B.I.O.S. MISCELLANEOUS REPORT No. 83.

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ADVANTAGES AND DISADVANTAGES OF FREQUENCY AND PHASE MODULATION IN THE LIGHT OF THE SPECIAL REQUIREMENTS DEMANDED BY AVIATION, AS WELL AS ITS APPLICATION TO WIRELESS NAVIGATION

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I. INTRODUCTORY REMARKS AND GENERAL DISCUSSION OF PROBLEM

There are three possible ways of modulating a high frequency: (1) The amplitude modulation, principally used hitherto. (2) The phase modulation, and (3) The frequency modulation. The frequency modulation forms a special case of phase modulation, since here the frequency range remains constant for all low frequencies of the same amplitude to be transmitted.

Theoretical research on frequency and phase modulation has been known for a long time (1,2) NOTE: ALL FIGURES IN BRACKETS REFER TO THE GLOSSARY AT THE END OF THE BOOK). Nevertheless the advantages of these modulation methods were completely misjudged at first, inasmuch as only efforts were made to reduce the required frequency band for a wireless transmitter.

After the appearance of side bands in frequency and phase modulation had shown that such narrowing of the required frequency band does not occur, frequency modulation was again abandoned and for a long time merely regarded as an interference phenomenon accompanying amplitude modulation.

The tendency in wireless technique towards still shorter waves, in particular the development of decimetre wave technique, caused a re-approach to the problem of frequency modulation. Owing to the lack of frequency constancy in decimetre wave transmitters, frequency modulation at first inevitably occured with amplitude modification.

It was acknowledged that the freedom from interference due to frequency modulation was the most important modern feature in this respect.

At first the American development tended towards attaining a highly efficient system of ultra short wave transmission, as free from interference as possible. This has been generally realised by the use of wide band frequency modulation with large frequency range. (± 75 kilo cycles and modulation frequency up to 15 kilo cycles). However, the adaptation of this wide band frequency modulation for official communications (particularly for military purposes) was found difficult owing to the width required.

Official communications require ample clearness at highest possible range at which values of the signal/noise ratio of 10:1 and modulation frequencies up to 3,000 cycles can be considered entirely sufficient. For wireless transmission purposes these values must be approximately 100:1 and 15,000 cycles respectively. In view of these requirements it was anticipated, when using frequency modulations for official communications, that it would be possible to use a smaller modulation factor $\left(\frac{\Delta f}{f_{m\ max.}}\right)$ firstly, owing to the lower modulation frequencies of smaller range, and secondly, on account of the lower signal/noise ratio. Also that, in spite of this, frequency modulation would be considerably more advantageous than amplitude modification with respect to the margin of interference. Experimental tests have shown that with a maximal transmitted modulation frequency of approximately 4,000 cycles, the range can be reduced to 10,000 cycles without considerable loss in transmission efficiency. This is confirmed in Fig. 1 where the interference ratio for a wireless communication is shown over different distances with amplitude and frequency modulation at 10 kilo cycles and 50 kilo cycles range respectively. Measurements by Crosby [5] showed that in simple signal communication traffic, even smaller ranges ($\Delta f = f_{m\ max.}$) gives a better signal over noise ratio at very small field densities. This is due to the fact that it is possible to use a very small type of receiver, and that the incoming noise decreases with the root of the band width. The latter feature may be of importance within the range of short waves but in the case of ultra short waves the above improvement is not applicable since the band width is not determined by the transmitted side bands but, by the frequency constant of the transmitter and receiver. Consequently, it is impossible to go below a minimum band width, for which reason it is permissible to utilize this band width to the full for frequency modulation.

It follows from the above that the narrow band frequency modulation does not require any considerably wider frequency bands than amplitude modification. Consequently there is no objection to applying it to official communications.

Frequency modulation mainly appeared to be advantageous in branches of wireless communication subject to pronounced interference. Practice has shown that in particular ultra short wave sets on aircraft are sensitive to interference due to aero engine ignition systems or emitted by travelling motor cars and industrial plants.

Parallel to the designing of suitable transmitters and receivers for frequency modulation, research showed interest in the phenomena accompanying wave propagation. While such phenomena were absent in ultra short wave transmission, they appeared in connection with short waves.

In the case of multiple transmission paths due to ionospheric influence, pronounced distortions may occur with frequency modulation under certain conditions (humming oscillations). Close examination showed that such humming oscillations are mainly induced by the difference in transit time between waves coming in along two or more paths, and the frequency range.

The anticipated advantages of frequency modulation were fully confirmed by experimental tests with ultra short waves, while in connection with short waves resitriction (limitations) relative to transmission frequency and frequency range apply.

Since the present paper particularly concerns itself with aeronautical requirements, the corresponding efficiency demands on the used apparatus are briefly summarised.

The use of wireless in aircraft implies fixed requirements regarding each individual set. Owing to lack of space and strict limitation of weight, only a certain capacity regarding transmitter output, the number of stages and the number of valves for the receivers and auxiliary apparatus appears permissible.

The requirements of an ample frequency constant in transmitter and receiver (temperature requirements) together with easy mode of operation (harmonising the various stages, remote control) must be fulfilled with restricted power.

For these reasons transmitters of a few to approximately 100 watts are used in association with receivers of high sensitivity and selectivity. In contrast hereto, ground stations can have higher transmission output with higher capacity.

In aviation wireless is used in connection with signals, flight control and navigation. When judging the advantages and disadvantages of the three respective types of modulation, the long and medium wave ranges (bands) can be excluded since they are merely used for telegraphic purposes. Short wave and ultra short wave bands are the main interest in connection with telephony and telegraphy with tone control.

Long and medium distance communications are covered by the short wave band, while ultra short wave bands are exclusively used for plane to plane or air to ground communications. Navigation methods which are still in their development stage occupy a position by themselves.

The abundance of the phenomena tends to justify a comparative distinction between the advantages and disadvantages of the three types of modulation, of the systems used and of their application to modern navigation methods. It will be the subject of the present paper, while taking into account the special requirements regarding aviation.

II. ADVANTAGES AND DISADVANTAGES OF FREQUENCY AND PHASE MODULATION IN CONTRADISTINCTION TO AMPLITUDE MODULATION WHEN APPLIED TO AVIATION

After the large number of papers published on the difference between frequency (phase) and amplitude modulation, the present treatise will deal with the practical use and effects of frequency modulation (phase modulation) for wireless sets used in aviation. A clear definition of the above notions appears therefore appropriate. [4].

In modulation with **a single** sine like voltage, the three types of modulation can be represented as follows:

1. Amplitude modulation:

$$F_{(t)} = A_o \sin \omega_o t + A_1 m \sin \omega_o t \sin \omega_m t =$$

$$= A_o \sin \omega_o t + \frac{Ao}{2} m \sin (\omega_o + \omega_m) t$$

$$+ \frac{Ao}{2} m \sin (\omega_o - \omega m) t \quad . . (1)$$

in which A_o = Amplitude, $2 \pi f_o = \omega_o$ = carrier frequency.

$2 \pi fm = \omega_m$ = modulation frequency.

m = degree of modulation.

The amplitude modulation can be resolved into the carrier frequency ω_o with an amplitude A_o and two side bands with the amplitude $1/2 A_o m$. The side bands are in phase with the carrier and differ by w_m from the carrier frequency. The amplitude of the side bands is determined by the degree of modulation m.

2. Frequency modulation:

$$F_t = A_o \cos \left(\omega_o t + \frac{\Delta \omega \max}{\omega_m} \sin \omega_m t \right) =$$

$$= A_o \sum_{n = - \infty}^{n = + \infty} I_n \left(\frac{\Delta \omega \max}{\omega_m} \right) \sin (\omega_o + n . \omega_m) t \quad .(2)$$

$\Delta w \max$ = Frequency range, $\frac{\Delta \omega \max}{\omega_m \max.}$ = [illegible] = modulation index

With frequency modulation (apart from the carrier) an endless number of side bands occur in the margin $n \omega_m$, the amplitude of which varies according to the Bessel function I_n

h the proposition $\frac{\Delta\ \omega\ max}{\omega_m}$. The amplitude of the side ids varies with w_m , whereby the even sidebands are in or of phase with the carrier while the odd ones are rotated 90° or 270°.

For a low modulation index ($\mathcal{H} \leqq 0.5$) only two side nds actually occur, when the frequency modulation can be pressed by :

$$F\ (t) = A_0 \sin\ \omega_0 t + A_0 \frac{\Delta\ \omega\ \ max}{\omega_m} \cos \omega_m t \sin \omega_0 t\ \ . \ .(3)$$

.e. the sidebands are rotated by 90° relative to the carrier ave, and the amplitude is inversely proportional to the odulation frequency ω_m.

3. Phase modulation:

$$F\ (t) = A_0\ \cos\ (\omega_0 t + \Delta\ \Phi \sin\ \omega_m t\ ) =$$

$$= A_0 \sum_{n\ =\ -\infty}^{n\ =\ +\infty} J_n\ (\Delta\Phi)\ \sin\ (\omega_0 + n\ .\omega_m)\ t\ \ .\ .\ .\ .\ .\ \ (4)$$

$\Delta\ \Phi = \frac{\Delta\ \omega\ max}{\omega_{m\ max}}$ = Phase range.

This produces the same frequency spectrum as with frequency modulation, with the exception that the side band amplitudes are independent of ω_m. For a small range of phase ($\Delta\ \Phi \leqq 0.5 \leqq 28°$) we obtain

$$F\ (t) = A_0\ \sin\ \omega_0 t + \Delta\ \Phi\ A_0 \cos\ \omega_m t\ \ \sin\ \ \omega_0 t\ \ .\ .\ .\ .\ (5)$$

Likewise two side bands will occur which are rotated by 90° against the carrier, but possess constant amplitude.

A. Transmitter.

As already mentioned at the beginning the main advantages of frequency modulation lie in the interference suppression on the receiver side. Fundamental differences occur however in the use of frequency modulation or phase modulation in the transmitter as opposed to amplitude modulation. The advantages and disadvantages from the transmitting point of view must first be analysed. The advantages and disadvantages of frequency and phase modulation as opposed to amplitude modulation, insofar as they affect both frequency modulation and phase modulation, will be dealt with first of all.

(a) Power, efficiency of the final stage and volume control.

With frequency modulation, the communication to be transmitted, independent of the amplitude, is included with the alteration of the frequency. The main transmitter stage of the transmitter can therefore be operated with peak power output. This signifies, in contrast to a grid modulated transmitter, a quadruple carrier power radiation, or an advantage in receiver field density of 100%. Apart from this power gain in the final stage, there occurred a simultaneous considerable improvement in efficiency. The efficiency of a final stage operated at peak power output lies until entering the ultra short wave field downwards at about 70%, whereas with amplitude modulation with grid or plate -B- modulation o about 20% or 35% efficiency can be attained.

Plate -B- modulation, on account of the heavy requirements of the modulation amplifier which uses about 60% of the high frequency output for low frequency, is rarely used for aircraft transmitters (question of weight and space).

In contrast to amplitude modulation, frequency and phas modulation offer therefore on account purely of C. operation the advantage of greater utilized output and higher efficiency.

Furthermore with frequency modulation it is particularl easy to control the power radiated. For military communications this can readily be applied to limiting the range of transmission. With amplitude modulation, power regulation is possible either by introducing power absorption links in the antenna circuit or by reducing the working voltage of the individual transmitter stages. In so doing, the transmission efficiency (slight distortion) must be maintained, which in practice cannot be attained without greater consumption.

As opposed to this the arrangement for output control by frequency modulation is extremely simple, inasmuch as th power for the final stage for instance can be regulated with de limits by varying the negative grid bias voltage, with-t influencing the modulation.

(b) Required low frequency output for modulation.

Amplitude and frequency modulation transmitters further ffer from each other by the low frequency power required or modulation.

With small amplitude modulation transmitters which are mainly used for aircraft purposes, the modulation nearly always takes place in the final stage (grid or suppressor grid modulation.) To modulate the frequency either a reactance valve or a push-pull modulator is used according to the method employed (compare III A. a and b). The minimum of low frequency output is required by the direct frequency modulation method with a reactance valve. In AM - grid modulation the modulation amplifier steps up the final stage to a certain output by the existing grid current (Order of magnitude 1 W), while in suppressor grid modulation (practically without power) a relatively high alternating voltage (order of magnitude 100 V) is required.

In contrast hereto direct frequency modulation combines the advantage of a practically power-free modulation with low voltage (order of magnitude: a few volts).

The consumption required by the amplifier for modulating the FM transmitter is thus the same with the direct modulation method, mainly used on aircraft, as with amplitude modulation.

This advantage is partly counteracted by the requirement of a variable amplifier. The modulation valve of a FM transmitter is sensitive to low frequency over - modulation. The frequency range is proportional to the low frequency amplitude (sound strength) along the straight section of the modulation characteristic curve (diagram No. 3). When this amplitude exceeds a fixed magnitude, low frequency distortions occur similarly to what happens in amplitude modulation owing to overmodulation of the modulation characteristic. Whereas however with amplitude modulation the degree of modulation is definitely determined by the modulation of the transmitter, the conditions fundamentally differ in frequency modulation.

$$\text{The degree of modulation} = \frac{\text{sound strength}}{\text{max.sound strength}} = \frac{\Delta f}{\Delta f\ \text{max.}} \quad \text{is}$$

(shaped like the fig. 8) is then converted into a kidney-shaped characteristic by beam transmitter excited in suitable phase at the centre of the two pairs of aerials. Each time the maximum of the characteristic passes through the North, transmission is completely blocked over a width of $\frac{1}{2}$ degree. On its arrival at a receiver, the characteristic causes a sinusoidal field density (strength) fluctuation which is completely uniform in all directions. Yet, the effect of interrupting the radiation at each traversing of the North point differs in each direction (See fig.42). In the northerly direction the interruption accurately coincides with the sinusoidal curve maximum of the receiver field strength observed in the receiver (e.g. by a cathode ray valve). Eastwards the maximum has already been exceeded by 90° at the moment of interruption, while southwards the excess amounts to 180°. The relative positional angle of the receiver and transmitter is therefore continuously indicated.

In addition to the use of F.M. for signal transmission and navigation, (discussed under A and B) it has also been successfully applied to a widely different field of action (e.g. ultrasonics have been applied to particularly complicated processes of manufacture, especially with regard to the chemical industry). Here, owing to the presence of stationary waves, it is often required to influence the frequency by F.M. in order to prevent their disturbing development.

