enamelled copper.

$L_{12}L_{13}$ — Oscillator coils for F.M. range.
Diameter of coil former
8 mm
Number of turns of L_{12}
3 (pitch 2 mm)
Wire for L_{12}
1 mm enamelled copper
Number of turns of L_{13}
3.5 (with midtap)
Wire for L_{13}
0.5 mm enamelled copper
L_{13} is wound between the turns of L_{12}.

$L_{14}L_{15}$ — First I.F. transformer for F.M. A drawing of this transformer is given in fig. 98 (dimensions in mm). A screening can is employed with an internal diameter of 30 mm and a height of 60 mm. Coil formers type 7977, diameter 7 mm and with iron-dust core of 6 mm length and 6 mm diameter.
L_{14} and L_{15} are identical and have each 48 turns close-wound of 0.3 mm enamelled copper wire. Self-inductance without iron-dust core 5.7 μH. The connections are as follows (see also fig.65):

1. anode supply of frequency changer triode ECH 81 (II)
2. anode of triode ECH 81 (II)
4. bias voltage for heptode ECH 81 (II)
5. control grid (via switch) of heptode ECH 81 (II).

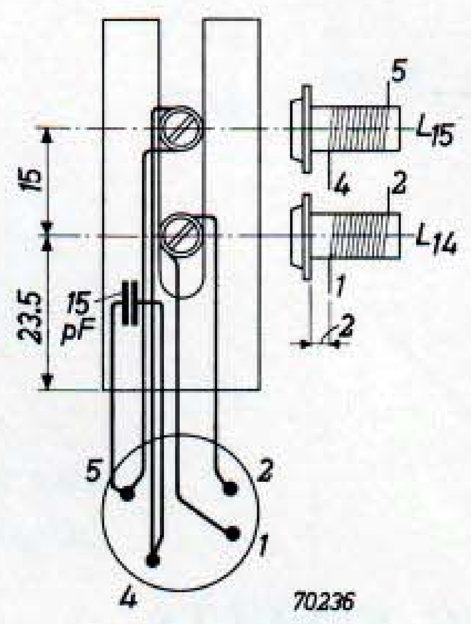


Fig. 98.

$L_{16}L_{17}$ — Aerial coils for short-wave A.M. range.

$L_{18}L_{19}$ — Aerial coils for medium-wave A.M. range.

$L_{20}L_{21}$ — Aerial coils for long-wave A.M. range.

L_{22} — I.F. wave trap for A.M. (452 kc/s).

$L_{23}L_{24}$ — Second I.F. transformer for F.M.
A drawing of this transformer is given in fig. 99 (dimensions in mm). The transformer is screened with a can of 30 mm internal diameter and 60 mm height. Coil formers type 7977, diameter 7 mm and with iron-dust core of 6 mm length and 6 mm diameter.

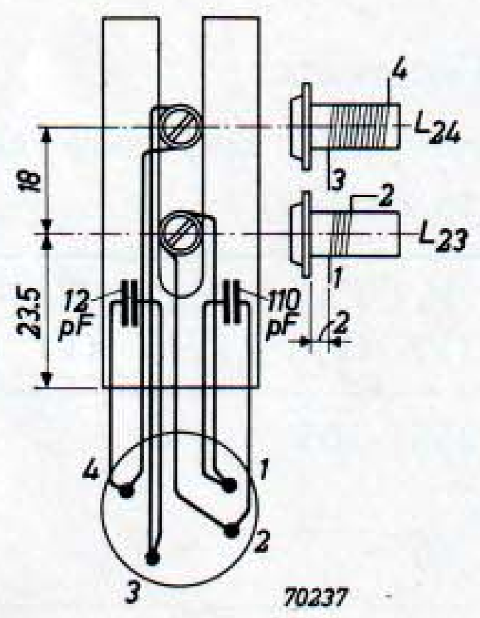


Fig. 99.

L_{23} has 10 turns close-wound of 0.2 mm enamelled copper wire. Self-inductance of L_{23} without iron-dust core 1.1 μH.
L_{24} has 48 turns close-wound of 0.3 mm enamelled copper wire. Self-inductance of L_{24} without iron-dust core 5.7 μH.

The connections are as follows (see also fig.65):

1. anode supply of heptode ECH 81 (II)
2. anode (via switch) of heptode ECH 81 (II)
3. earth
4. control grid (via switch) of EF 85.

$L_{25}L_{26}$ First I.F. transformer for A.M., type 5730. The control grid of the EF 85 is tapped at 0.3 on the secondary.

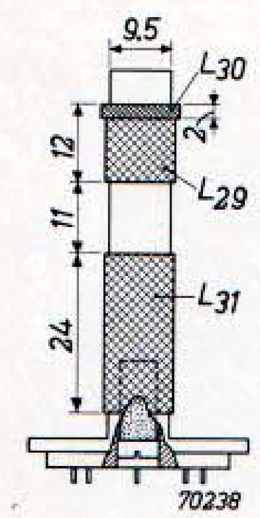


Fig. 100.

$L_{27}L_{28}$ Second I.F. transformer for A.M., type 5730. The detector diode is tapped at 0.7 on the secondary.

$L_{29}L_{30}L_{31}$ Discriminator transformer for ratio detector. The drawing of this transformer is given in fig. 100 (dimensions in mm). The dimensions of the screening can are 30 × 60 mm.

