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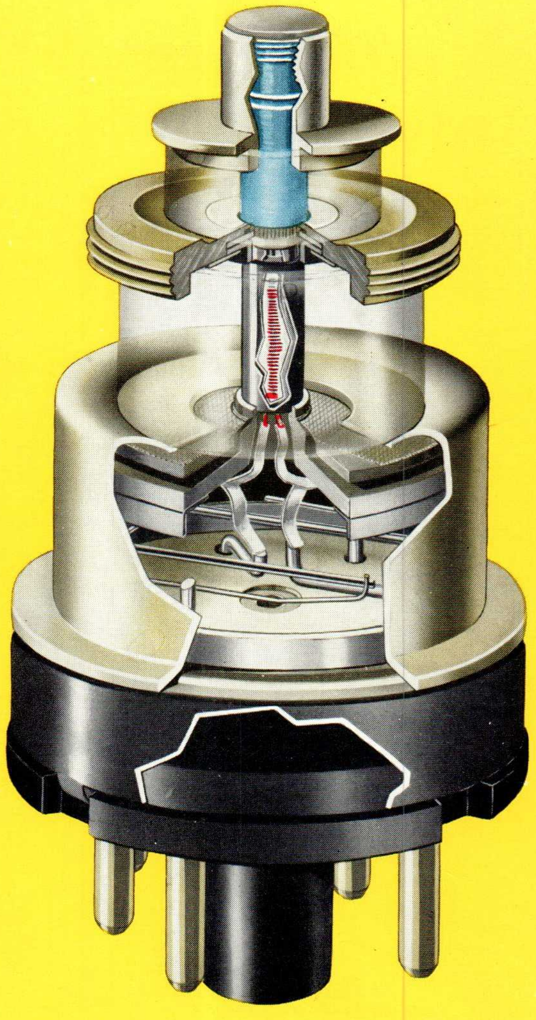

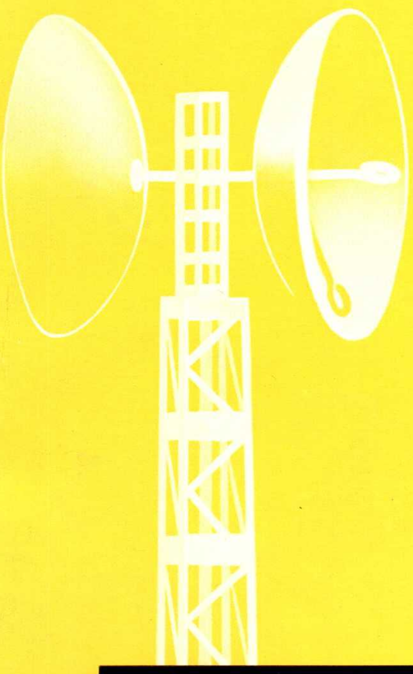

Broad-band 4000 Mc\s amplifier unit

with the triode EC 56
or EC 57
for microwave communication links

PHILIPS ELECTRONIC MARKETS DEPARTMENT

PREFACE

Point-to-point connections for transferring intelligence (e.g. audio, video, facsimile), such as AM, FM or pulse-coded modulation, may in principle consist either of wireless connections (beam transmitters) or of line connections (cables). The choice between these two systems will as a rule be determined by the local conditions in each individual case.

For wide-band transmission the use of a beam transmitter may be preferred to a line connection, because (expensive) coaxial cables and line-amplifiers can be dispensed with. Especially in cases where cables would have to be very long, or where their laying and maintenance would be difficult (rocky or watery areas), the beam transmitter is to be preferred to a line connection.

These arguments are valid both for multi-channel telephony and for TV link connections. Particularly in this application, which has become very up to date, the beam transmitter renders excellent and indispensable service. For semi-permanent link connections (commentaries) the beam transmitter is even the only practical solution.

For rapidly exchanging data, the beam transmitter will indubitably be appealed to, included the exchange between data-processing machines, the use of which may be expected to increase steadily.

Several types of electron tubes can be used as microwave amplifying tubes in beam transmitters. Proceeding development in the field of the short-wave technique has succeeded in manufacturing triodes, with their inherent advantages, for use on centimetric waves.