VII. POSSIBILITIES OF FURTHER APPLICATION OF FREQUENCY MODULATION, ESPECIALLY FOR AIRCRAFT PURPOSES.

When considering the possibilities of a further application of frequency modulation, it must immediately be pointed out that this is possible in all fields where up to the present the application of frequency modulation had only been tentatively effected, and where, despite the more advantageous characteristics of frequency modulation, amplitude modulation is still widely used for the intended purpose. Following the discussion in chapter VI of existing practical application of frequency modulation, the following fields of application suggest themselves:

A) Signals transmission.

1. Broadcasting.
2. Commercial Telephony.
3. Television.
4. Wireless Photography.
5. Indirect uses.

B) Navigation

With reference to A 1:

Regarding multi-programme broadcasting with improved reception in the post-war period, a choice will be required between high frequency line radio and USW broadcasting with frequency modulation. The author is of the opinion that the latter method appears the more hopeful. Furthermore, on account of television, the introduction of the entire USW technique will be unavoidable. The extent of the adoption of F.M. is shown by the number of broadcast stations - over 600 - and subscribers (over 30,000,000) found in Europe today.

With reference to A 2:

Commercial telephony appears to offer the best opportunities to frequency modulation. The same applies to aviation. All telephonic communication methods from ground to air and between aircraft should be converted to F.M. In most cases a simultaneous change over from long or limiting to ultra short waves is consequently to be expected. Such a decision was adopted in the U.S.A. in 1940, allowing a transition period of 3 years. It will probably be impossible to carry out this plan within the specified time owing to America's entry into the war. A conversion to the 2.3 metre wave zone was to have been carried out. (The 123 - 132 megacycle range is reserved). The zone of F.M. application is vast, both with regard to military aviation during the war and civil aviation in the post war period.

Relay circuits, displacing cables in all types of single or multi channel operation with telephony, telegraphy, teleprinting, radio photography and television, offer a still more comprehensive field of action to frequency modulation, thus establishing competition of higher efficiency relative to line and cable engineering combined. Aviation in this connection only represents a trifling part of engineering in general, insofar as it makes use of the latter, i.e. in interconnecting the many ground stations in all types of operation, including the feeding of radio transmitters and receivers. The above suffices to express the opinion regarding the further possible application of F.M. to the subjects under A 3 and A 4.

To 5. In ionosphere research a greater wave range can be covered by transmitters with the assistance of frequency modulation and a series of problems in this field can thus be more effectively investigated.

Otherwise, no specific prophesies can be made in respect of other indirect uses of frequency modulation. It appears to the author, however, to be certain that in view of the expanding application thorough knowledge of F.M. engineering will result also in new, indirect fields of application being discovered and opened up.

To B. In all previous applications of frequency modulation in the field of navigation (although definite frequency modulation methods are used), it is really a matter of indirect utilisation, as in no case the complete method shown under A, is put into operation. This applies also to what is stated under A 5:the growing application of frequency modulation to many other fields produces an increased knowledge of frequency modulation engineering, which will lead to the opening up of further fields of application in navigation.

Independent of this, the following particular problems already become obvious:

1. For blind landing sets, a general method has already been introduced in Europe, whereby audio modulated transmitters are used on 9 metre (beacon) and 7.9 metre (approach signal) waves with A.M. methods. The existing normalised European system must, however, sooner or later be modified, since

(a) the indicated line of approach is bent and does not correspond to the landing path [136] and

(b) in the U.S.A. long, ultra short and decimeter waves are partly used for beacons, while 4 m waves are used [16, 137, 138] for approach signals.

Further, for the distant future a standardised blind landing set will have to be introduced, which will cover all requirements. When this takes place a decision will have to be made whether it will not be more suitable to replace amplitude modulation by frequency modulation. In favour of frequency modulation it must be said that the existing range which is regarded at present as ample is obtainable with many smaller and simpler transmitters; against it, there will arise the necessity of exchanging the present very simple receivers for the complicated frequency modulation receivers. For the beacon signal an additional device would have to be provided in the receiver, by which the amplitude variations occurring outside the guiding beam would be made visible, since due to the effect of the limiter circuit this criterion of the entire guiding beam method would be primarily lost. This can be done in a simple manner. Transmitters for beacon signals, and approach signal transmitters and receivers could use normal frequency modulation methods without additional equipment.

2. The communication of data given by meteorological balloons as per VI B.1 makes it necessary for determining at different flight altitudes that optical or wireless measured direction finding takes place continuously from two points. If a combination of methods VI B.1 and VI B.2 is achieved - and this must be regarded as entirely possible - then the desired additional data can be obtained without the second station, and any unreliability created by the co-operative effect of the two stations would disappear. A precise method in respect of the technically suitable combination of VI B.1 and VI B.2 has not, however, up to the present emerged.

3. In wireless position finding further effective uses, showing an improvement on those described under VI B.3 for frequency modulation, will emerge, also here again simply on account of the growing proficiency in frequency modulation technique. One type of frequency modulation would be, for instance, a wireless beacon as follows: A rotating beacon in the style of blind landing beacons [135] is designed. It produces by the alternating emission of dots and dashes with different directional diagram, a guiding beam of about 50 width with the usual European type of aerial with 3 dipoles. With the American type with 10 dipoles the result is a width of 1.5° [137] , and any desired lesser width can be obtained without difficulty. By using a reflector, moreover, it can be ensured that only one guiding beam is emitted (with the beacon as per [135]). Two beams with a 180° displacement are used. By using correspondingly short waves the aerial structure to be rotated can be reduced to satisfactory dimensions. The fundamental frequency of the beacon transmitter is now additionally frequency modulated, that is to say, in the manner that to each point of the compass a distinctly specific frequency

is co-ordinated; for instance, the lowest frequency is emitted in the northerly direction. By rotating the guiding beam clockwise, the frequency increases proportionally to the angle of turn up to the maximum after a complete turn. When passing through the North point, it suddenly drops to the lowest value and the action is repeated so as to produce a saw-tooth like frequency curve. Direction finding at the receiving station is thus reduced to simple frequency measuring. If the frequency measurement is possible at an accuracy ratio of 400:1, the accuracy of position finding is already 1° (quadrant = 100°). Since the frequency measurement is readily improved upon, the accuracy of position finding can also be given a higher value. For this purpose it is of advantage that the angular points of the saw-tooth curve of frequency modulation supply reliable datum points. The method can be modified in a variety of manners. For instance; a set for frequency modulated telephony reception in aircraft can be used in addition for this purpose. Instead of the head phone, the frequency gauge alone is used. A locking circuit is interposed, however, which only frees the path to this gauge within the guiding beam. Such a locking circuit is readily arranged, since the dot-dash similarily, which only exists within the guiding beam, can be used as a measuring for opening the path.

In general it can be stated that such type of radio beacons must become important in the future. Aircraft direction finding which has hitherto taken place almost exclusively from the ground, must sooner or later be replaced, by direction finding taking place in the aircraft, by aid of ground radio beacons. The tremendously increasing number of aircraft using the skies makes this change of method necessary.

In summarizing the contents of this chapter it can be stated in regard to a possible further expansion of the use of frequency modulation that, in the field of signals, there is plenty of room. From this aspect it is now only necessary for the set designers and constructors to convert it into actuality. In the field of navigation, however, research must still be undertaken to ascertain whether the possibilities indicated offer advantages over the hitherto existing amplitude modulation method. In addition to this, the fact of the increasing proficiency of a large body of engineers with frequency modulation and the continuous association of ideas on the subject of signal transmission as well as navigation will open up new fields, which have never even been dreamed of at the present time.

be set at optimal in respect of range, linearity, frequency constancy etc. Regarding the selection of the oscillator frequency and the quartz frequencies, certain restrictions must be observed on account of the ambiguity of the superhetting principle, similar to those with superhet receivers. Care must be taken that no harmonics of the two mixer frequencies and of their undesired totals and differences fall in the transmission range of amplifier 5. This amplifier conceals several far from simple problems. It must be tunable over the entire frequency range and show a selectivity which widely suppresses the undesired frequencies produced by the mixer (stage). According to the purpose of the set fixed limits are set for the humming factor. Since in the amplifier 5 the modulation index m as well as the carrier frequency are still comparatively small, it is very often not easy to keep within these limits. These difficulties arise principally in sets with several telephony channels. On the other hand, with single channel sets they scarcely appear at all.

5. Frequency control of the carrier.

On the one hand, it is required of the frequency modulated stage that its frequency can be modulated, that is to say, varied, whereas, on the other hand, the average frequency must be kept constant with the greatest possible degree of accuracy. These two contradictory requirements require special measures for the maintenance of frequency constancy.

With simple sets for which no great expenditure is warranted, it suffices to design the oscillator as "frequency rigid" as possible. This is attained by the use of a high reactance output, i.e. by large C and small L. in the oscillator circuit and, when required, by use of temperature compensation.

CROSBY (28.116) indicates a system for keeping the frequency constant in broadcast transmitters, which is based on the so-called "fine tuning", as has been developed in the last few years for wireless receivers. This method is reproduced in principle in fig 27. The frequency of the oscillator f_{osc} and the frequency f_q of a quartz 8, are fed to a mixer stage 7. At the output end of the mixer stage the difference frequency $f_r = f_{osc} - f_q$ is filtered out by suitable selective means, whereby f_r is selected in the order of magnitude of 0.5 to 2 MHz. This frequency is fed to the RIEGGER circuit 6, whose frequency determining circuit F is tuned to f_r. The working method of the RIEGGER circuit variation ΔE_{go}. That the range should also remain the same, N_1 must also, according to equation (21) remain constant, with varying ω_o. This is attained by varying, in the oscillator circuit diagram No.15, both L_S as well as C_S, inversely proportional to the frequency.

If C_1 is kept stable, E_{g1} increases proportionally with ω_o. On this account the modulation curve is displaced parallel to itself, without altering its steepness to any great extent. The operating point is, naturally, moved, but ΔN remains the same as previously for a specific variation ΔE_{go}. If the corresponding range $\Delta\omega$ is to remain the same, then N_1/ω_o must remain constant. As, however, $N_1/\omega_o = E_{pl}{}^2/C_S$, so C_2 must remain constant, and the frequency variation can therefore only be brought about by varying L_S.

The second method is unusable for push-pull modulators, since with varying E_{g1}, the two component characteristics are displaced relative to each other and can only be made to coincide again by varying the fixed primary voltage. The same difficulty arises if the plate alternating voltage oscillates strongly with variation in wave.

If the linearity and constancy of the frequency impetus are of primary importance, the above methods will not be used. Instead, the carrier frequency of the frequency modulated stage will be left constant and converted by superhetting to the desired aerial frequency.

The construction of the transmission arrangements takes place then in a form as for instance is shown in diagram No.27. The modulator, section 2, likewise connected in push-pull, lies parallel to the push-pull oscillator. The oscillator frequency is superhetted in the mixing stage 4, with the frequency of the crystal oscillator 3 - (either direct or multiplied). In the selective amplifier 5, the desired superhetting frequency is filtered out and (after further multiplication and amplification) fed to the aerial, whereby the terminal connection (stage) functions as C_1 amplifier. With frequency change, the quartz crystal 3 is changed. The sections 6, 7 and 8, in fig.27 contain the frequency control and will be dealt with in the subsequent section. Since the oscillator frequency always remains the same even with wave change, the oscillator and modulator can amplitude modulation. In other words, if at a reception point with high jamming level a frequency modulated signal is received free of disturbance, a much stronger signal would be required with amplitude modulation (approximately 10 or 15 times as strong) to guarantee an equal standard of reception at this point. The observation of this phenomenon was made at various stations simultaneously in 1935. The ultra short wave technique, frequency modulation with large range and a limiter, were all known methods; the credit is due to ARMSTRONG (3.4) that the possibilities and the importance of their combination have been recognised, and it is for this reason that the system of the "wide band frequency modulation" is rightfully coupled with his name.

1. Elimination of interference by individual interfering stations and disturbing spectra.

It is not difficult to explain how jamming immunity came about (86.21) For this purpose we consider an unmodulated carrier expressed by

$$e = E \sin \omega_{10} t$$

and a second, likewise unmodulated carrier, which we call the disturbing factor expressed by

$$e_s = E_s \sin \omega_1{}' t = E_s \sin (\omega_{10} + \mu) t.$$

Let the frequency difference between e and e_s be μ. The superposing of e and e_s produces a whistling note of the fundamental frequency μ, which will be audible or inaudible according to whether μ lies in the audio field or not. Let the receiver band pass curve be wide enough to allow both e as well as e_s to pass unhindered. Let the receiver be a normal superhet. It will, therefore, convert the high frequency ω_{10} into the intermediate frequency ω_0. At the output end of the intermediate frequency amplifier we receive the resulting signal e_r, fig.28, caused by the addition of e plus e_s. The vector E_s rotates relative to vector E with the angular speed μ ; the terminal points of E_s and E_r describe therefore the circle B F C D. It can be seen from the diagram that E_r - (both with regard to amplitude and phase) is modulated in twofold manner by the jammer E_s. In regard to the amplitude, E oscillates between OB and OC; the whistling note impressed by E_s

In the receiver the phase modulated signal becomes distorted when demodulated by the frequency to amplitude converter, but is subsequently freed from distortion in the de-emphasis filter. An example will explain this. Let a standard frequency modulation have a range of + 40 kilo cycles. If we assume equal voltage amplitudes at 0.5 and 10 kilo cycles, it will thus have a band width of ± 40 and ± 64 kilo cycles according to fig.1. When the pre and de-emphasis system is applied, the same system will at similar assumptions have a band width of ± 40 and ± 250 kilo cycles. Since in a standard program the voltages of the low frequency region actually show a drop according to the curve 1 in fig.36, we find that a normal system will produce at 10 kilo cycles a band width of ± 10 kilo cycles, but that a pre and de-emphasis system will give a band width of ± 40 kilo cycles. The method thus simply represents an endeavour to utilise to the full a given band width for program output with frequency modulation, in contradistinction to a given amplitude range when amplitude modulation is used. The object therefore is the obtaining of a highest possible disturbance ratio.

V. The reciprocal interference of two frequency modulated carrier waves.

In amplitude modulation the relationship between two stations with adjacent frequency may be chosen so that the side bands overlap. In European broadcasting the difference between the carrier waves is 9000 cycles, i.e. twice the band width. This state is far from ideal, but as the higher frequencies of the low frequency band are weak with regard to power, the reciprocal interference is acceptable when the stations are set up at a great distance from each other.