L_{29} has 37 turns close-wound of 0.3 mm enamelled copper wire. Self-inductance is 7.4 μH.

L_{30} is wound over L_{29} and has $6^3/_4$ turns of 0.3 mm enamelled copper wire.

L_{31} is bifilarly wound with a pitch of 0.75 mm. Number of turns 2 × 14 of 0.5 mm enamelled copper wire. Self-inductance with iron-dust core 5.6 μH.

L_{31} is tuned with an iron-dust core of 6 mm diameter and 12 mm length.

T_1 Output transformer with matching resistance of 7 kΩ. Speech coil impedance 5 Ω.

T_2 Mains transformer. Secondary voltage 2 × 275 V_{rms} (D.C. output 85 mA). Heater winding 6.3 V, 2.7 A.

ADDENDUM

In the description of the 5-tube receiver given in the preceding pages it has been indicated that when the secondary of the second I.F. transformer $L_{23}L_{24}$ for F.M. is detuned, instability may occur as a result of increasing input impedance of this transformer. Although the circuit is perfectly stable when the receiver is accurately trimmed, the fact that detuning of L_{24} may result in instability can be troublesome when trimming. It has been found, however, that by modifying the characteristic data of the I.F. transformer $L_{23}L_{24}$ stability can be obtained under all conditions of detuning, without reducing the total gain of the receiver.

The I.F. transformer $L_{23}L_{24}$ was so designed that the required low input impedance (2 kΩ) was obtained mainly by choosing a low L/C ratio for the primary. Since, however, the coupling was overcritical ($KQ = 1.4$) considerable detuning of the secondary might result in an almost threefold increase of input impedance, in the extreme case the input impedance becoming equal to the effective primary circuit impedance of 6.1 kΩ. This can be prevented by using an undercritically coupled I.F. transformer. In order to obtain sufficient bandwith and a low input impedance the primary is shunted by a damping resistor of 3.7 kΩ, the primary circuit impedance without extra damping being 38.5 kΩ and the total tuning capacitance 30 pF. The characteristic data of the new I.F. transformer are:

Primary L_{23}

Total tuning capacitance	30 pF
Extra damping resistance	3.7 kΩ
Effective primary circuit impedance Z_1	3.4 kΩ
Effective quality factor of the primary Q_1	6.8

Secondary L_{24}

Total tuning capacitance	30 pF
Effective secondary circuit impedance Z_2	31.5 kΩ
Effective quality factor of secondary Q_2	63

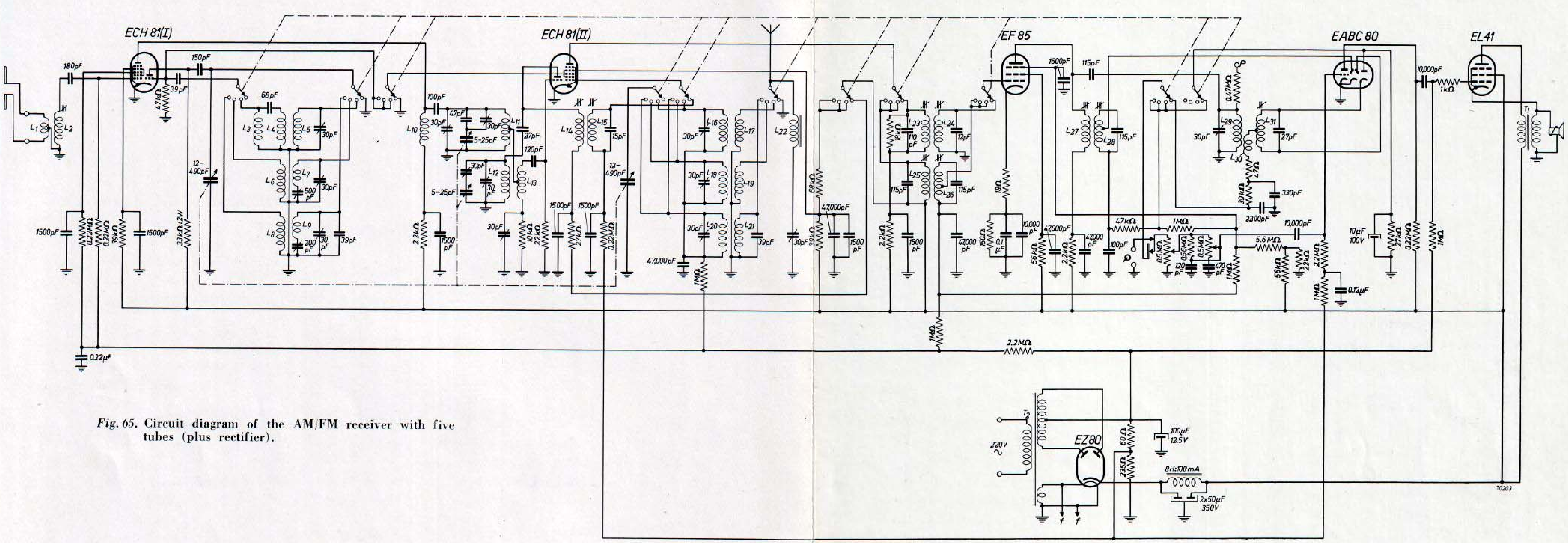


Fig. 65. Circuit diagram of the AM/FM receiver with five tubes (plus rectifier).