In this Bulletin a description is given of a 4000 Mc/s beam transmitter amplifier that can be equipped with the disc seal triodes EC 56 or EC 57. Due to the incorporation of a "ferrite isolator", a recent application of ferrites in microwave technique, it has been found possible to build the amplifier as a complete unit, the tuning and maintenance of which is extremely simple. As a consequence, an unlimited number of amplifiers can be connected in cascade, the EC 56 being used in the low-power stages and the EC 57 in the output stage.

Detailed information on these and additional merits of the amplifier is given in this Bulletin, whilst also the amplifier (type 88935) and the available accessoires, viz. the interstage isolator (type 88936/00 and the antenna isolator (type 88936/02), are described. In Appendices the theoretical considerations on which the design is based, are given in full detail.

CONTENTS

INTRODUCTION

The microwave amplifier with the EC 56/EC 57 described in this Bulletin is designed for use in beam-transmitter relay stations, which a.o.can provide the transmission of TV or telephony signals. Below, the specific properties of this amplifier are briefly discussed on the basis of the application mentioned above.

In beam transmitters use is made of the quasi-optical properties of very short radio waves, with the aid of which it is rather simple to produce narrow beams in which the transmitted power is highly concentrated. The C.C.I.R. [1]) has laid down directives for the application of relay stations, in which amongst others the frequency bands are allotted. One of these bands ranges from 3800 to 4200 Mc/s, for which band the amplifier in question has been designed. For the transmitter the F.M. system, the use of which has also been dictated by the C.C.I.R., has a great advantage over A.M., namely the high efficiency with which the microwave amplifiers can be operated.

Considering the choice of microwave amplifiers in relay stations, the following items will be of paramount importance.

BANDWIDTH, OUTPUT POWER, DISTORTION

In general the amount of information to be relayed is proportional to the bandwidth. With a view to a reasonable quality of a frequency-modulated TV signal, the bandwidth should amount to some tens of Mc/s. In multi-channel telephony the bandwidth is important in connection with the number of channels for which the band allows. The amplifier described has a bandwidth of 50 Mc/s between the 0.1 dB points, which is sufficiently large for the transmission of one TV channel or some hundreds of telephony channels.

The power transmitted in a given solid angle is determined by the output power of the transmitter and the antenna gain. For a good quality of reproduction this transmitted power should have a given minimum value, which is highly dependent on local circumstances, such as atmospheric absorptions and the distance to be bridged. Since this distance (scatter-propagation disregarded) is limited by the optical horizon, it will in practice amount to some tens of kilometres.

Another factor determining the minimum transmitted power is the noise factor of the receiver. The smaller this noise factor, the smaller the signal at the input of the receiver need be in order to obtain a given minimum signal-to-noise ratio at the output of the receiver.

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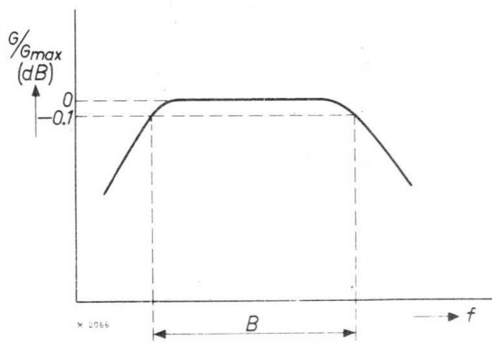
[1]) Comité Consultatif International des Radiocommunications.

In practice it appears that an output of some hundreds of milliwatts is as a rule sufficient. The amplifier described, equipped with an EC 57, will deliver, at a power gain of 8 dB and a 0.1 dB bandwidth of 50 Mc/s, an output power of 1.8 W.

Although amplitude linearity of a frequency-modulated signal in itself is of no importance, a curved frequency-response characteristic gives rise to phase distortion ("level-to-phase conversion"). In order to reduce this type of distortion as much as possible, the amplifier described is so designed that the frequency response curve shows a horizontal part that, measured between the 0.1 dB points, has a width of 50 Mc/s (see Fig.1). An additional advantage of the flattened response curve is the possibility of connecting a number of amplifiers in cascade without any loss of bandwidth whatever.



Another origin of phase distortion is found in group delay times. Their influence in the EC 56/EC 57 amplifier is, although it can completely be compensated, negligibly small [1].

Fig.1. Frequency response curve of the amplifier described.