With frequency modulation the side bands must not overlap. If they do, one signal frequency, would during part of the low frequency period, fall within the band pass of the receiver tuned in to the other signal and thus create correspondingly strong interference (88). The difference between two frequency modulated ranges must, therefore, be at least equal to the frequency difference in order to prevent non-permissible interference. Only under these conditions can the weaker signal be separated in a disturbance-free manner from a stronger one. Measurements by GUY (41) show that with the indicated carrier difference, according to the efficiency of the receiver, excellent the reactive coupling method low intermediate frequency amplification at small band width and large low frequency amplification. The lesser consumption, therefore, from the amplification point of view, would appear to lie with the second method.

VII. Phase Modulation.

CROSBY (22) investigated whether phase modulation of a small displacement is adaptable to signal transmission. In this, the phase displacement had a maximum of about 60° so that the sidebands of the second and third classification already disappeared in the frequency spectrum. He describes various transmission and reception methods. Regarding the signal over interference ratio, he finds the same value as with amplitude modulation. Finally, there only remains the one advantage: the higher efficiency of the transmitter. Since nowadays quite a large number of methods of amplitude modulation are known, whereby this high efficiency is likewise attained, the advantage may be regarded as illusory.

VIII. Importance of Frequency modulation for Aircraft Wireless.

We have become acquainted in frequency modulation with a method whereby, in disturbances of all types, a larger signal over noise ratio is obtainable than with amplitude modulation. On this account the method must be applied, when either a high signal over noise ratio must be attained, e.g. in broadcasting, or when despite very strong local interference perfect transmission is required. The latter is the case with police radio (reception in the midst of street traffic) and with aircraft wireless.

Since, for obtaining a higher ratio, a frequency range must be selected, which is greater than the low frequency band of the transmission, it follows, that frequency modulation always requires a larger band width than amplitude modulation. Frequency modulation could be used without difficulty in the long, medium and short wave range except for this fact. Moreover, the short waves are mostly used in long distance and trans-atlantic traffic. When applied, they suffer from many fading phenomena. Frequency modulation suffers in exactly the same way as amplitude modulation.

The main sphere of application of frequency modulation lies therefore in the field of ultra short waves.

Here the required frequency bands can be provided, and here the characteristics of frequency modulation and ultra short waves mutually support each other. The question whether frequency or amplitude modulation should be used is determined by the interference level which is peculiar to the circuit or the site of reception. With a connection between two fixed points, (for example when on account of sufficiently high frequency condition and grouping the actual ratio of interference considerably exceeds the required ratio) frequency modulation would be of little use. If on the other hand fading phenomena have to be allowed for or a high level of disturbance is experienced at the site of reception, the application of frequency modulation will always show an advantage relative to amplitude modulation. In order to use this advantage to its full extent, the range and low frequency band must be proportionally selected, since due to the fact that the "improvement" through frequency modulation relative to amplitude modulation only sets in at a certain threshold value, this selection is of extreme importance. If, for instance, the range is selected too large, reception will be completely free of disturbance at high reception level, while with weaker fields, the advantage of frequency modulation would be exceeded before the minimum of permissible disturbance ratio is reached. This point is of particular importance to aircraft radio. A high level of disturbance is to be expected within the machine, on the other hand, for telephony and telegraphy communication a disturbance ratio of about 12 DB (1.4 Neper = 1:8) would be sufficient. A width of about 4000 Hz suffices as low frequency band. If we now use equation (41) as basis for the crackling caused by the impulse type of transmission, the required range will be:

$$\Delta \omega_{max} = \pm 8 \text{ kHz.}$$

A greater reception range would cause a greater disturbance ratio but would increase the field strength required for advantage and thus reduce the range. This range is so inconsiderable that it offers no appreciable difficulties in regard to the band width, either at the transmitter or the receiver. The total band width of 16 kHz does not impair either the density of bundling, which is determined by the frequency constancy of the oscillator in the transmitter and or receiver.

Not only the peculiarities of frequency modulation but also the properties of the ultra short waves (used as carriers) are most suitable and advantageous in the case of aircraft radio.

Suitable, comparatively light aerials must be fitted to the machine for these frequencies without impairing its aerodynamic properties. Since vertical and horizontal polarisation only differ close to the earth surface, and horizontal polarisation is more suitable for constructional reasons, this type of aerial is preferred. With regard to the ground station, it would not be difficult to instal beam aerials with reflectors. These can be suspended from mobile masts and thus possess the advantage of mobility. The beam aerials produce, through grouping a multiple output at the reception site; its backward radiation is stopped by the reflectors. With regard to ultra short waves, it is known that beyond the horizon the field density rapidly decreases on the earth surface, but it still persists to ample extent at greater altitudes. Since the height of flight mostly lies at 1000 - 2000 metres, ranges up to 300 to 400 km must be allowed for at waves between 7 to 8 metres. At earth surface, however, no guaranteed reception is possible at such distances.

The main advantage obtained by aircraft transmitters is the gain in output since at equal weight a four times greater power can be given to the transmitter. The only disadvantage is the difficulties caused on the transmitter by the change in wave length, explained in detail in section III)4. But in exactly the same way as experience has taught us to construct receivers enabling a change over from variable reception frequency to a constant intermediate frequency, a change in transmitter construction will likewise enable us to change over from a fixed oscillator frequency to a variable transmission frequency.

Moreover, it appears to the author that the use of frequency modulation in aircraft radio will, by no means, be confined to the sphere of ultra short waves. The range of ± 8 kHz given above corresponds to a band width which appears to be also acceptable for the short wave band. The suppression in the short wave range would be the same as in the ultra short wave range. Whether the one or the other wave range is preferable, appears therefore to be more a question of organisation than technique, and must be left unanswered here.

(110) Weit. I.R. Operating problems in frequency modulations transmitters, Part I: Communications, Bd. 21, 1941 (Mai) S.5, Part II: Communications Bd.21 1941 (Juni) S.7.

(111) Westinghouse Company: Brit. Patent 287459 vom 19. Marz 1928.

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(113) Wheeler, H.A. The solution of asymmetrical sideband problems with the aid of the zero-frequency carrier. Proc. IRE. Bd. 29, 1941 (August) S.446.

(114) Wheeler, H.A. Two signal cross modulation in a frequency modulation receiver. Proc. IRE. 1940 (Dezember) S.537.

(115) Wing, A.K. and J.B. Young, A transmitter for frequency modulation broadcast service using a new high frequency tetrode. RCA Review Bd.5. 1941 (Januar) S. 327.

(116) Winlund, E.S. Drift analysis of the Crosby frequency-modulated transmitter circuit. Proc. IRE d. 29, 1941 (Juli).

(117) Woodyard J.F. Application of the auto-synchronized oscillator to frequency modulation. Proc. IRE Bd. 25, 1937 (Mai) S.612.

(118) Wundt and Hoffmann. Heterodyne phenomena at the reception of frequency modulated waves. "Lorenzberichte" No.3/4 1941. p. 63.

(119) Zenneck - Rykop. Textbook of Wireless telegraphy. 5th Edition. Stuttgart 1925. p.710 Also see -
H.G. Möller. Electron valves and their technical application.

(120) Zuhrt. Decreased disturbance due to frequency modulation in dependence upon amplitude limiting "Hochfrequ. Techn." Vol. 54. 1939, p.37.

(121) Bentley. J.O. U.S.A. PATENT 2 011 392.

(122) Matsuo, S. Direct reading radio wave reflection type absolute altimeter for aeronautics. Proc. IRE. 1938 (Juli) S.848.

K.Ltd. 37-230/69725/4.46.

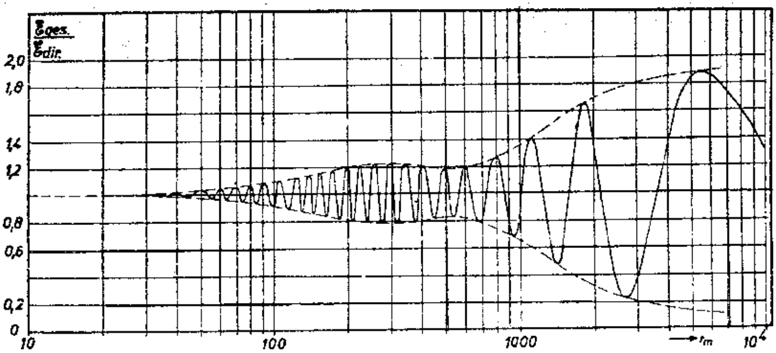


Abb. 21. Flughöhe $H_1 = H_2 = 100$ m $\lambda = 7{,}5$ m $\varepsilon = 4$ $\sigma = 10^{-13}$
Resultierende Feldstärke aus direkter und am Boden reflektierender Welle für zwei 100 m hoch fliegende Flugzeuge

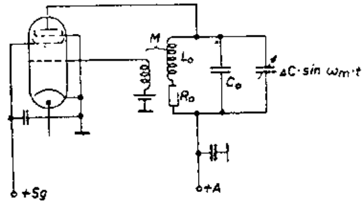


Abb. 22. Modulation der Frequenz eines Steuersenders durch eine veränderliche Kapazität

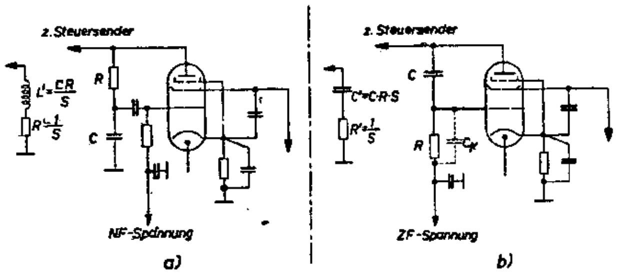


Abb. 23. Schaltung einer Röhre als veränderlicher Blindwiderstand
a) veränderliche Induktivität, b) veränderliche Kapazität

an

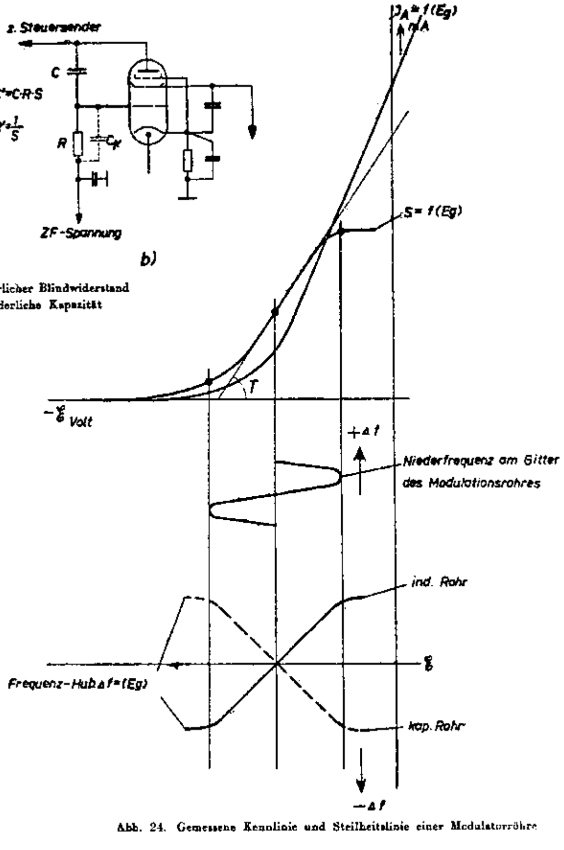


Abb. 24. Gemessene Kennlinie und Steilheitslinie einer Modulatorröhre

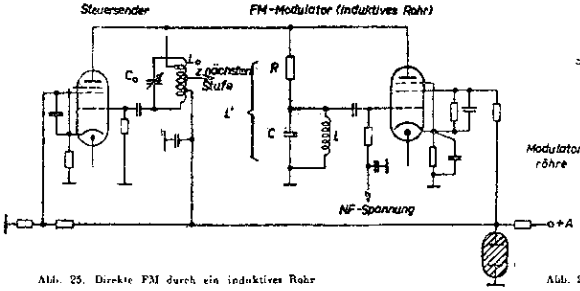


Abb. 25. Direkte FM durch ein induktives Rohr

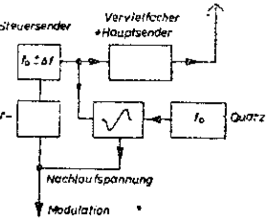


Abb. 27. Blockschema der „synchronisierten FM"