Primary and secondary $L_{23}L_{24}$

Coupling KQ	0.7
Transfer impedance Z_t	4.9 kΩ
Input impedance Z_i	2.25 kΩ

The constructional details of this transformer only differ from those previously given in that the number of turns of the primary can be increased to that of the secondary.

With these data it may be calculated that the gain between the control grid of the heptode section of the second ECH 81 tube and the control grid of the EF 85 is $S \cdot Z_t = 2.4 \times 4.9 = 11.7$. With the I.F. transformer previously used this figure was 14.4.

For the transformer $L_{14}L_{15}$ a coupling $KQ = 1$ was used and this has to be increased to $KQ = 1.4$. The transfer impedance is then slightly reduced from 7.8 kΩ to 7.5 kΩ. The bandwidth for a reduction in response of 3 db measured between the input of the frequency changer and the control grid of the EF 85 then becomes 190 kc/s, which is a sufficiently high value.

The feedback caused by the capacitance between the anode of the triode and the anode of the heptode section of the ECH 81 can, as before, conveniently be expressed in the factor:

$$p^2 = \omega \cdot C_{aHaT} \cdot S \cdot Z_i \cdot Z_t,$$

and the apparent increase of transfer impedance of $L_{14}L_{15}$ by:

$$Z_t' = \frac{Z_t}{1 - p^2}.$$

With the data given above the factor p^2 has a value of 0.59 and the apparent transfer impedance thus becomes:

$$Z_t' = \frac{7.5}{1 - 0.59} = 18.3 \text{ k}\Omega,$$

which is the same as that previously obtained. The conversion gain is therefore not changed.

From the foregoing discussion the conclusion might be drawn that, although the stability is greatly improved by choosing other characteristic data for the I.F. transformers, the total gain is reduced, because the gain of the I.F. heptode has dropped from 14.4 to 11. Since, however, the stability is no longer endangered by detuning of L_{24}, it is no longer necessary to employ automatic grid bias for the EF 85. Also the non-bypassed cathode resistor for this tube can be omitted, so that the cathode can be connected to the chassis. A fixed bias of —2 V is already available in the receiver and can be applied to the grid via the secondary L_{24} of the preceding I.F. transformer. As a result of the omission of the non-bypassed cathode resistor, the EF 85 tube operates with maximum mutual conductance, which results in an increase of gain of this stage, practically compensating the reduction in gain of the heptode.

2. ALTERNATIVE FRONT END WITH ECH 81,
without special precautions against radiation

With the distribution of functions in the front end described on the preceding pages a very low oscillator voltage at the aerial terminals could be obtained, namely approx. 2 mV (see also fig. 1). Is was, however, necessary to take special precautions against the feedback occurring via the capacitance between the frequency changer anode and functions previously described, the radiation is increased.

When the following stages of the receiver are chosen according to the block diagram represented in fig. 2, a sensitivity at the grid of the first I.F. tube of 700 μV can be reached. Since the unit represented in fig. 101 has a gain at F.M. of about