OPERATING VOLTAGE

The operating voltage of a relay station is of great importance in places devoided of a mains connection, such as sparcely populated areas or places that are difficult to approach (mountain tops etc.). The EC 56/EC 57 has an anode voltage of 180 V, which is in good agreement with those communication systems having a battery voltage of 200 V.

Furthermore a low operating voltage is of great interest for safety reasons, and with a view to insulation.

THE CONTINUITY OF THE TRANSMITTER

In view of the importance of link systems it is obvious that failures in relay stations have to be reduced to a minimum. In this respect the EC 56/EC 57 amplifier has the advantage that every amplifying stage of a cascade circuit is produced as a separate unit, so that it can be replaced at once. Moreover, all units of the cascade circuit are identically tuned and adjusted, so that they are mutually interchangeable. Adjusting the unit can therefore be brought about outside the transmitter, in which case a swept-frequency oscillator is an indispensable expedient (see page 19).

When during operation an amplifying tube breaks down, it can be replaced immediately, during which time the apparatus need not be switched off. Except for the tuning of the anode circuit no re-adjustments need be carried out before the transmission has come to an end.

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[1]) See Appendix II.

DESCRIPTION OF THE AMPLIFIER

Basically the amplifier is a triode in grounded-grid circuit with tuned input and output circuits. These circuits (between grid and cathode and between grid and anode) are formed by quantities with distributed constants, whilst the input and output couplings are provided by waveguides. The basic set-up of the amplifier is shown in Fig.2.