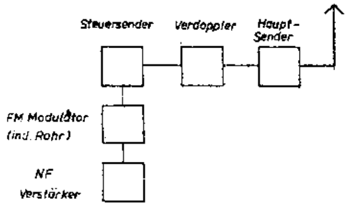


Abb. 26. Blockschema eines direkt modulierten FM-Senders

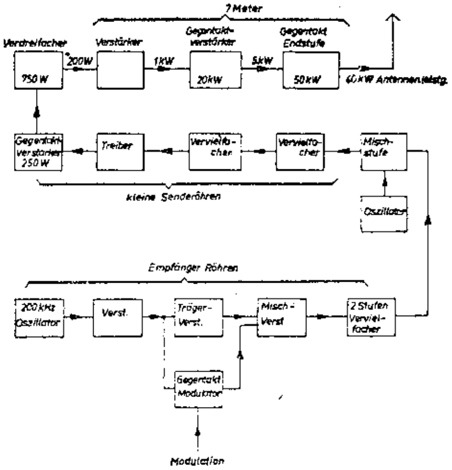


Abb. 28. Blockschema eines Senders für indirekte FM nach Armstrong

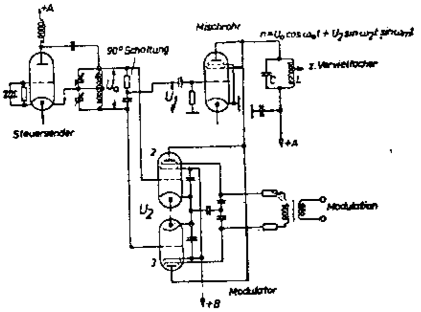


Abb. 30. Vereinfachte indirekte FM-Schaltung

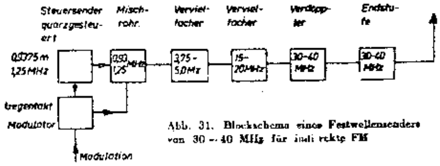


Abb. 31. Blockschema eines Festwellensenders von 30—40 MHz für indirekte FM

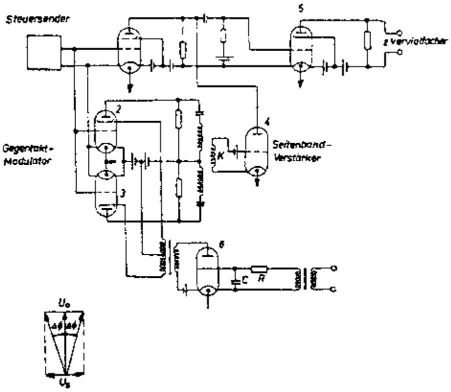


Abb. 29. Indirekte FM nach Armstrong

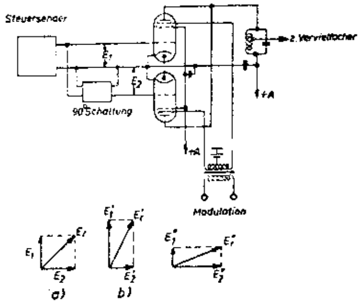


Abb. 32. Modulator für indirekte FM

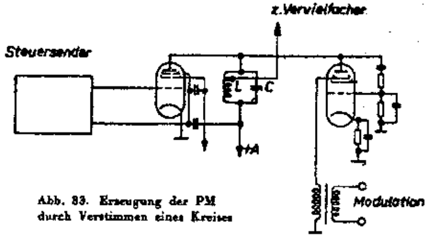


Abb. 33. Erzeugung der PM
durch Verstimmen eines Kreises

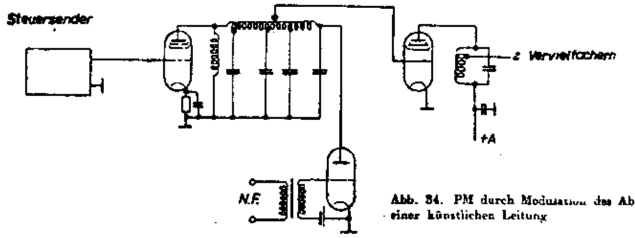


Abb. 34. PM durch Modulation des Abschlußwiderstandes
einer künstlichen Leitung

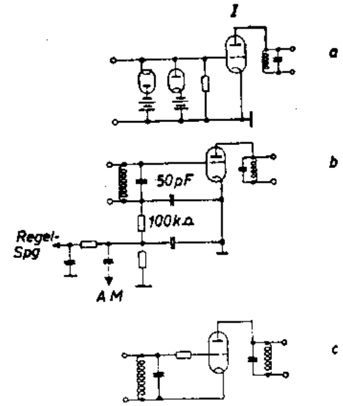


Abb. 35. Begrenzerschaltungen

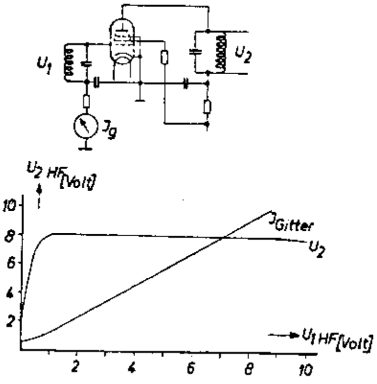


Abb. 36. Begrenzercharakteristik

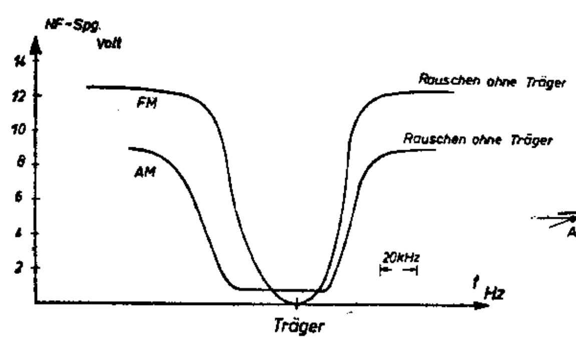


Abb. 37. Rauschunterdrückung bei unmoduliertem Träger mit 10 µ V Eingangsspannung

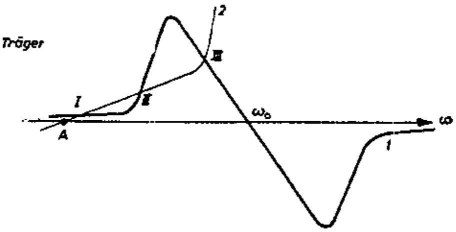


Abb. 39. Kennlinie der Umwandlung
und selbsttätigen Nachstimmung

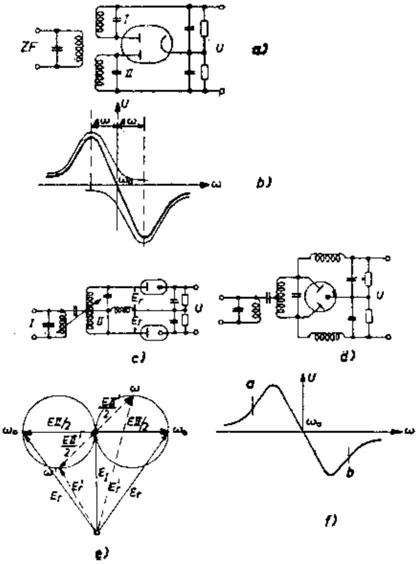


Abb. 38. Gegentakt-Umwandler

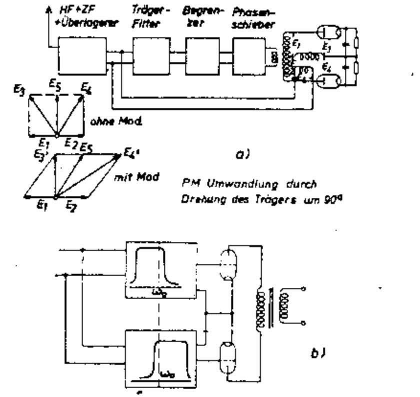


Abb. 42. PM-Umwandlung durch Gleichrichtung jedes Seitenbandes mit dem Träger

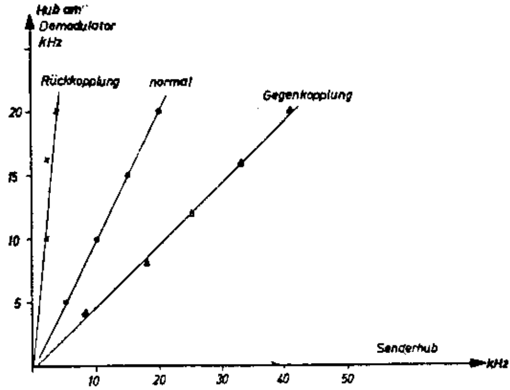


Abb. 40. Hubänderung der ZF durch Gegen- bzw. Rückkopplung des Oszillators (Mod. Frequ. = 1000 Hz)

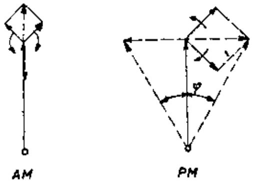


Abb. 41. Vektorbild für AM und PM bei kleinem Phasenhub

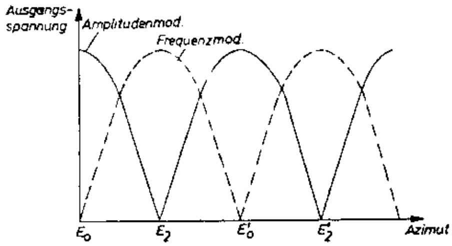


Abb. 43. Prinzipbild AM-Empfänger — FM-Empfänger

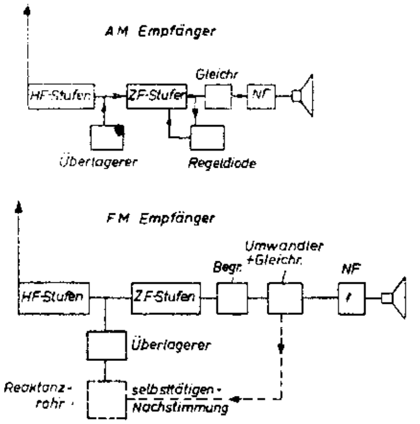


Abb. 44. Entstehung eines Richtdiagrammes des Modulationsgrades

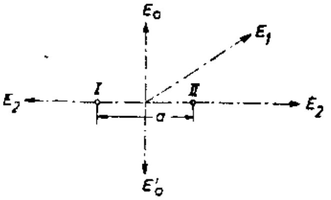


Abb. 45. Richtdiagramm des Modulationsgrades

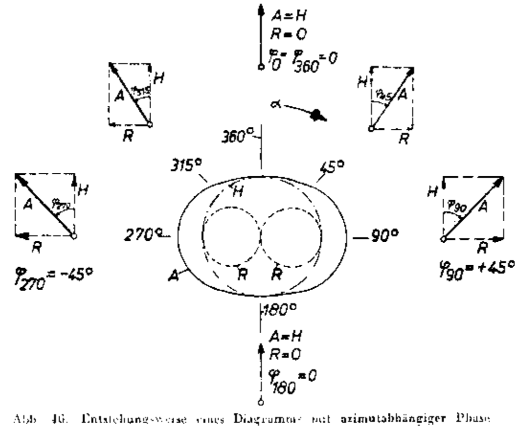


Abb. 46. Entstehungsweise eines Diagramms mit azimutabhängiger Phase

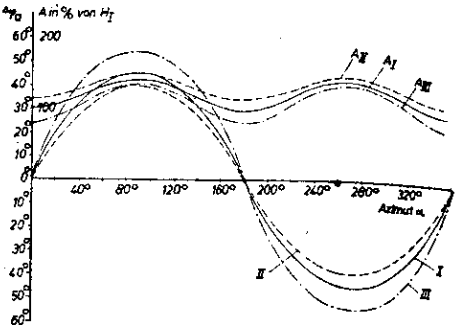


Abb. 47. Verlauf der Phasenänderung

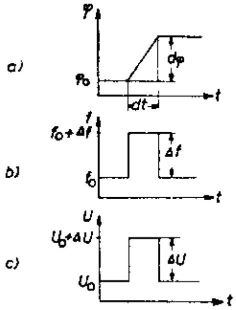


Abb. 48. Zusammenhang zwischen Phasenänderung, Frequenzhub und Spannungsverlauf hinter dem Frequenzdetektor

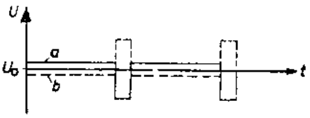


Abb. 49. Für die Seitenkennung gewünschter Spannungsverlauf

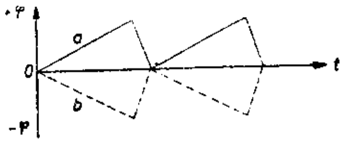


Abb. 50. Für Abb. 49 notwendige Phasenänderung

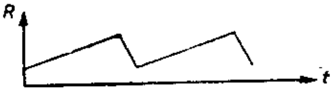
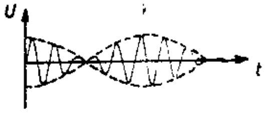
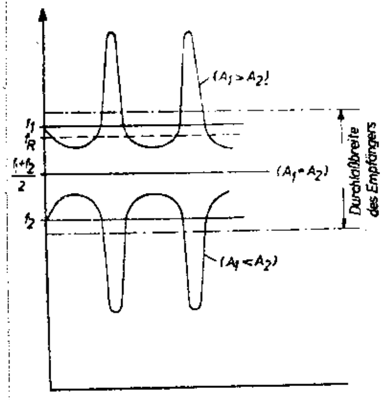


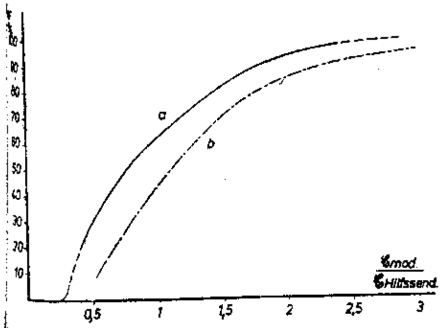
Abb. 51. Für Abb. 50 **erforderliche Modulation**



bb. 52. Schwebung bei **Amplitudengleichheit** ($A_1 = A_2$)



bb. 53. Frequenzbild bei Überlagerung zweier Frequenzen und f_2 mit den Amplituden A_1 und A_2 für die drei Fälle: $A_1 > A_2$, $A_1 = A_2$ und $A_1 < A_2$



Niederfrequente Ausgangsspannung abhängig vom Verhältnis der nnung des modulierten Senders zum unmodulierten Hilfssender

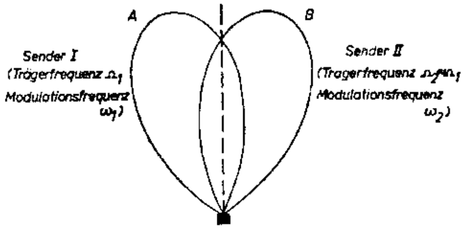


Abb. 55. Schema des Verfahrens mit verschiedenen Modulationsfrequenzen

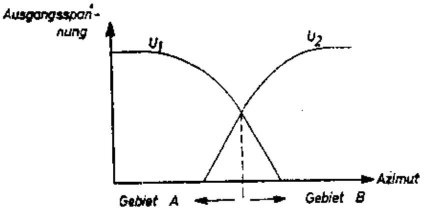


Abb. 56. Verlauf der niederfrequenten Ausgangsspannungen U_1 und U_2 mit den Frequenzen ω_1 und ω_2 abhängig vom Azimut

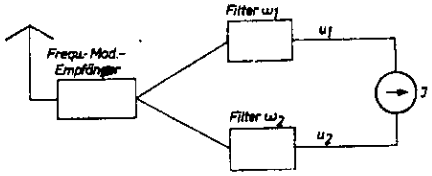


Abb. 57. Schema des Empfängers zum Verfahren mit verschiedenen Modulationsfrequenzen