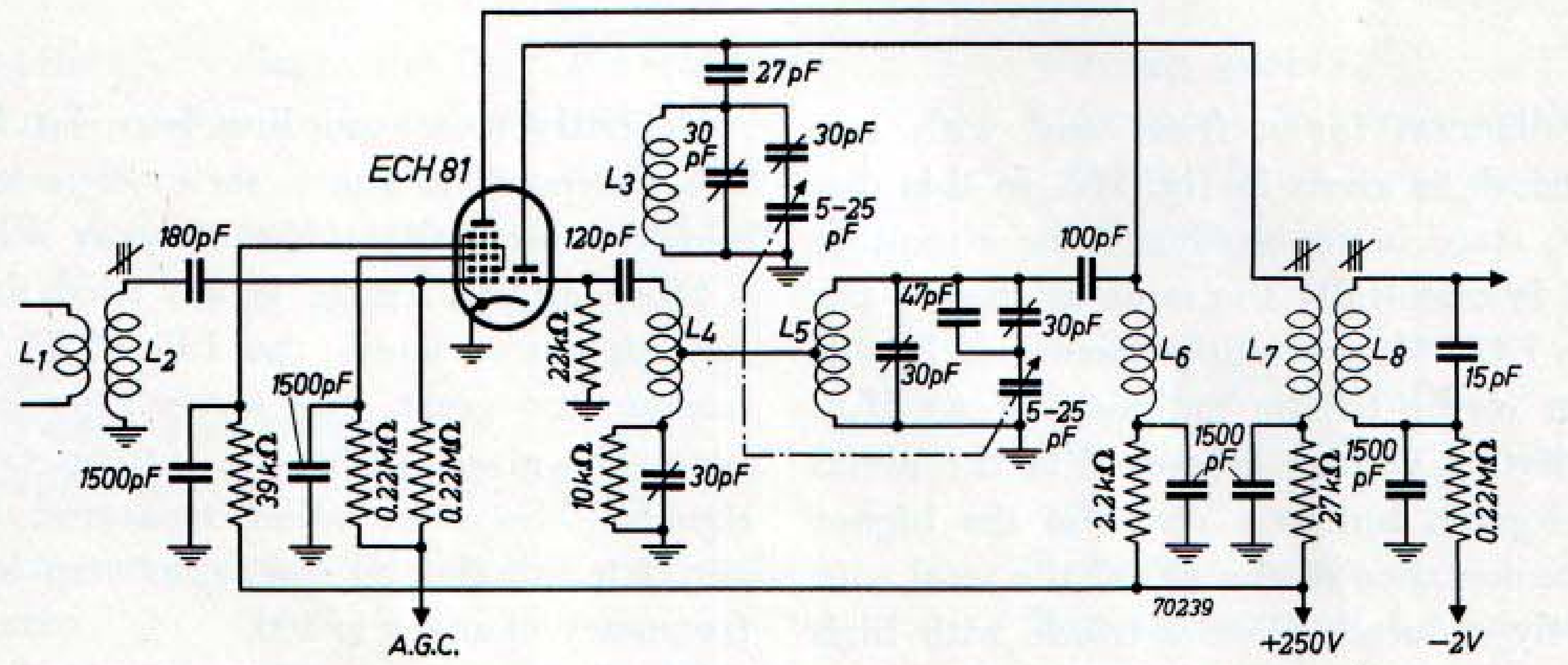


Fig. 101. Front end with an ECH 81 triode-heptode, the heptode section being used as H.F. amplifier and the triode section as frequency changer.

the anode of the heptode I.F. amplifier, the tubes for these functions being in one envelope. With properly designed I.F. transformers for F.M. stability could be ensured under all conditions of detuning and this result has been obtained without any additional cost. In this connection it should be emphasized that the production of receivers with low radiation, regardless whether this is made compulsory by existing anti-interference regulations or not, is in the interest of the entire set-making industry.

The circuit of an alternative front end, in which feedback between the anode of the frequency changer and the anode of the first I.F. amplifier is avoided, is, however, also given. In this arrangement (see fig. 101) the heptode section of an ECH 81 tube is used as H.F. amplifier and the triode of the same tube as frequency changer and although the H.F. and oscillator circuits are now concentrated around one tube, thus forming an F.M. tuner unit, compared with the distribution of functions previously described, the radiation is increased.

100 the sensitivity at the aerial terminals becomes approx. 7 μV, for 50 mW output of the final stage and a frequency sweep of 2 × 15 kc/s. The data of the coils used in fig. 101 are the same as those given previously in the description of the five-tube receiver.

Another important characteristic figure of a front end is the attenuation of signals having a frequency around the I.F. of 10.7 Mc/s. In this design the attenuation measured between the aerial terminals and the input of the frequency changer (tap on L_4) is 200, which is a sufficiently high value, so that it is not necessary to use an I.F. wave trap.

In the table below the current in the oscillator grid leak of 22 kΩ and the radiation voltage at the aerial terminals (75 Ω) are given as functions of the oscillator frequency.

Oscillator frequency (Mc/s)	Current in grid leak (μA)	Radiation voltage (mV)
98	305	40
102	295	43
108	275	32
110	260	22

Finally, the characteristic performance figures of a receiver with this front end are again given:

Sensitivity	7 μV
Equivalent noise voltage	1.8 μV
Radiation voltage	20—40 mV

3. FRONT END WITH EC 92 AS FREQUENCY CHANGER, with low grid leak and without feedback of the I.F.

A circuit diagram for a front end with one EC 92 R.F. triode is given in fig. 102. In this diagram an H.F. stage is not used and the circuiting of the triode is essentially the same as that of the triode of the ECH 81 previously discussed. It will be clear that owing to the omission of an H.F. stage the radiation voltage measured at the aerial terminals is higher, but as a result of the higher conversion conductance of the EC 92 the total gain is only slightly reduced. Since a triode with high conversion conductance is used for frequency changing, the equivalent noise voltage at the aerial terminals is even lower than that obtained with a heptode H.F. stage.

The data of the aerial circuit L_1L_2 are given below:

Frequency range		88—100 Mc/s
Tuning capacitance		5—25 pF
Series capacitance		28 pF
Parallel capacitance		12 pF
Circuit impedance without extra damping	approx.	5.2 kΩ
Capacitive load of frequency changer input ($0.6^2 \times 28$)		10 pF
Resistive load of frequency changer input $\left(\frac{1}{0.6}\right)^2 \times 700$	approx.	2 kΩ
Circuit impedance with damping by frequency changer input	approx.	1.4 kΩ

From the data given above it may be calculated that the optimum gain between the aerial terminals (75 Ω) and the tap on L_2 (tap 0.6) is 2.6. A gain of 2.8 has actually been measured. To obtain a sufficiently close coupling between L_1 and L_2 it was necessary to use a series capacitor of 47 pF, which reduces the effect of stray self-inductance.

Since an H.F. stage is not used the sensitivity for signals around the I.F. of 10.7 Mc/s might become too great. The series capacitor of 47 pF, however, gives additional attenuation of these signals. The attenuation measured between the aerial terminals and the input (tap on L_3) of the frequency changer is 300.