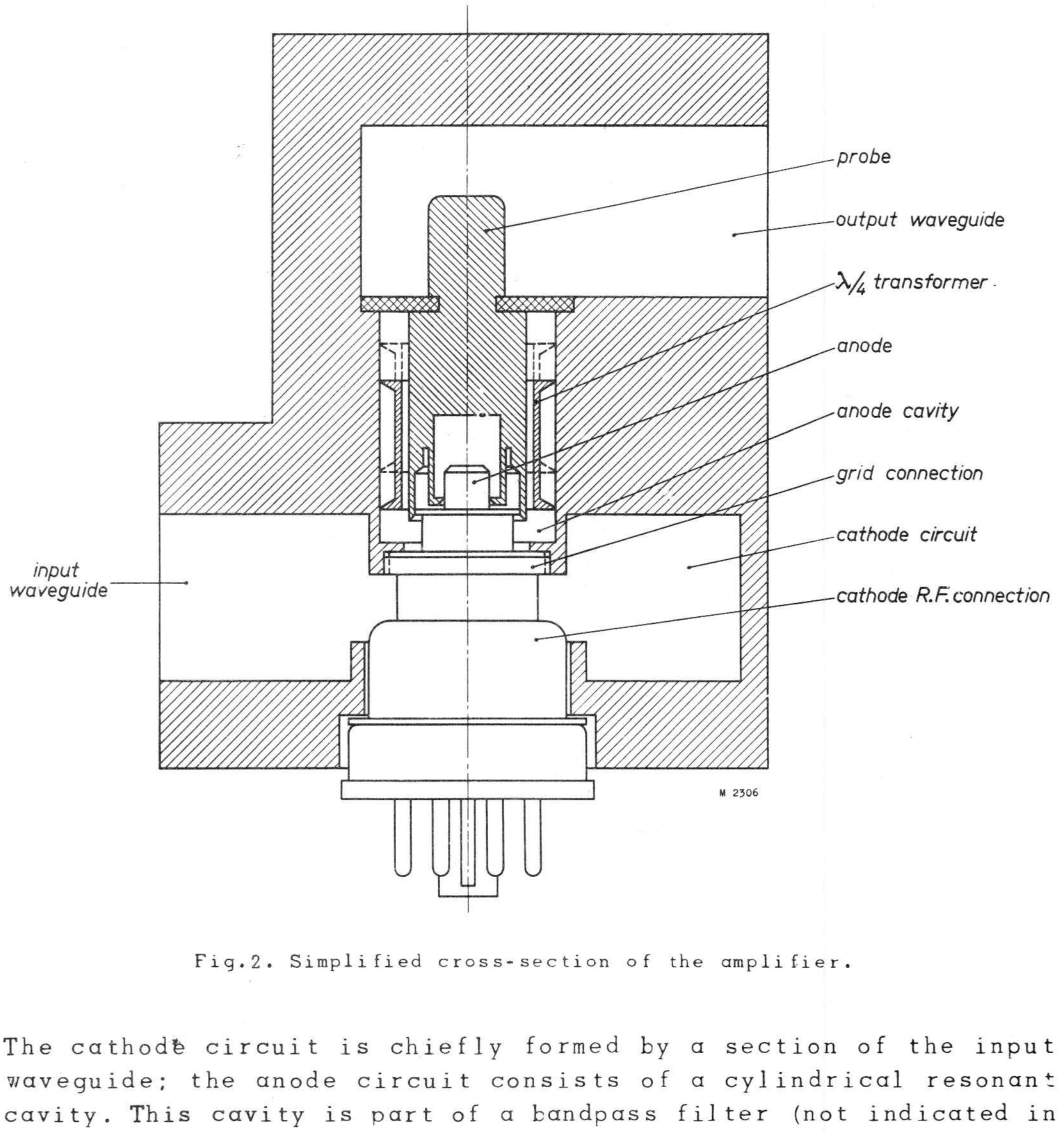

Fig.2. Simplified cross-section of the amplifier.

The cathode circuit is chiefly formed by a section of the input waveguide; the anode circuit consists of a cylindrical resonant cavity. This cavity is part of a bandpass filter (not indicated in Fig.2), which will be discussed in the following section.

The grid connection of the tube is screwed into the partition formed by the common wall of the cathode and anode circuits. This construction ensures a good R.F. contact between the grid connection of the tube and the circuitry, as well as a good separation between the two resonant circuits.

The anode cavity is tunable by means of a movable piston that, moreover, serves as a $\lambda/4$ transformer in the coaxial line which connects the cavity to the output waveguide. This transformer proved to be necessary to reduce the damping of the output waveguide on the cavity. The coupling between the coaxial line and the output waveguide is achieved by means of a probe functioning as a coaxial-to-waveguide transition.

As a result of the requirements made on the bandwidth and the power matching, the actual amplifier is more complicated than described above. Both the cathode and the anode side are provided with adjustable elements, whilst a ferrite isolator is connected to the output circuit to prevent reaction from the next stage having any unfavourable effect on the performance.

In the following Section the discussion of these elements will be based on their design.

THE CATHODE CIRCUIT

When considering the matching of the input side of the amplifier to the driver, the input impedance of the amplifier should be discussed first. The nature of this impedance is rather complicated; it can, however, with good approximation be represented by the equivalent circuit shown in Fig.3*a*. In this figure C_{KG} represents the cathode-to-grid capacitance, $1/S$ the electronic input damping of the tube (S = mutual conductance), L_K the inductance of the cathode and C_L the capacitance between the RF connections of grid and cathode.

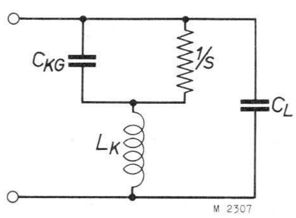

Fig.3*a*. Equivalent circuit of the input impedance.

It appears that at a given frequency within the band considered (approx. 3900 Mc/s) the total input impedance is real and equals the characteristic impedance of the input waveguide. This can be seen in Fig.3*b*, in which the impedances (admittances) of the components and their combinations are plotted in a Smith-diagram, normalized on the characteristic impedance of the input waveguide.

It is obvious that such a correct matching as indicated in Fig.3*b* exists at one frequency only. The deviations occurring at other frequencies are shown in Fig.4, in which curve *I* represents the input admittance of the amplifier with the frequency as parameter and the anode short-circuited for R.F.

Fig.4 shows that between 3800 Mc/s and 4000 Mc/s the mismatching is relatively small, whereas above 4000 Mc/s the V.S.W.R. in the input waveguide assumes rather high values. In the amplifier the mismatching is corrected by means of a variable impedance transformer inserted in the input waveguide. To avoid a too heavy reduction of the bandwidth the transformer ratio must not be excessive. At frequencies above 4000 Mc/s the input waveguide is therefore provided with a fixed reactance, which results in reducing the mismatching in such a way that the values of the frequency in Fig.4,