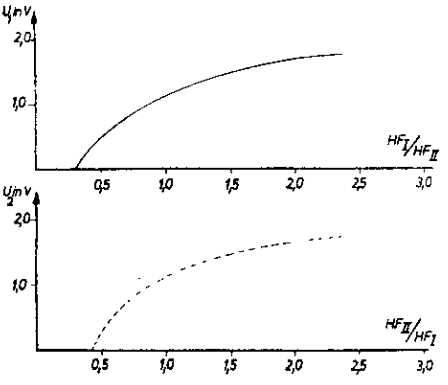
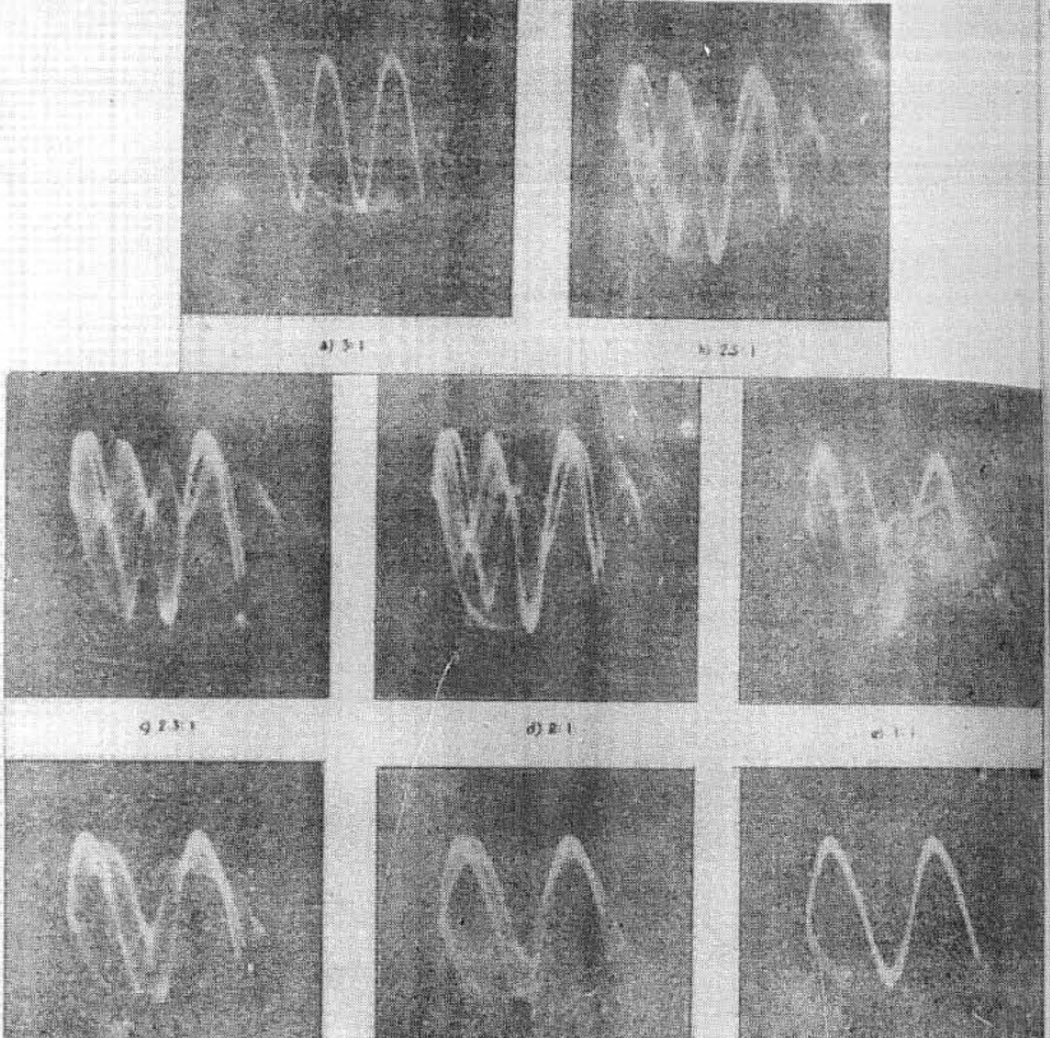


Abb. 58. Niederfrequente Ausgangsspannungen U_1 und U_2 in Abhängigkeit vom Verhältnis der Hochfrequenzspannungen HF_1 und HF_2 (Die Kurve für U_1 wurde gemessen, die für U_2 in 2 Punkten kontrolliert)



a) 3:1 b) 2,5:1 c) 2,5:1 d) 2:1 e) 1:1 f) 1:2 g) 1:2,5 h) 1:3

Abb. 59: Kurvenverlauf der Tonfrequenz im Braunschen Rohr.

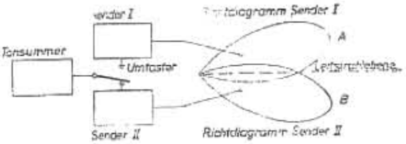


Abb. 60. Schema der Umtastung einer Modulationsfrequenz

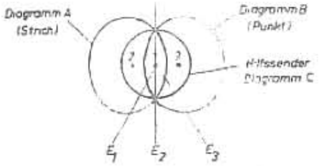


Abb. 61. Arbeitsweise des Verfahrens mit Zusatzträger

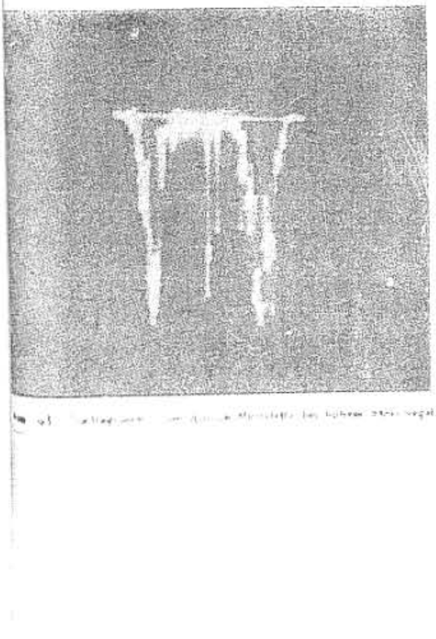


Abb. 63. [illegible]

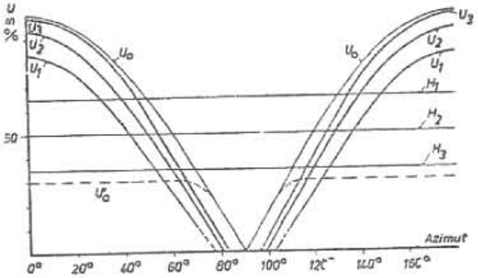


Abb. 62. Diagramm eines Adcocks mit Zusatzträger

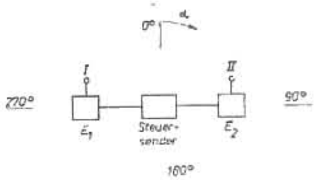


Abb. 64a. Anordnung eines Blindlandefunkfeuers nach [illegible]

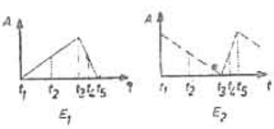


Abb. 64b. Amplitudenmodulation von E_1 und E_2

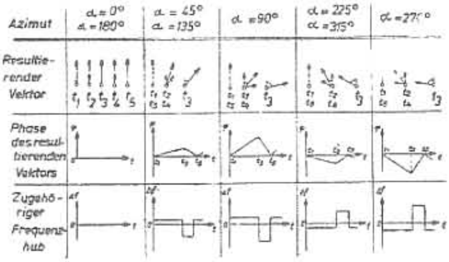


Abb. 64c. Phasenänderung und zugehöriger Frequenzhub der Anordnung nach Abb. 64a und 64b

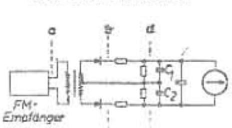


Abb. 65. Zusatzgerät für Rechts-Links-Anzeige

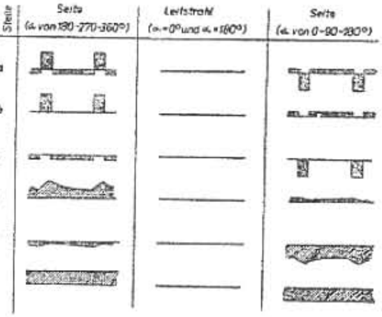


Abb. 66. Arbeitsweise des Zusatzgeräts

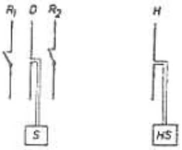


Abb. 67. Umtastfunkfeuer mit Zusatzträger

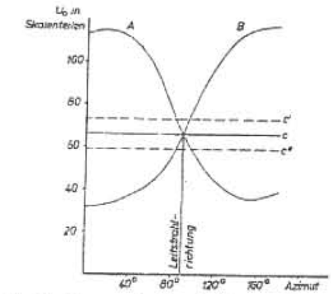
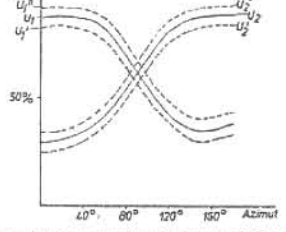


Abb. 68a. Diagramm eines Umtastfunkfeuers mit Zusatzträger



bb. 68b. Diagramm eines Umtastfunkfeuers mit Zusatzträger

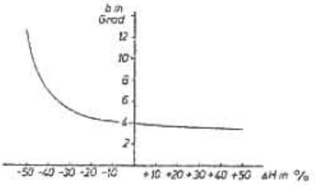


Abb. 69. Leitstrahlbreite b in Grad (bezogen auf 5 % Amplitudenunterschied) in Abhängigkeit von den Amplitudenschwankungen des Zusatzträgers ΔH in Prozent

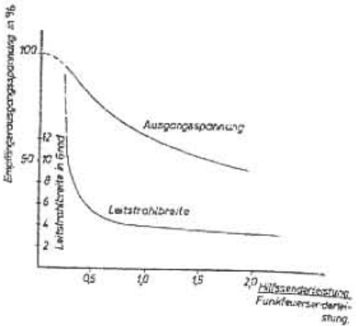


Abb. 70. Abhängigkeit der Leitstrahlbreite und der Empfängerausgangsspannung in der Leitstrahlrichtung vom Verhältnis der Senderleistungen

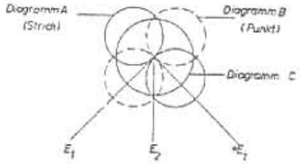


Abb. 71. 4-Strahlenfunkfeuer mit Zusatzträger

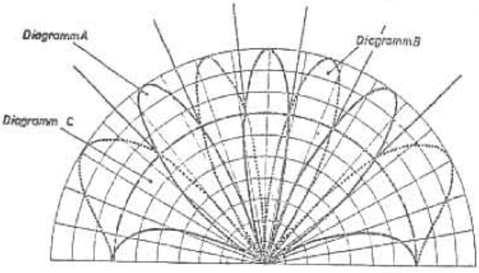


Abb. 72. Diagramm eines Umtastfunkfeuers mit einem Strahlerabstand von 1,75 λ

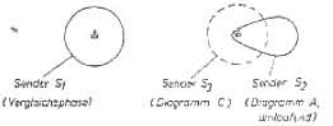


Abb. 73. Schema des Phasenmeßverfahrens mit Zusatzträger

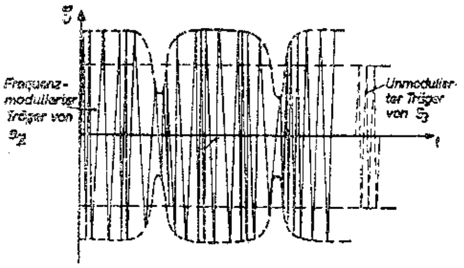


Abb. 74. Arbeitsweise des Phasenmeßverfahrens (hochfrequenzseitig)

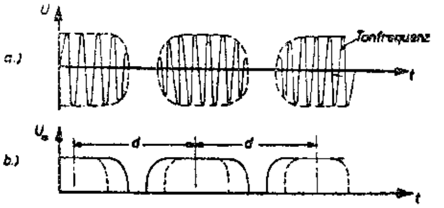


Abb. 75. Bild der Abb. 74 nach a) einmaliger und b) doppelter Demodulation

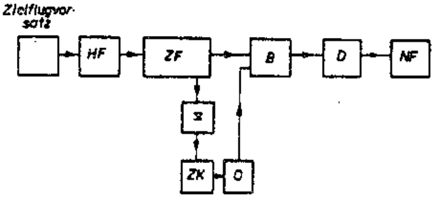


Abb. 76. Schema eines FM-Zielflugempfängers

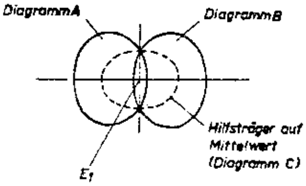


Abb. 77. Arbeitsweise eines FM-Zielflugempfängers bei einem Tastzeichenverhältnis von 1:1

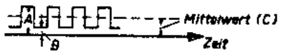


Abb. 78. Empfangsbild in Richtung E_1 (Abb. 77) bei einem Tastzeichenverhältnis von 1:1

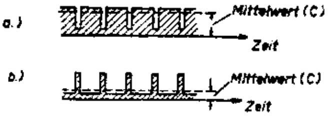


Abb. 79. Empfangsbild im Strichgebiet (a) und Punktgebiet (b) bei einem Tastzeichenverhältnis von 1:7

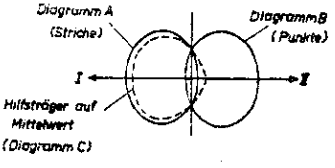


Abb. 80. Arbeitsweise eines FM-Zielflugempfängers bei einem Tastzeichenverhältnis von 1:7