The data of the oscillator circuit L_3L_4 are:

Frequency range		98.7—110.7 Mc/s
Tuning capacitance		5—15 pF
Series capacitance		30 pF
Parallel capacitance		10 pF
Circuit impedance (with feedback coil)	approx.	4.5 kΩ
Current in grid leak of 18 kΩ		190 μA[15])
Oscillator voltage at the grid		3 V_{rms}
Conversion conductance		2.5 mA/V
Mean anode current		5 mA

The I.F. transformer L_5L_6 indicated in fig. 102 only differs from that given in fig. 98, in that the total tuning capacitance across the primary is slightly reduced, viz. 30 pF instead of 36 pF, whilst the secondary is wound with a spacing of about 0,1 mm to obtain a higher quality factor. The transfer impedance of L_4L_5, inclusive of all extra damping, then becomes about 9 kΩ, so that the conversion gain is $2.5 \times 9 = 22.5$. Taking the voltage gain in the feedback coil L_3 into account (factor of about 1.1), the total gain between the aerial terminals and the input of the first I.F. tube becomes $2.8 \times 1.1 \times 22.5 \approx 70$. In a receiver

[15]) Squegging starts at currents of $> 350\ \mu$A.

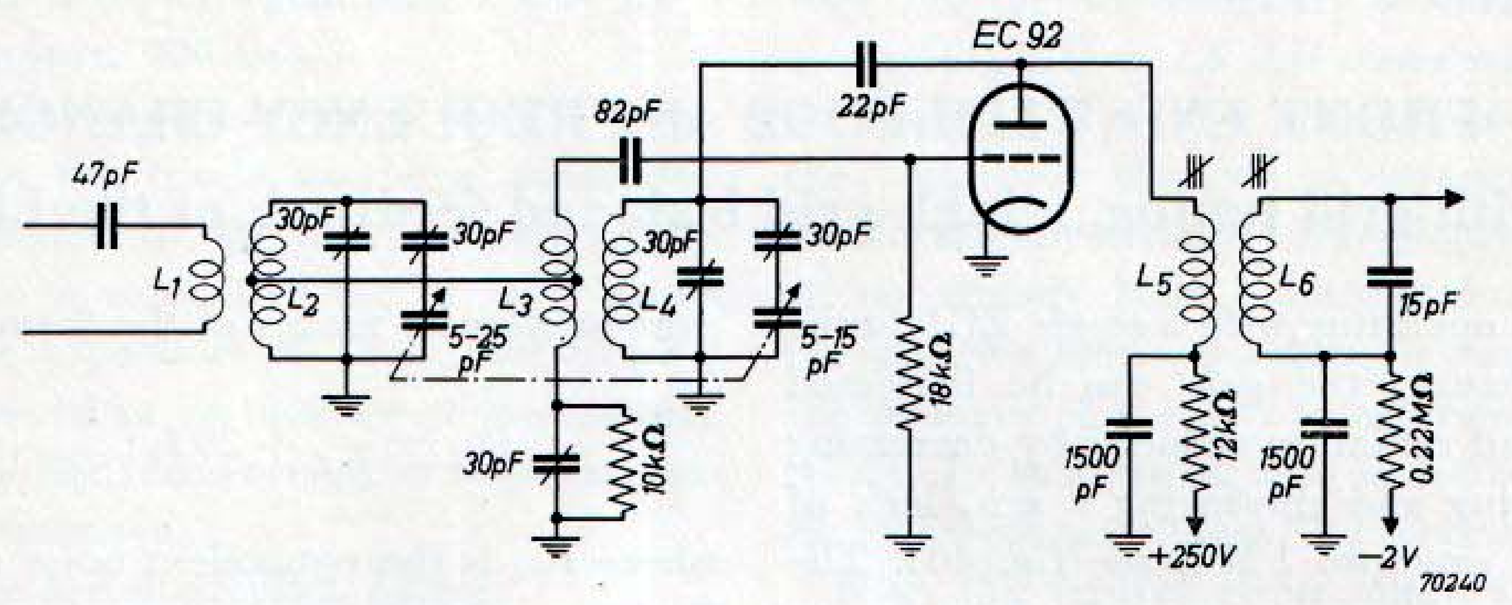


Fig. 102. Front end with an EC 92 triode operating as frequency changer.

according to the block diagram of fig. 3 the sensitivity for 50 mW output, at a frequency sweep 2 × 15 kc/s, will then be approx. 10 μV. The characteristic performance figures of such a receiver are:

Sentivity	10 μV
Equivalent noise voltage	1.3 μV
Radiation voltage	15—80 mV

The constructional details of the H.F. and oscillator coils are:

L_1L_2	Diameter of coil former	7 mm
	Number of turns L_1 (close wound)	$1^2/_3$
	Wire diameter of L_1 (enamelled copper)	0.5 mm
	Number of turns L_2 (close wound)	$3^2/_3$
	Wire diameter L_2 (enamelled copper)	0.5 mm
	Winding pitch L_2	1.5 mm
	L_1 is wound as a continuation of L_2, the latter being tapped at 0.6 from below.	
L_3L_4	Diameter of coil former	8 mm
	Number of turns of L_3	3
	Wire diameter of L_3 (enamelled copper)	0.5 mm
	Number of turns of L_4	3
	Wire diameter of L_4 (enamelled copper)	1 mm
	Winding pitch L_4	3 mm
	L_3 is wound between the turns of L_4, the former being provided with a midtap.	