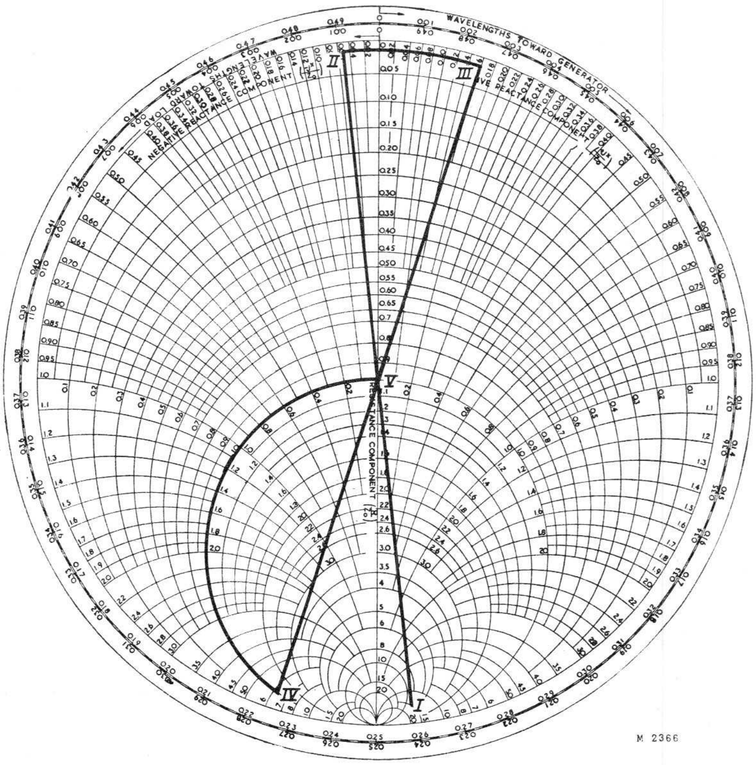

Fig.3b. Impedances and admittances of the elements of Fig.3a, plotted in a Smith-diagram, and normalised on the waveguide admittance. The reference plane passes through the axis of the tube. *I*: $S + j\omega C_{KG}$; *II*: $1/(S + j\omega C_{KG})$; *III*: $II + j\omega L_K$; *IV*: $1/(II + j\omega L_K)$; *V*: $IV + j\omega C_L$.

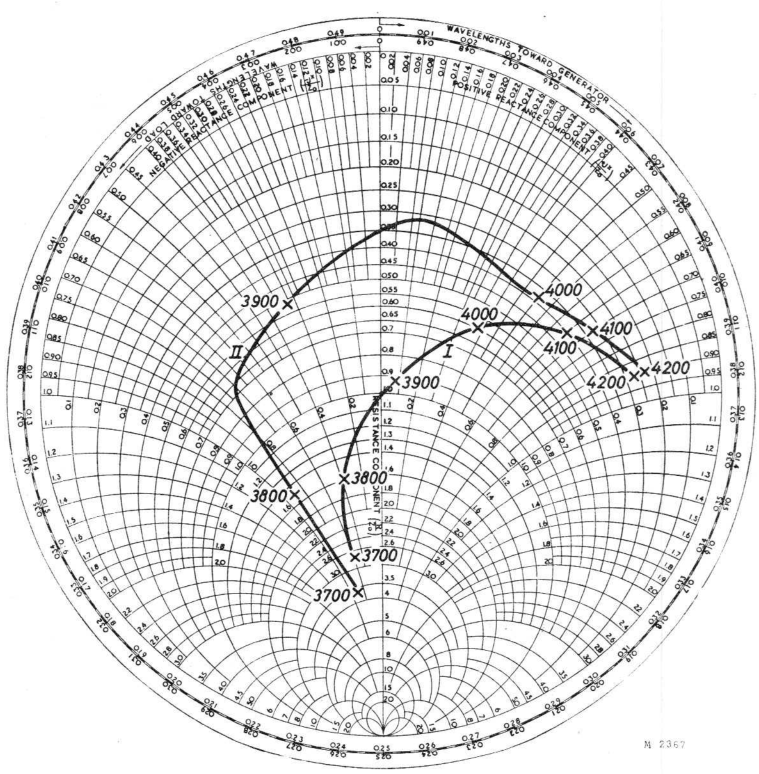

Fig.4. Input admittance of the amplifier plotted in a Smith-diagram with the frequency as parameter; *I*: anode circuit short circuited, *II*: anode circuit tuned to the operating frequency.

curve *I*, are increased by 200 Mc/s. Due to the presence of the additional reactance, the part of curve *I* located between 3800 and 4000 Mc/s is now valid for the frequency range from 4000 to 4200 Mc/s. The remaining mismatch can be corrected with the aid of the variable impedance transformer.