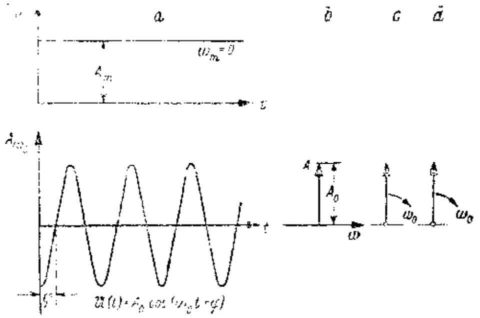


Abb. 1. Unmodulierte Schwingung

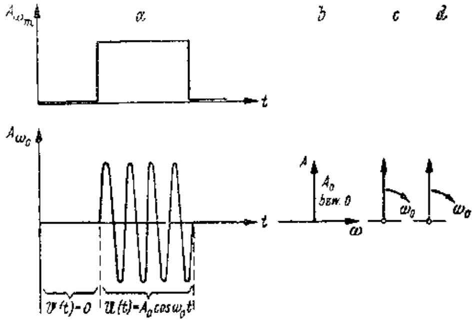


Abb. 2. Amplituden-Modulation, Telegraphie

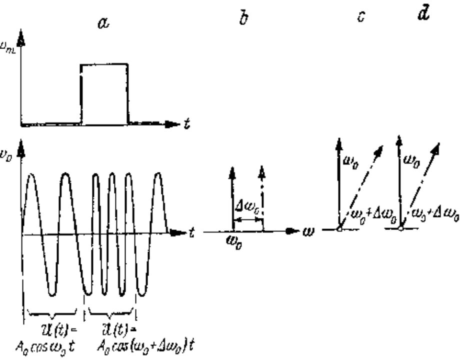


Abb. 3. Frequenz-Modulation, Telegraphie

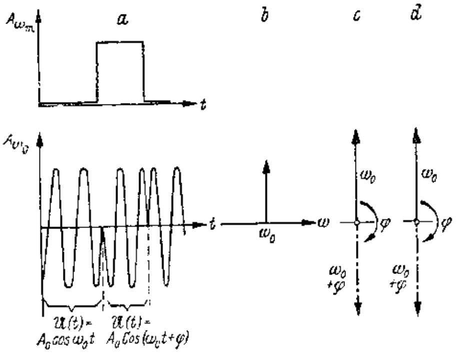


Abb. 4. Phasen-Modulation, Telegraphie

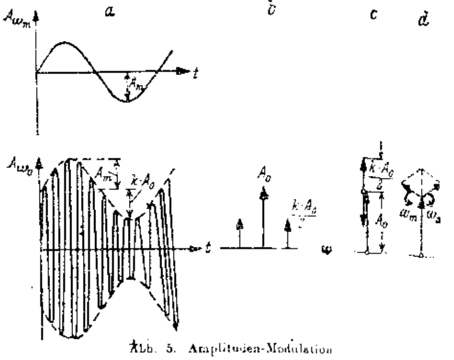


Abb. 5. Amplituden-Modulation

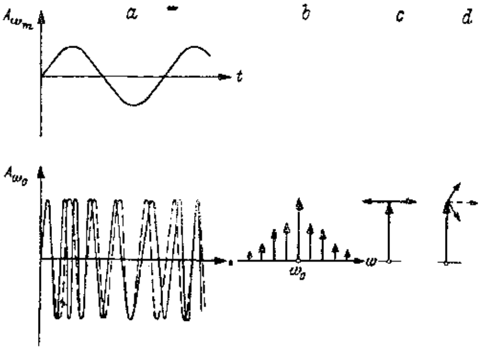


Abb. 6. Frequenz-Modulation

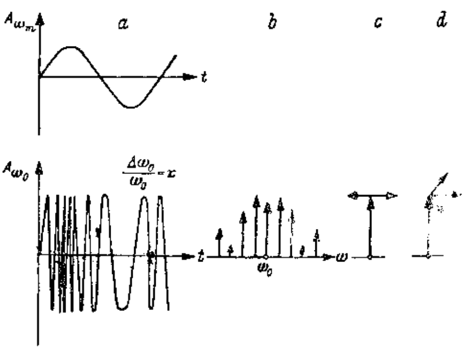


Abb. 7. Phasen-Modulation

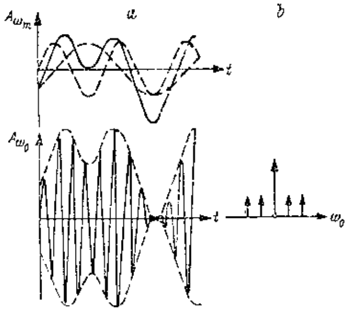


Abb. 8. Doppelton-Amplituden-Modulation

d

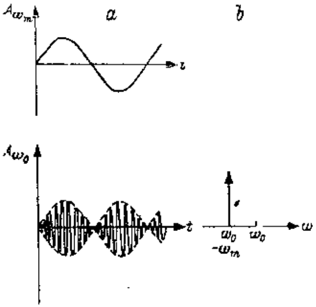


Abb. 9. Einseitenbandtelephonie

c) Anoden-B-Modulation

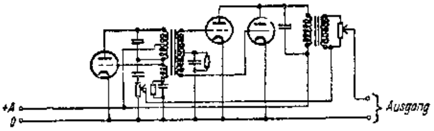


Abb. 10. Schaltung für Doppeltonerzeugung für tönende Telegraphie

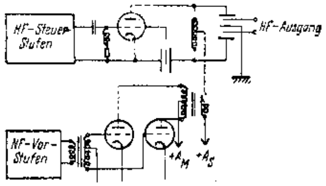


Abb. 11. Sender mit Anoden-B-Modulation

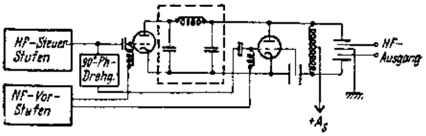
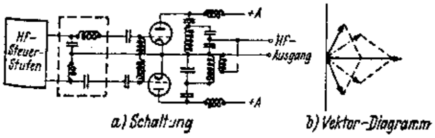
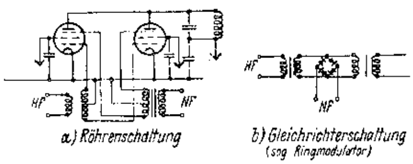


Abb. 12. Sender mit Doherty-Modulation



a) Schaltung b) Vektor-Diagramm



a) Röhrenschaltung
b) Gleichrichterschaltung (sog. Ringmodulator)

Abb. 14. Modulationsschaltungen, die eine Unterdrückung der Trägerwelle ergeben

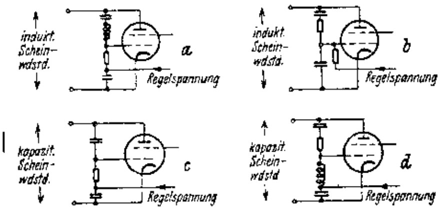
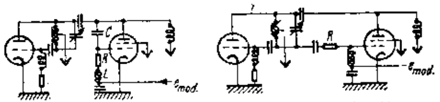


Abb. 15. Schaltungen für Parallelröhre mit a) und b) induktivem, c) und d) kapazitivem Scheinwiderstand in Abhängigkeit von der Gittervorspannung



a) Schaltung von Feldkeller (Bedingung $L = C \cdot R^2$)
b) Schaltung von Sheaffer (Bedingung R abgleichen)

Abb. 16. Parallelröhrenschaltungen für FM ohne Ohmsche Komponente

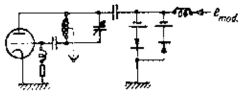


Abb. 17. FM durch gesperrte Trockengleichrichter

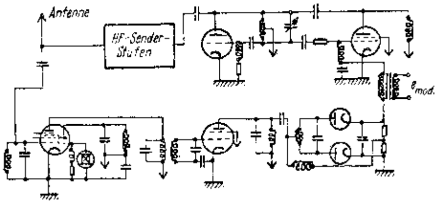


Abb. 18. Frequenzstabilisierte FM-Schaltung mit Vergleichs-Quarz

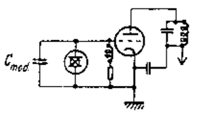


Abb. 19. FM-Schaltung bei einem Quarzoszillator in Pierce-Schaltung

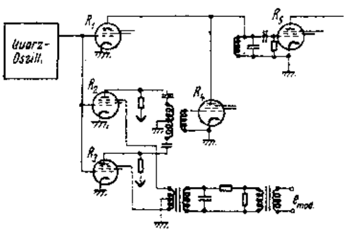


Abb. 20. Armstrong-FM-Schaltung

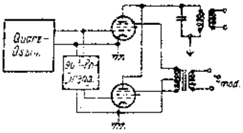


Abb. 21. Zwei-Penthoden-PM-Schaltung

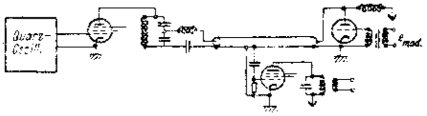


Abb. 22. PM-Schaltung mit Reflexionen in einem Energieleitungsstück

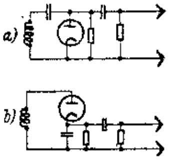


Abb. 23. Die beiden Schaltungsarten der Zweipolröhrengleichrichtung

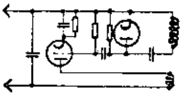


Abb. 24. Zweipolröhrengleichrichtung mit Rückkopplung

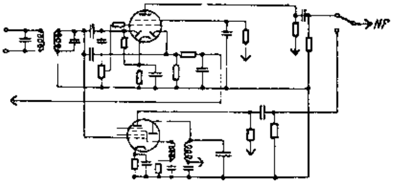


Abb. 25. Wahlweiser Empfang von Telegraphie mit Überlagerung oder Telephonie

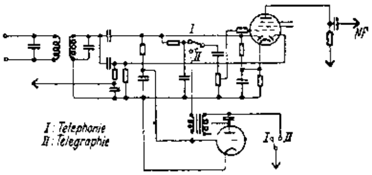


Abb. 26. Telegraphie-Empfang mit Tontastgenerator

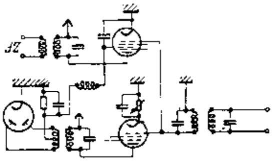


Abb. 27. Störspitzenunterdrückungsschaltung

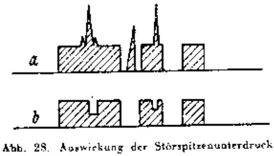


Abb. 28. Auswirkung der Störspitzenunterdrückung
a) ohne Unterdrückungsschaltung
b) mit Unterdrückungsschaltung

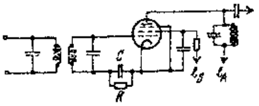


Abb. 29. Begrenzerschaltung für FM-Empfang

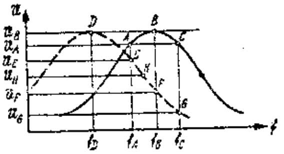


Abb. 30. Prinzip des FM-Empfangs mit verstimmtem Resonanzkreis

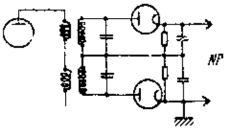


Abb. 31. FM-Demodulation mit Gegentaktgleichrichter

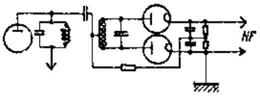


Abb. 32. FM-Demodulator mit Phasensprungschaltung

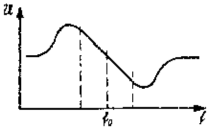


Abb. 33. Demodulationskennlinie für die Schaltungen nach Abb. 31 oder 32

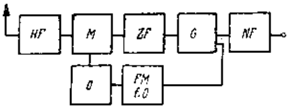


Abb. 34. FM-Gegenkopplung im Empfänger

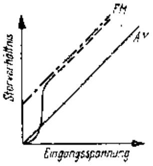


Abb. 35. Störverhältnis bei AM ————
bei FM — · — · · · · —
bzw. — — — —
(vgl. Kap. V k_1 und k_2)

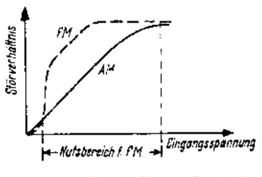


Abb. 36. Störverhältnis bei AM und FM unter Berücksichtigung der Faktoren k_{1-3} (Kap. V)

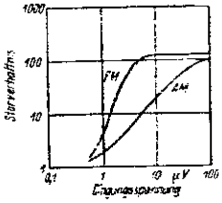


Abb. 37. Gemessene Störverhältnisse bei AM und FM bei geringem **Störpegel**

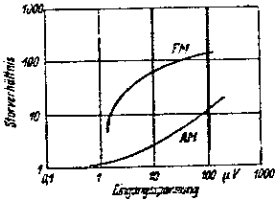


Abb. 38. Gemessene Störverhältnisse bei AM und FM bei hohem Störpegel

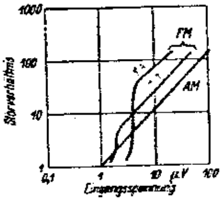


Abb. 39. Abhängigkeit des Störverhältnisses vom Frequenzhub

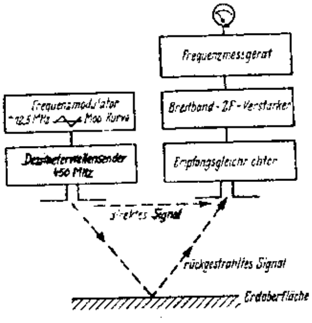


Abb. 40. Meßgerät für freie Flughöhe

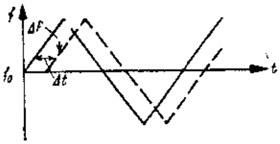


Abb. 41. Modulationskurve für das Meßgerät
für freie Flughöhe nach Abb. 40
——— Sendesignal — — — rückgestrahltes Signal

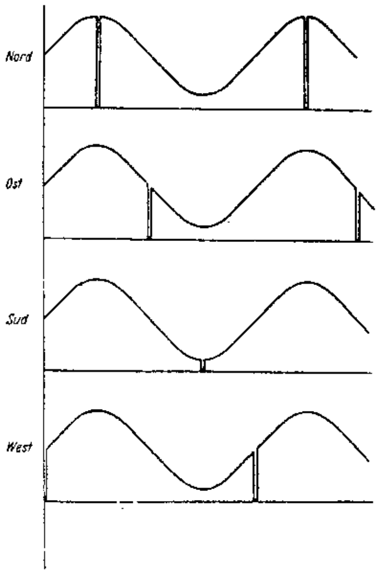


Abb. 42. Funkfeuer unter Benutzung einer Phasenmessung
Auswirkung der Unterbrechung der Abstrahlung in den verschiedenen Richtungen

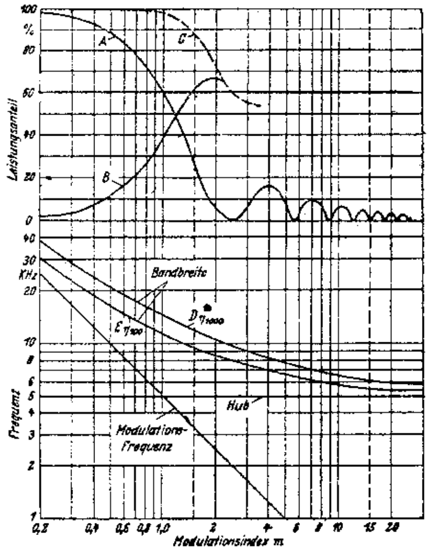


Abb. 1. Bandbreite und Energieverteilung für Frequenzmodulation
Hub-Konstant = 5 kHz
Kurve A: Leistungsanteil des Trägers
Kurve B: Leistungsanteil des stärksten Seitenbandpaares
Kurve C: Summe A + B
Kurve D: Bandbreite wenn $^1/_{1000}$ der Gesamtleistung vernachlässigt wird
Kurve E: dito, jedoch $^1/_{100}$ vernachlässigt