4. FRONT END WITH EC 92 AS FREQUENCY CHANGER, with grid tuning, a high grid leak and feedback of the I.F.

In a front end operating with a single EC 92 tube as frequency changer the gain can be increased and the noise and radiation reduced by decreasing the input damping and employing a grid leak of high value, for example 1 MΩ, see fig. 103. The grid leak of the oscillator is normally kept low to prevent squegging, but with a high grid leak squegging can be prevented by simple means. For this purpose in the circuit of fig. 103 use is made of a $\frac{1}{4}$ W carbon resistor of 120 Ω wound with 20 turns

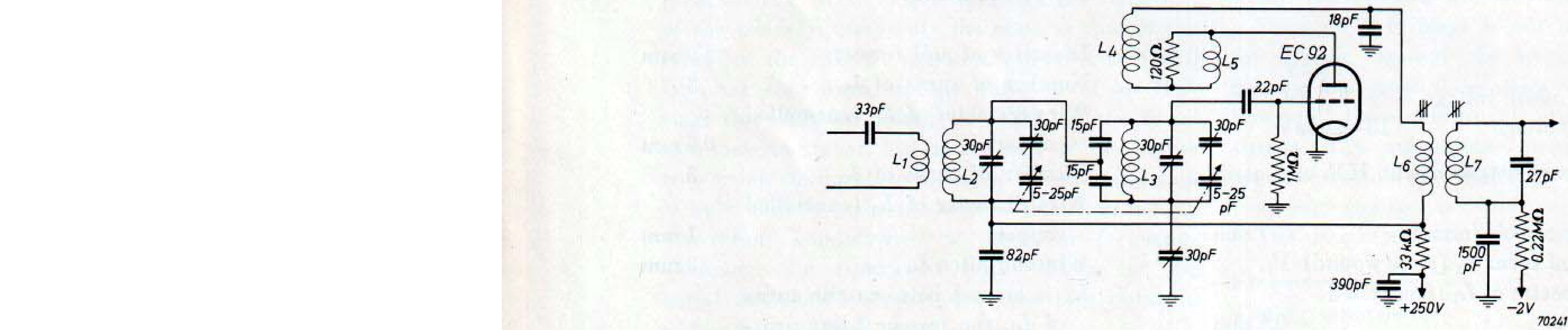


Fig. 103. Front end with an EC 92 triode operating as frequency changer with a high grid leak and feedback of the I.F.

of 0.3 mm enamelled copper wire (L_5).

The use of a grid leak of high value makes it possible to increase the input impedance of the frequency changer from about 700 Ω (see fig. 102) to about 18 kΩ. This is achieved by making the anode circuit inductive (L_5). A higher aerial gain can then be obtained, which involves a higher transformer ratio of the aerial circuit, so that the radiation voltage measured at the aerial terminals is reduced.

It has been found that the phenomena responsible for the noise in a self-oscillating triode are analogous to those occurring in a pentode. With the triode the noise due to shot effect is inversely proportional to the conversion conductance and the partition noise is proportional to the grid current. The equivalent noise resistance of the self-oscillating triode can be calculated with some approximation by means of the formula:

$$R_{eq} = \frac{2.5}{S_c^2} + 20\, I_g \left(\frac{1}{S_c^2} + Z_g^2\right),$$

where R_{eq} is the equivalent noise resistance in kΩ, S_c the conversion conductance in mA/V, I_g the grid current in mA and Z_g the effective impedance in kΩ between grid and cathode.

Two conclusions may be drawn from this formula. The first leads to the well-known condition that for low shot noise the conversion conductance should be high. Since with the EC 92 a high conversion conductance can be obtained shot noise will be low. The second conclusion is that the grid current of the self-oscillating frequency changer must be kept low, either by choosing a low oscillator amplitude or by employing a grid leak of high value. Because the conversion conductance is maximum for one given oscillator amplitude only, the reduction in partition noise should be obtained by increasing the value of the grid leak resistor.

There are types of carbon resistors giving rise to an additional amount of noise when direct current flows. It is therefore important to employ for the grid leak a carbon resistor of good quality with respect to noise.

Whilst with the circuit of fig. 102 an equivalent noise voltage at the aerial terminals of 1.3 μV (grid leak 18 kΩ) could be obtained, with the circuit of fig. 103 it is 0.5 μV (grid leak 1 MΩ) for a bandwidth of approx. 200 kc/s.

The damping on the primary L_6 of the I.F. transformer caused by the triode has been eliminated by positive feedback of the I.F. anode voltage. For this purpose a capacitive tap is used across the primary (see capacitors of 18 pF and 82 pF). This feedback results in an increase of the transfer impedance of the I.F. transformer, so that the conversion gain is increased.

The data of the aerial circuit L_1L_2 are:

Frequency range		88—100 Mc/s
Tuning capacitance		5—25 pF
Series capacitance	approx.	30 pF
Parallel capacitance	approx.	5 pF
Circuit impedance without extra damping	approx.	8.75kΩ
Capacitive load of frequency changer input $0.8^2 \times 20 =$		13 pF
Resistive load of frequency changer input		18 kΩ
Circuit impedance with damping by frequency changer input (without aerial damping)		5.9 kΩ

The gain measured between the aerial terminals (75 Ω) and the tap on the oscillator circuit is 7.5. The attenuation for I.F. signals (10.7 Mc/s) measured between the aerial terminals and the grid of the frequency changer is about 1200.