The fixed reactance discussed consists of two matching strips inserted in the input waveguide close to the cathode RF connection of the tube.

In the preceding the input impedance has been considered with the anode short-circuited. When, however, the anode circuit is tuned to the operating frequency, which is actually done, a reaction occurs, as a result of which the input admittance deviates from curve *I* of Fig.4. This can be seen in curve *II*, showing the input admittance with tuned anode circuit [1]).

The total reaction is the combination of three effects, viz.: (1) reaction via the electron current in the tube, (2) capacitive reaction via the anode-to-cathode capacitance, and (3) inductive coupling between the anode and cathode circuits via the grid wires of the tube.

The deviation of curve *II* with respect to curve *I* depends strongly on the value of the amplification factor (μ) of the tube: the higher the value of μ, the smaller the deviation will be. Tubes with a high μ would therefore be preferable as far as small mismatching and consequently small reduction of the bandwidth are concerned. Output and gain are, however, unfavourably affected by a high amplification factor. The EC 56/EC 57 has therefore been so designed that the value of its amplification factor gives a reasonable compromise between bandwidth on the one hand, and power gain and output power on the other.

As a result of the heavy damping by the small input impedance of the tube, the bandwidth of the cathode circuit is relatively large. The overall bandwidth of the amplifier is therefore mainly determined by the bandwidth of the anode circuit.

THE ANODE CIRCUIT

As was mentioned in the preceding, a bandpass filter is incorporated in the anode circuit of the tube. The filter consists of two resonant circuits and a coupling element. One of these circuits is the anode cavity; the other is formed by a resonant iris inserted in the output waveguide, whilst the coupling element consists of the waveguide section that is located between the resonant circuits and is provided with a variable reactive element.

From measurements it follows that, at tuned anode circuit and disconnected coupling element and iris, the output damping of the amplifier is very small. This is to be attributed to the positive feedback occurring when the anode cavity is tuned. The apparent quality factor of the latter may therefore be regarded as being very high.

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[1]) In this respect "anode circuit" means the bandpass filter with a flattened response curve, the 0.1 dB bandwidth of which is 50 Mc/s (see next Section: "The anode circuit").

From calculations on the bandpass filter (see p.42) a condition has been derived that must be satisfied in order to have a response curve with maximum flatness [1]. Furthermore, it appears that with such a response curve the 0.1 dB bandwidth of the bandpass filter is *exclusively* determined by and directly proportional to the 3 dB bandwidth of the second resonant circuit (iris), provided the quality factor of the first resonant circuit (cavity) is infinitely high. Although the actual quality factor of the anode cavity has a finite value, in practice the statement mentioned above also holds for the case in question. Thus the amplifier has the important feature that its 0.1 dB bandwidth is practically independent of spreads in tube data, whilst its bandwidth can be adjusted by the choice of a given iris.

The iris, which forms an integral part of the amplifier assembly, consists of two cylindrical matching strips and a tuning screw located in the output waveguide. With the aid of the tuning screw the iris can be tuned to the desired frequency.

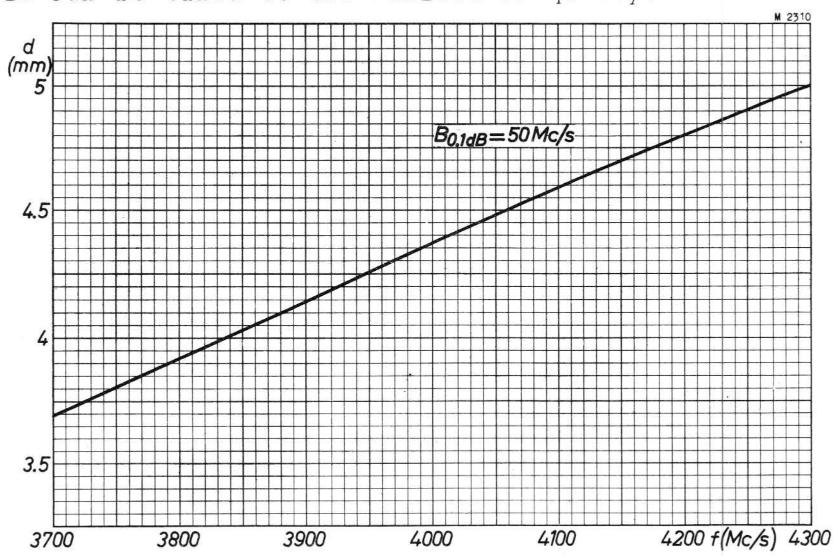

Fig.5. Relationship between the diameter of the matching strips of the resonant iris and the resonant frequency for a 0.1 dB bandwidth of the amplifier of 50 Mc/s. The value for the diameter is also valid for the average diameter of two unequal strips.