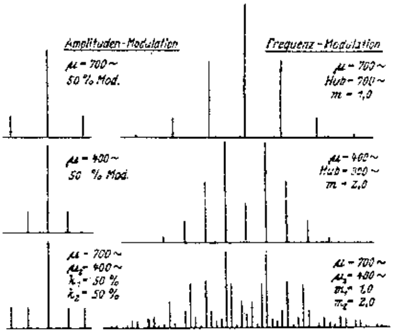


Abb. 2. Spektralverteilung bei Amplituden- und Frequenzmodulation

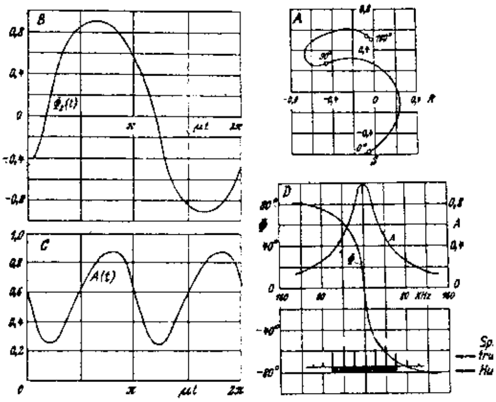


Abb. 3. Verzerrung eines frequenzmodulierten Signals beim Durchgang durch einen abgestimmten Kreis. Das Signal hat einen Hub von + 60 kHz, Modulationsindex m = 3, Modulationsfrequenz 20 kHz

A. Polarkurve des Ausgangssignals
B. Phase am Ausgang
C. HF-Amplitude am Ausgang
D. Amplituden- und Phasenverlauf des Schwingungskreises
(Parallel-Resonanzkreis $d = 001$,
$f_0 = 4000$ kHz
Durchlaßbreite 40 kHz)

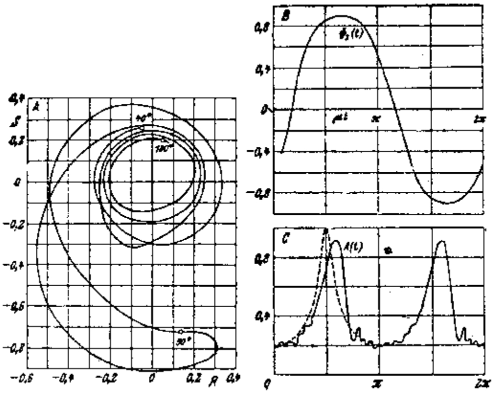


Abb. 4. Verzerrung eines frequenzmodulierten Signals beim Durchgang durch einen abgestimmten Kreis. Das Signal hat einen Hub von ± 100 kHz, einen Modulationsindex m = 24 und eine Modulationsfrequenz von 4160 Hz

A. Polarkurve des Ausgangssignals
B. Phase am Ausgang
C. HF-Amplitude am Ausgang
D. Der Schwingungskreis ist der gleiche wie für Abb. 3

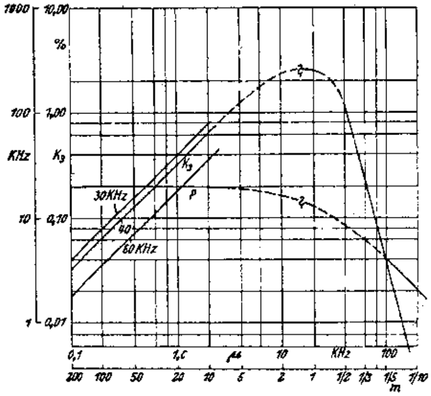


Abb. 5. Klirrfaktor k_3 und Amplitude der Grundwelle P in Abhängigkeit von der Modulationsfrequenz μ. Der Hub ist ± 20 kHz. Die Kurven beziehen sich auf einen einkreisigen Verstärker (Parallelresonanzkreis) mit: Dämpfung $d = 0{,}01$, Trägerfrequenz 4000 kHz, gesamte Durchlaßbreite 40 kHz. Für große Werte von m ist der Klirrfaktor k_3 auch für Durchlaßbreiten von 30 und 60 kHz angegeben.

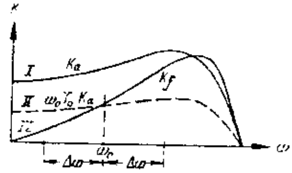


Abb. 6. Klirrfaktor für Frequenzmodulation nach Holzler

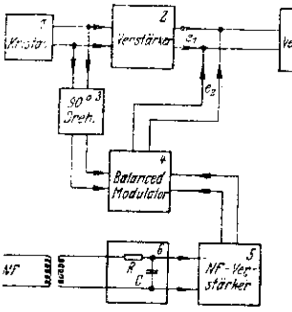


Abb. 7. Grundsätzliches Schaltbild eines frequenzmodulierten Senders nach Armstrong

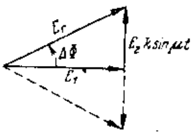


Abb. 8. Entstehung des Phasenhubes nach Armstrong

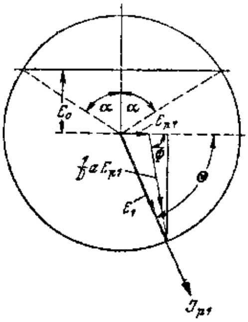


Abb. 12. Zeigerdiagramm des mit einem Scheinwiderstand belasteten Verstärkers

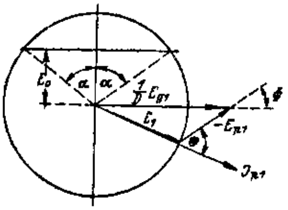


Abb. 12a. Zeigerdiagramm des Blindstromgenerators

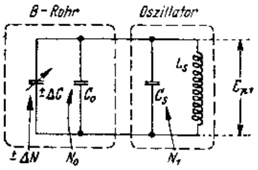


Abb. 9. Bestimmung von Frequenzhub und Blindleistung $C_0 + C_s = C$; $N_0 + N_1 = N$

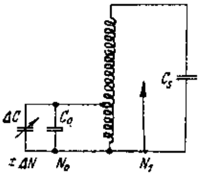


Abb. 10. Transformatorische Ankopplung der variablen Kapazität

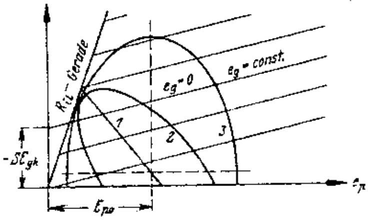
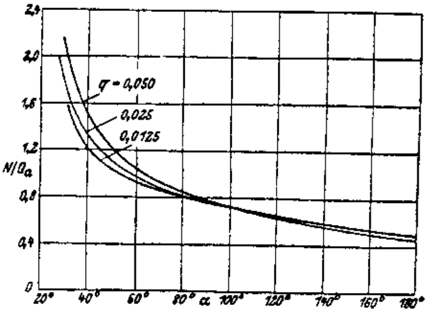


Abb. 11. Idealisierte Kennlinienschar einer Penthode mit Arbeitskennlinien



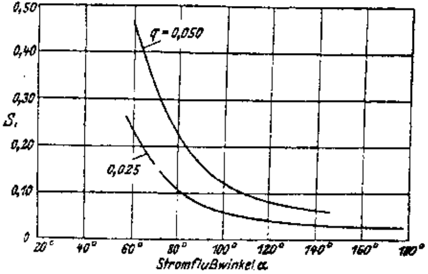


Abb. 13. Zusammenhang zwischen Blindleistung und Stromflußwinkel

$$\text{Blindleistung} \quad q = \frac{Q_a \; R_i L}{E_{po}^2}$$

Abb. 14. Zusammenhang zwischen Gitterspannung und Stromflußwinkel

$$\text{Erregung } S_i = \frac{\sqrt{2}\, S\, E_{g1}\, R_i L}{E_{po}}$$

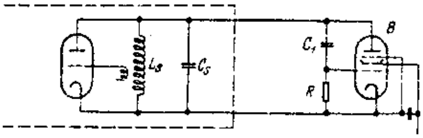


Abb. 15. Modulationsschaltung mit direkter Rückkopplung

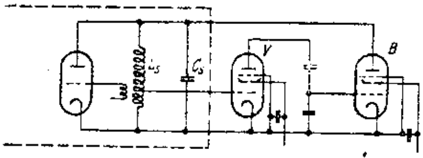


Abb. 16. Modulationsschaltung mit indirekter Rückkopplung

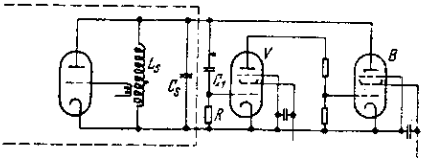


Abb. 17. Modulationsschaltung mit indirekter Rückkopplung und Modulation der Vorröhre

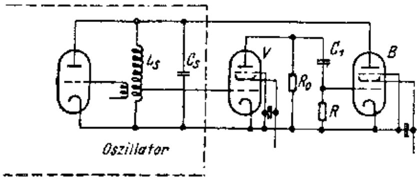


Abb. 18. Modulationsschaltung mit indirekter Rückkopplung und Modulation der Vorröhre

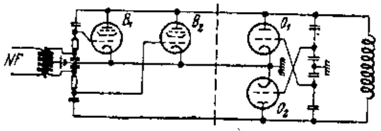


Abb. 19. Gegentaktschaltung

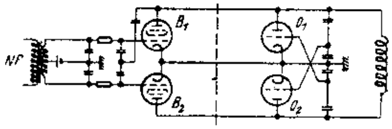


Abb. 20. Gegentaktschaltung

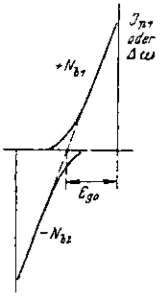
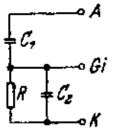


Abb. 21. Linearisierung durch Gegentaktschaltung

$$\frac{X_{C1}}{R_1}\,\frac{X_{C2}}{R_2} = 1 + \frac{X_{C1}+X_{C2}}{X_{C3}}$$

und das Spannungsverhältnis ist

$$\frac{1}{a} = \frac{E_{p1}}{E_{g1}} = -j\left[\frac{X_{C1}+X_{C2}}{R_2} + \frac{X_{C1}}{R_1}\left(1+\frac{C_3}{C_2}\right)\right]$$



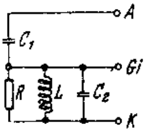
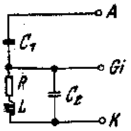


Abb. 22. Gewöhnliche Rückkopplungsschaltung bei Blindstromgeneratoren
Abb. 23. Rückkopplungsschaltung mit Kompensation durch Parallel/L



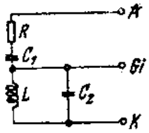


Abb. 24. Rückkopplungsschaltung mit Kompensation durch Serien/L
Abb. 25. Rückkopplungsschaltung mit Kompensation durch Serien/C

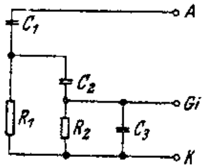


Abb. 26. Rückkopplungsschaltung mit mehreren R-C-Gliedern

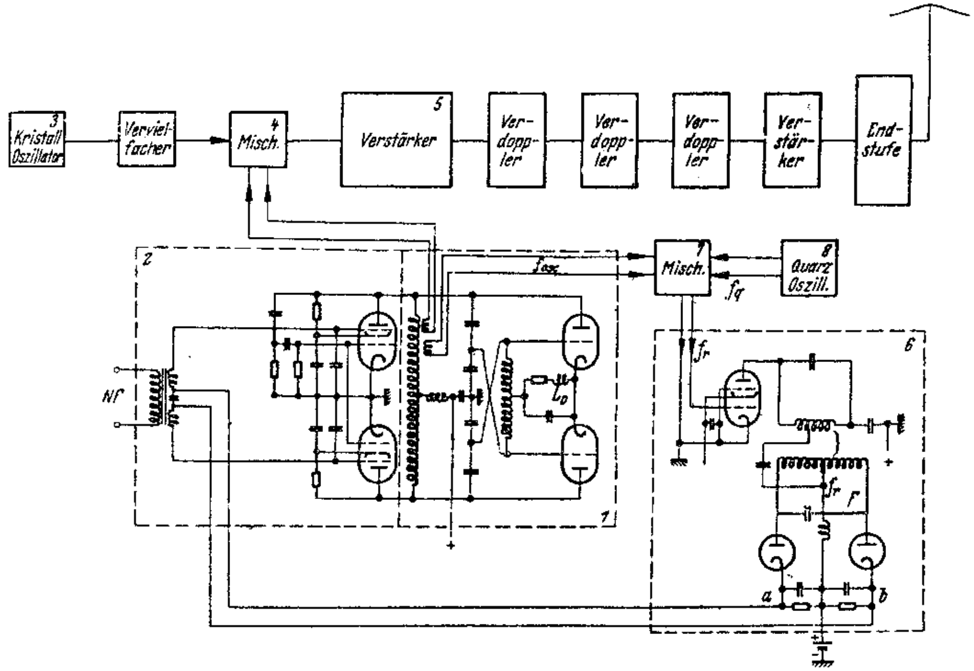


Abb. 27. Grundsätzliche Schaltung eines frequenzmodulierten Senders größeren Wellenbereiches mit Quarzsteuerung

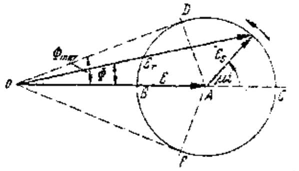


Abb. 28. Zeigerdiagramm eines gestörten frequenzmodulierten Signals

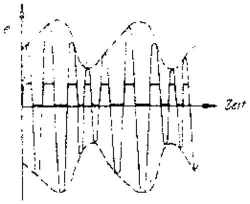


Abb. 29. Zeitlicher Verlauf eines gestörten frequenzmodulierten Signals

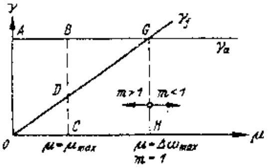


Abb. 30. Störungsbeseitigung bei Frequenzmodulation

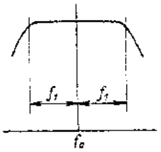


Abb. 31. Durchlaßkurve

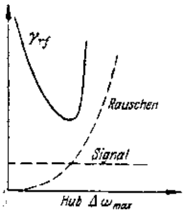
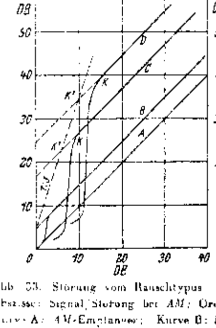


Abb. 32. Zur Erklärung des Schellwertes



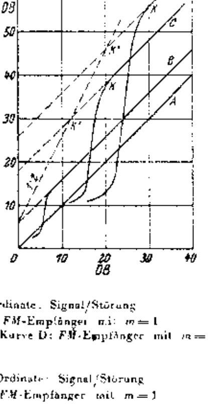
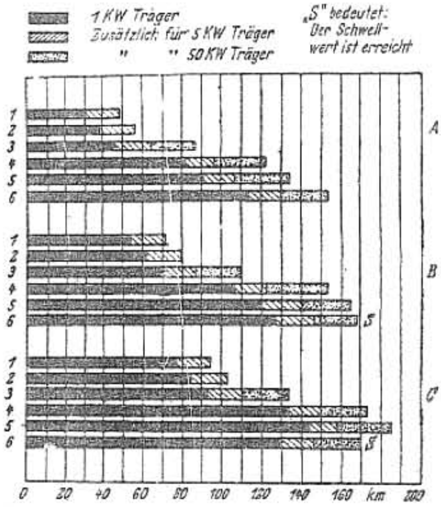