In contrast to the circuits dealt with previously, in the circuit of fig. 103 the oscillator frequency is chosen lower than the signal frequency, whilst grid tuning is employed instead of anode tuning. The data of the oscillator circuit are:

Frequency range		77.3—89.3 Mc/s
Tuning capacitance		5—25 pF
Series capacitance	approx.	25 pF
Parallel capacitance	approx.	6 pF
Circuit impedance at 94 Mc/s	approx.	12 kΩ
Current in grid leak of 1 MΩ at 94 Mc/s		4.2 μA
Oscillator voltage at the grid		3 V_{rms}
Conversion conductance		2.1 mA/V
Mean anode current		3.5 mA

The total tuning capacitances of the I.F. transformer L_6L_7 in the anode circuit are 25 pF for the primary and 42 pF for the secondary. These capacitances also include the wiring and switch capacitances, which do not appear directly from the circuit of fig. 103. The constructional details are the same as those given with fig. 98, except for the numbers of turns, which are for the primary 60 turns close wound of 0.25 mm enamelled copper wire and for the secondary 40 turns 0.3 mm. With a coupling $KQ = 1.4$ this transformer has a transfer impedance of 17.5 kΩ, but since the anode of the frequency changer is capacitively tapped at 0.8 the effective transfer impedance becomes 14 kΩ. It has already been indicated that as a result of the positive feedback, there is no damping across the primary of the I.F. transformer caused by the triode. In this circuit the conversion gain of the EC 92 frequency changer is therefore $2.1 \times 14 \approx 30$.

With the figures given above it is possible to calculate the total gain between the aerial terminals and the secondary of the I.F. transformer. It is then necessary, however, to take into account the capacitive voltage division between the midtap on the oscillator circuit and the grid of the triode. This voltage division amounts to 0.55, so that the total gain becomes $7.5 \times 0.55 \times 31 \approx 130$. In a receiver according to the block diagram of fig. 3 a total sensitivity of 5 μV at the aerial terminals will then be obtained (frequency sweep 2×15 kc/s, A.F. output 50 mW). The characteristic performance figures of the receiver are then:

Sensitivity	5 μV
Equivalent noise voltage	0.5 μV
Radiation voltage	4—15 mV

The constructional details of the H.F. and oscillator coils are as follows:

L_1L_2	Internal diameter of both coils (no former)		15 mm
	Number of turns L_1		$1^1/_2$
	Pitch L_1	approx.	3 mm
	Number of turns L_2		$2^1/_4$
	Wire diameter L_2 and L_1		1.5 mm
	Pitch L_2	approx.	3 mm
	L_1 and L_2 are coaxially mounted at a distance of approx.		5 mm
L_3L_4	Internal diameter of L_3 (no former)		15 mm
	Number of turns L_3		3
	Pitch L_3	approx.	3 mm
	Internal diameter L_4 (no former)		7 mm
	Number of turns L_4		2
	Wire diameter L_4 and L_3		1.5 mm
	Pitch L_4	approx.	3 mm
	The coils are mounted coaxially with L_4 in the centre of L_3.		
L_5	Five turns of 0.3 mm enamelled copper wire, wound on a $^1/_4$ W carbon resistor of 120 Ω. The combination serves for the suppression of squegging and for increasing the H.F. input impedance of the triode.		

5. FRONT END WITH 2 × EC 92,

operating respectively as grounded-grid amplifier and frequency changer.

In the preceding description it has been shown that the performance of a self-oscillating frequency changer can be considerably improved by using an inductive anode circuit, a grid leak of high value and applying positive feedback of the I.F. voltage in the anode circuit. A similar improvement of performance can be obtained by using the normal oscillator circuit with a grid leak of low value (for example 18 kΩ) and without feedback of the I.F. and by adding a grounded-grid H.F. stage equipped with an EC 92 triode. This arrangement has the advantage that the circuit can be kept simple, whilst, owing to the efficient screening between the oscillator and the aerial circuit, the balancing of the oscillator input is less critical than in the case of direct frequency changing.

The circuit diagram is given in fig. 104. The frequency changer circuit is entirely identical with that of fig. 102, the conversion gain between the input (tap on L_5) and the secondary of the I.F. transformer being 25.

Since the aerial circuit is heavily damped by the input resistance of the grounded-grid stage, fixed tuning can be employed for the frequency range of 88—100 Mc/s. With the feeder connected to the aerial terminals the bandwidth of this circuit is 20 Mc/s. The data of this circuit are given below:

Frequency range	88—100 Mc/s
Total tuning capacitance	12 pF
Circuit impedance without extra damping	approx. 7 kΩ
Resistive load of grounded-grid amplifier $135/0.3^2 =$ (tapping ratio of tuned circuit 0.3)	1.5 kΩ
Circuit impedance with extra damping caused by input grounded-grid amplifier	1.25 kΩ