At a constant configuration of the iris its bandwidth depends on the resonant frequency. Since the bandwidth is determined by the diameter of the (inductive) matching strips, the latter have been made interchangeable, so that for every frequency within the band the 0.1 dB bandwidth of the amplifier can be adjusted to 50 Mc/s. This relationship between strip diameter and resonant frequency is shown in Fig. 5.

THE FERRITE ISOLATOR

It is well known that at microwaves non-reciprocal phenomena can be realised with the aid of ferrites. Advantage is taken of this property in the so-called "ferrite isolator", a fourpole causing in one direction a low, and in the opposed direction a high attenuation. The performance of this isolator is based on the occurence of gyro-magnetic resonances in ferrites [2].

[1]) See Appendix I, Section 3.

[2]) *H.G.Beljers*, Amplitude Modulation of Centimeter Waves by means of Ferroxcube, Philips Techn.Rev., Vol.18, p.82 (No.3).

In the EC 56/EC 57 amplifier the ferrite isolator is used for preventing undesired feedback (reflections), caused by incorrect matching of the following stage (amplifier or antenna).

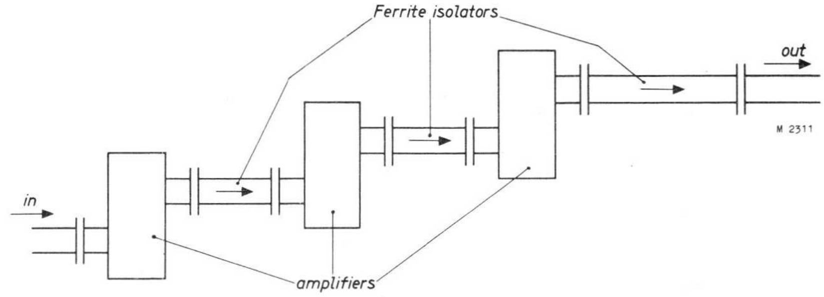

Fig.6. Schematic representation of the cascade circuit of three amplifiers with ferrite isolators.

The set-up of a multi-stage amplifier with the application of ferrite isolators is schematically shown in Fig.6. The isolators are so connected that power propagated in the direction of the arrow is passed practically unattenuated. In the opposite direction a large attenuation occurs (20 to 40 dB). Reflections, caused by a following stage, are therefore heavily attenuated and have no influence whatever on the behaviour of the preceding amplifier. The unit amplifier-isolator can therefore be considered as being unidirectional. As a result, each of these units can be adjusted separately, which renders the complete adjustment of the multi-stage amplifier very simple.

The ferrite isolator (see Fig.7) consists of a waveguide section, in which a slab of ferroxcube is mounted in the direction of propagation. This slab is magnetized by a permanent magnet outside the waveguide. Since the field strength needed for the occurrence of gyro-magnetic resonance depends on the frequency of the microwave signal, the former has been made adjustable with the aid of a variable reluctance.

In order to increase the ratio between the attenuations of the incident and the reflected wave, a plate of quartz is cemented to the ferroxcube slab. For matching purposes either side of the isolator is provided with two tuning screws.

In order to check the amount of power passing the ferrite isolator, one of the side walls is provided with an aperture through which a small coupling loop can be inserted in the isolator. It is preferable to solder this loop onto a coaxial connector, type number UG 53 U, which can be mounted directly on the isolator. When the aperture is not used, it must be closed by a cover plate.

THE ANTENNA ISOLATOR

The ferrite isolator connected between the final amplifier and the load (antenna) is provided with a tapered quartz plate as a result of which the reflection of this "antenna isolator" is smaller than that of an "interstage isolator". As a consequence, it is also made somewhat longer (Fig.8).

Since the configuration of the antenna isolator is somewhat different from that of the interstage isolator, two additional matching strips are inserted at both sides.