Abb. 33. Störung vom Rauschtypus
Abszisse: Signal/Störung bei *AM*; Ordinate: Signal/Störung
Kurve A: *AM*-Empfänger; Kurve B: *FM*-Empfänger mit $m=1$
Kurve C: *FM*-Empfänger mit $m=4$. Kurve D: *FM*-Empfänger mit $m=10$

Abb. 34. Störung vom Impulstypus
Abszisse: Signal/Störung bei *AM*; Ordinate: Signal/Störung
Kurve A: *FM*-Empfänger; Kurve B: *FM*-Empfänger mit $m=1$
Kurve C: *FM*-Empfänger mit $m=4$; Kurve D: *FM*-Empfänger mit $m=10$



b. 35. Radius des Versorgungsbereiches in km für Amplituden- und quenzmodulation verschiedener Leistungen und verschiedener Modulasindizes bei einer Trägerfrequenz von 53 Mhz

ppe A: Ausgezeichneter Empfang; Störabstand 60 DB
ppe B: Sehr guter Empfang; Störabstand 50 DB
ppe C: Guter Empfang; Störabstand 40 DB

Amplitudenmodulation; Anodenverlust beim Sender gleich dem bei *FM*
Amplitudenmodulation; Aufnahme beim Sender gleich der bei *FM*
Amplitudenmodulation; gleich Trägerleistung wie bei *FM*
Frequenzmodulation; Modulationsindex 1
Frequenzmodulation; Modulationsindex 2
Frequenzmodulation; Modulationsindex 5

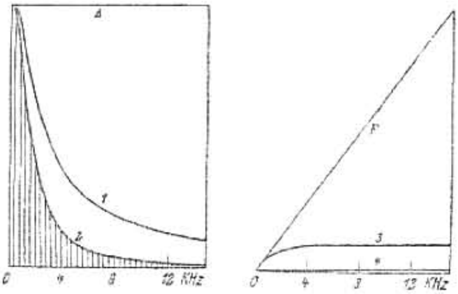
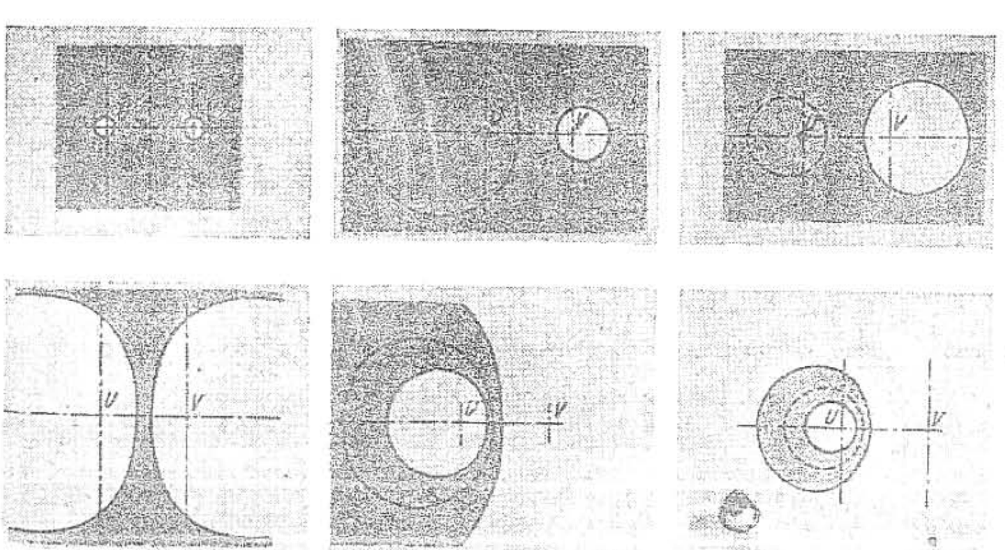


Abb. 36. Ohne Anheb-Absenk-Verfahren
Rechteck A: Störkrach bei AM
Dreieck F: Störkrach bei FM [illegible]
Mit Anheb-Absenk-Verfahren
Kurve 1: Krachspannung bei AM
Kurve 2: Krachleistung bei AM
Kurve 3: Krachspannung bei FM
Kurve 4: Krachleistung bei FM



37. Versorgungsbereich bei Gleichwellenbetrieb zweier amplituden bzw. frequenzmodulierter Sender (Abstand 20 km). Die Versorgungszonen getönt, die Zonen einwandfreien Empfangs erscheinen weiß. Die Grenzlinien beider Zonen entsprechen einem Feldstärkeverhältnis von [illegible] DB bei und 6 DB bei *FM*. (Nach unveröffentlichten Rechnungen des Verfassers vom Frühjahr 1938.)

a: Amplitudenmodulation — Gleiche Leistungen
b: Amplitudenmodulation — Senderleistungen wie 1 : 10
c: Amplitudenmodulation — Senderleistungen wie 1 : 100
d: Frequenzmodulation — Gleiche Leistungen
e: Frequenzmodulation — Senderleistungen wie 1 : 10
f: Frequenzmodulation — Senderleistungen wie 1 : 100

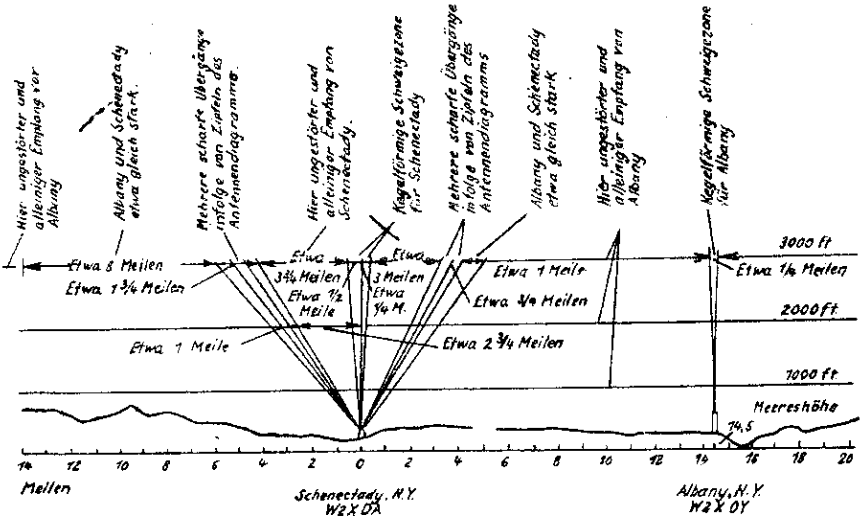


Abb. 38. Geländeschnitt zwischen Albany und Schenectady mit Empfangsbedingungen bei direkter Sicht. Gleichwellenversuch auf 41 MHz mit Sender W2XDA in Schenectady (20 Watt) und Sender W2XOY in Albany (150 Watt). Entfernung beider Sender 23 km. Die Entfernungen in der Abbildung sind in englischen Meilen (1.6 km) die Höhen in Fuß (30.5 cm) angegeben.

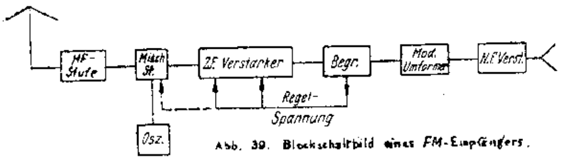


Abb. 39. Blockschaltbild eines FM-Empfängers.

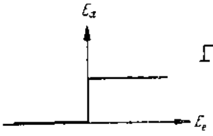


Abb. 40. Kennlinie des idealen Begrenzers

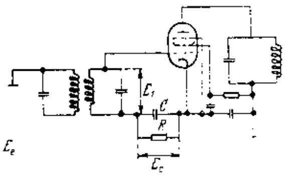


Abb. 41. Begrenzerschaltung

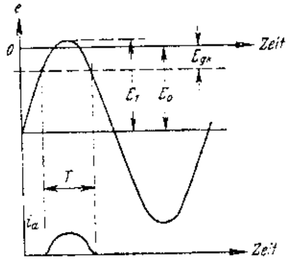


Abb. 42. Wirkungsweise des Begrenzers

Abb. 43 Zur Wirkungsweise des Begrenzers.

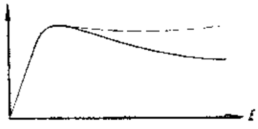


Abb. 44 Verlauf einer tatsächlichen Begrenzercharakteristik

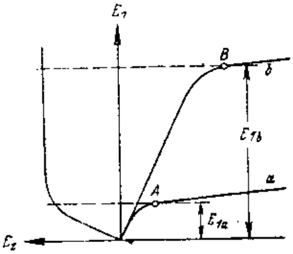


Abb. 45. Festlegung des Begrenzerpegels

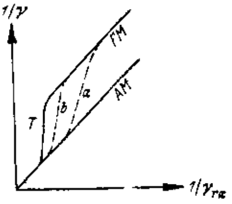


Abb. 45a

Sen-
der

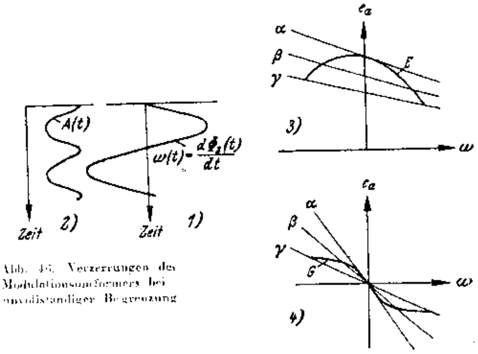


Abb. 46. Verzerrungen des Modulationsumformers bei unvollständiger Begrenzung

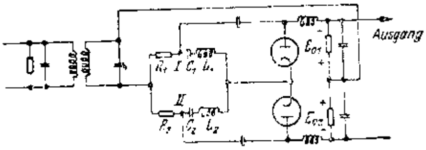


Abb. 47. Modulationsumformer nach Armstrong

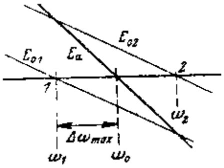


Abb. 48. Arbeitsweise des Modulationsumformers nach Armstrong

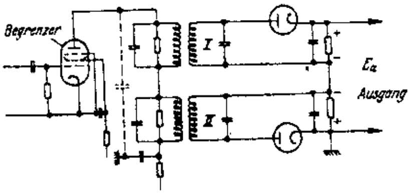


Abb. 49. Modulationsumformer mit 2 gegeneinander verstimmten Schwingungskreisen

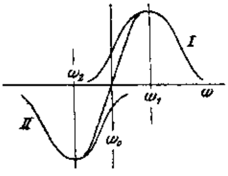


Abb. 50. Wirkungsweise der Schaltung Abb. 49

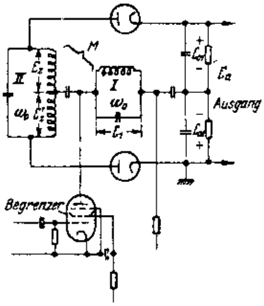


Abb. 51. Modulationsumformer in der Phasensprungschaltung nach Riegger

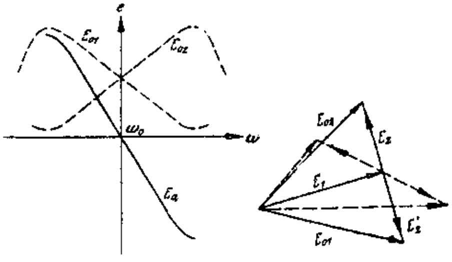


Abb. 52. Wirkungsweise des Rieggerkreises

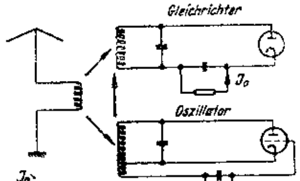


Abb. 53. Modulationsumformer durch Mitnahme

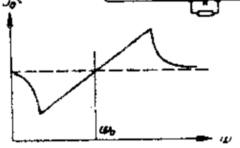


Abb. 54. Wirkungsweise der Schaltung nach Abb. 53

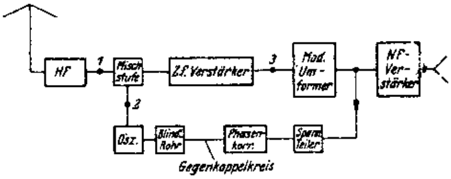


Abb. 55. Blockschaltbild eines Empfängers mit Frequenzgegenkopplung

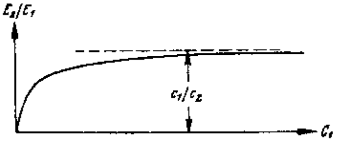


Abb. 56. Begrenzerwirkung der Gegenkopplung

Begrenzer.

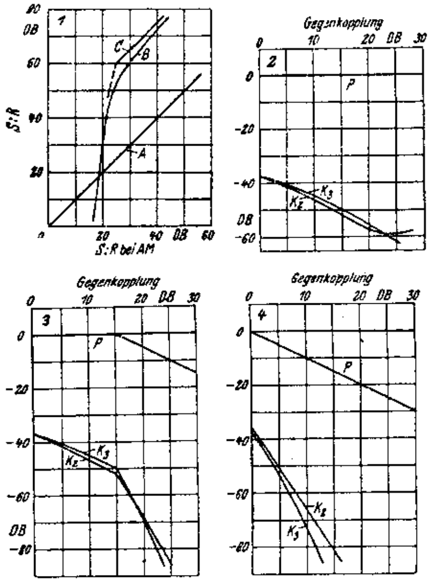


Abb. 57. Wirkung der Frequenz-Gegenkopplung

Bild 1: Dieses entspricht Abb. 33. Kurve A für AM-Empfänger. Kurve B für FM-Empfänger mit 25 DB Gegenkopplung. Kurve C für FM-Empfänger mit Begrenzer. Hub ± 125 kHz: Modulations-Frequenz 4 kHz: Modulations-Index = 31,1

Bild 2: Mit steigender Gegenkopplung wird Frequenzhub erhöht. NF-Ausgangsspannung mit Netzpegel P bleibt konstant.

Bild 3: Bis 15 DB Gegenkopplung wie bei Bild 1. Von 15 DB ab wird Frequenzhub nicht mehr erhöht.

Bild 4: Frequenzhub konstant. Mit steigender Gegenkopplung fällt NF-Ausgangsspannung