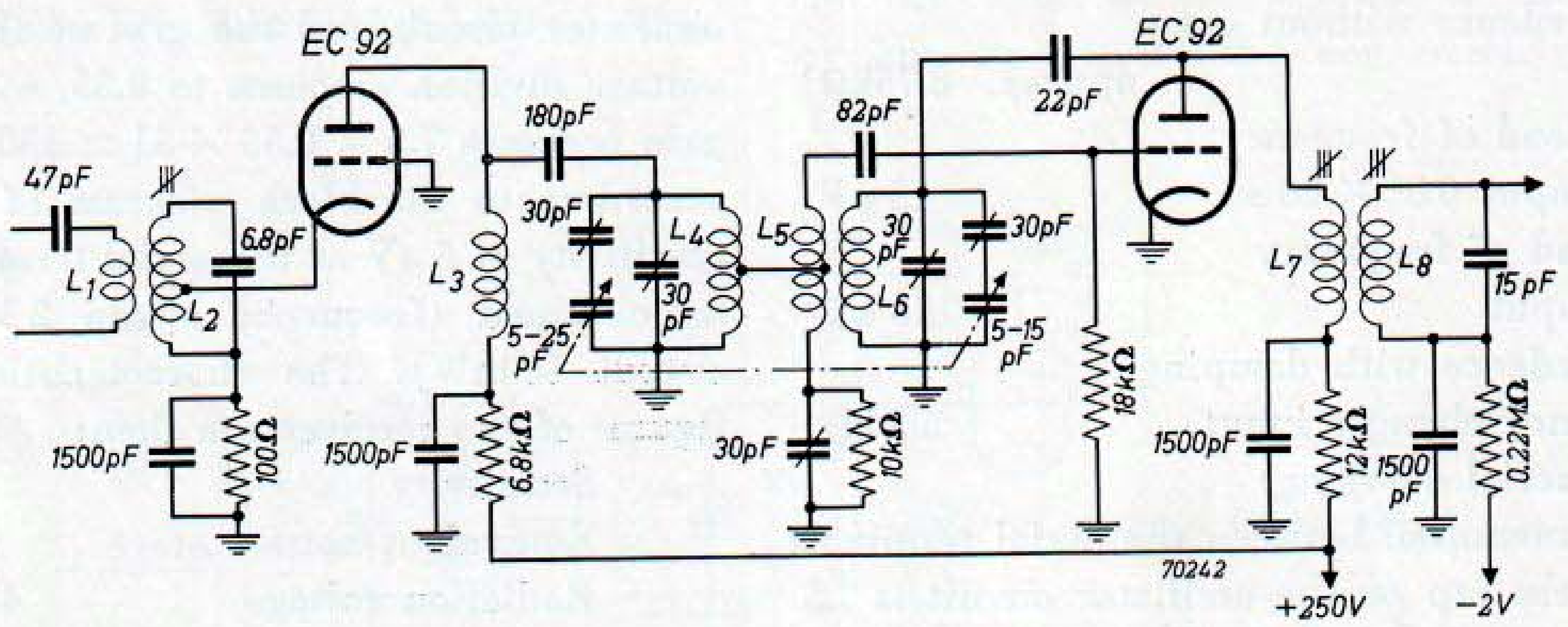


Fig. 104. Front end with two EC 92 triodes, the first operating as grounded-grid amplifier and the second as frequency changer.

When an aerial is used with a characteristic impedance of 75 Ω, the gain between the aerial terminals and the cathode of the H.F. tube is 1.3.

The anode circuit L_4 of the grounded-grid amplifier is tapped at 0.6 from below to reduce the damping caused by the frequency changer input (700 Ω). Including extra damping, the impedance of this circuit is 1.3 kΩ, so that the gain is $6.0 \times 1.3 \times 0.6 = 4.7$, the mutual conductance of the tube being 6.0 mA/V. This gives for the gain between the aerial terminals and the input of the frequency changer $1.3 \times 4.7 = 6$. The total gain, including that of the frequency changer stage is then 150. In a receiver according to the block diagram of fig. 4 a total sensitivity of 4.5 μV can be reached when an EF 85 tube is used in the second I.F. stage for F.M. When the EF 85 is replaced by an EF 41 pentode, the mutual conductance of which is 2.2 mA/V, the total sensitivity becomes 12 μV. The characteristic performance figures given below apply to the use of an EF 85 pentode in the second I.F. stage.

Sensitivity	4.5 μV
Equivalent noise voltage	0.6 μV
Radiation voltage	4—6 mV

The constructional details of the coils in the H.F. amplifier are:

L_1L_2 Coil former with iron dust core of 6 mm diameter and 6 mm length

Diameter of coil former	7 mm
Number of turns of L_1	$1^1/_6$
Wire diameter of L_1 (enamelled copper)	0.5 mm
Number of turns of L_2	$4^1/_3$
Wire diameter of L_2 (enamelled copper)	0.5 mm
Winding pitch of L_2 approx.	2 mm

L_1 is wound between the turns of L_2, the latter being tapped at 0.3 from below.

L_3 H.F. choke with 20 turns, close wound, of 0.3 mm enamelled copper wire, wound on a former of 8 mm diameter.

L_4 Three turns of 1 mm enamelled copper wire, wound with a pitch of 2 mm on a former of 8 mm diameter. L_4 is tapped at 0.6 from below.

As a final note it should be pointed out that in order to prevent oscillator currents from reaching the heater supply line, which would increase radiation via the grounded-grid stage, a filter circuit should be included in the heater supply of the frequency changer. This filter may consist of a choke of 20 turns enamelled copper wire of 0.3 mm wound on a former of 8 mm diameter and a capacitor of 390 pF. One side of the heater of the frequency changer is normally earthed and the choke is connected in series with the other side, the capacitor being connected between the supply line and earth. The filter components should be mounted close to the tube holder.

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