

GERMAN USE OF FREQUENCY MODULATION

(USFET Int. Rep. (FME - 1))

This report deals with the application of frequency modulation in German Communication and electronic equipment. It includes a brief history of the development, an outline of some of the more outstanding circuit techniques, and information on equipments designed for military use. Since very little has been discovered regarding the field use of any mass produced equipments employing FM, the bulk of the information concerns technical considerations of the FM problems as encountered by the development laboratories of the German Radio firms. In addition to the diagrams reproduced here circuits of an FM Transceiver and the Strassburg control receiver are given in the report.

I. HISTORY OF FM DEVELOPMENT

Telefunken: Dr. Hans Roder, Telefunken engineer, started with this firm in 1938, after spending a number of years working in the development laboratories of the G.E. Co. in Schenectady. He introduced several research projects on FM at Telefunken, based on his experiments at G.E.

A small amount of FM development had been accomplished, previous to his arrival, on magnetron oscillators in the region of 5 metres. This was a result of a discovery that FM was easier to accomplish than AM when working with magnetrons.

Roder initiated a large amount of study on the relative advantages of FM over AM in noise-level problems, interference between two stations operating at the same frequency, and relative amounts of equipment required for equal carrier power in multichannel work.

Several papers were written on the subject giving information on: suitability for VHF multichannel transmission, general properties such as bandwidth and distortion, types of modulation and detection systems, noise elimination, advantage of phase modulation in counteracting selective fading, and basic propagation studies at decimetric frequencies. For the latter Roder worked with the Reich Weather Service on problems of VHF propagation over the sea.

Strassfurter Rundfunk: Dr. Theodore F. Sturm, in charge of the laboratories at Strassfurter Rundfunk, began in 1938 to develop FM test apparatus in the range from 20 - 150 mcs. The

work was inspired by American reports on the improved signal/noise ratios and other advantages. The need for AFC in commercial receivers, and the possibilities for airborne altimeter provided additional reasons for basic investigation in FM.

After the start of the war the basic investigation work was dropped in favour of applying the use of in remote control (for guided missiles).

The Strassfurter Rundfunk laboratories worked with Telefunken and Lorenz in the development of a light weight FM pack set for the infantry. The designation of this equipment was the "Torn Fu D4" There are no indications of any production models of this set in existence, but information is available regarding circuit design.

In 1943 development began on the combination FM-AM tank receiver and transmitter known as the Fu Sprech K. Laboratory models were tested in 1944 and production was just beginning as the war ended.

Philips Eindhoven: Under Dr. Van Der Pol a number of scientists in the National Laboratories at Eindhoven accomplished a good deal of theoretical study on FM in the VHF ranges with special emphasis on basic principles, including limiter and discriminator techniques, phase shift and distortion problems, noise level problems, antennae, measuring techniques and test equipment, propagation and frequency studies, and atmospheric effects.

Since the end of the war Dr. Van Der Pol has published reports on these findings. There is little evidence that the German war effort received benefit from them.

Air Force: A proposal was made in March 1940 to introduce FM into the Air Force. Inquiries revealed that very little research had been accomplished at that time on the practical adaptation of FM in military communication sets. It was not until a year later that any information was forthcoming from commercial firms. To prove the advantages of FM, work was begun on some rebuilt FuGe XVII sets. The results were so encouraging that an immediate order was given to develop an airborne equipment similar to the FuGe XVII but operating on FM, and simultaneously to make a detailed study of the possibilities of this type of transmission.

This resulted in the production of FuGe XV by the Lorenz firm. It operated on either FM or AM.

Army: This branch of the service was very reluctant to adopt frequency modulation in their communication equipments. Apparently the chief reason for this was the trend towards standardization in circuit design in the early phases of the war so that large scale production could be exploited over a long period of time.

However, it was realised that a need sorely existed for a communication set, covering a wide frequency band, for use between vehicles, tanks, air-craft, etc. At times it was necessary to have 6 different equipments in one vehicle in order to maintain communication with all the necessary echelons of command. Often the number of existing frequency channels was too small, and the available range too short.

Hence in 1943 the Army indicated a desire for the development of an FM receiver for vehicular use, after being shown concrete evidence of the advantages of this type of transmission. Results on the laboratory models of the infantry pack set "Torn Fu D4" aided in convincing the Army of the obvious advantages.

Thus the plans were made for the construction of the FM tank set known as the Fu Sprech K. However, because of the need for communicating with the existing sets, the requirements stated that the equipment would be capable of AM operation as well.

II. BASIC INVESTIGATION AND CIRCUIT TECHNIQUES:

FM versus AM: Roder, in a paper on the use of FM in multichannel transmission proved that it contained the following advantages: the signal noise ratio is better for a given number of channels, and the improvement increases when more channels are used; for the same power conditions less tubes are necessary in the transmitter and less expensive equipment required; greater freedom exists from interference, hence greater range.

Advantages discovered by Sturm and others included possibility of operating transmitter circuits at higher efficiencies due to the fact that non-linear distortion was independent of tube characteristics as in AM, but depended on phase characteristics of the networks; the constant output level of an FM receiver independent of input level even at the limits of its sensitivity; ability to operate at small distances without danger of over-loading; possibilities of double-modulating one channel (e.g. FM for conversation, AM for navigation).

The inherent disadvantage, i.e., the need for wide bandwidth, was partly overshadowed by the "take over" effect

peculiar to FM. Thus, with two interfering signals, if one was at least 6 DB above the other, the weaker would be reduced to a degree such that it no longer interfered. This suggested the possibility of several transmissions at the same or at very close frequencies.

The fear of distortion due to multi-path propagation caused the development of FM to stay in the higher frequencies, where transmission was independent of the ionosphere. In this connection Roder suggested the use of phase modulation to overcome difficulties encountered in selective fading and showed the results to be similar to single sideband transmission (as in AM).

Much investigation was carried out to determine optimum frequency deviations, with results as shown in figure 1. The curves give relative signal to noise ratios plotted against receiver input level where frequency deviation was varied as a parameter. It was concluded that for cases where the field strength was small, large frequency deviation was undesirable, not only because it required more bandwidth, but it actually produced a signal to noise ratio smaller than what could be expected with AM. For this reason 10 kc/s was chosen as the deviation frequency where only voice frequencies were transmitted. The IF pass band was 35 kc/s.

In further attempts to decrease the noise level, analytical studies were made of tuned RF stages being fed by an antenna. The equivalent circuit considered is shown in figure 9. In this circuit, noises are generated by all the hypothetical resistors indicated R_a is the equivalent antenna, R_c represents the losses in the tuned circuit LC, R_g represents the tube admittance, and R_e represents the resistor generating a noise equal to what would be generated in the tube with its grid shorted to cathode. For optimum results it was found that R_a should be small in comparison to the parallel combination of R_c and R_g , but large in comparison to R_e . R_e was controlled by using a tube of the proper design, and R_g was controlled by means of a choke L in the screen circuit of the tube. Results indicated that it is possible to obtain sensitivities of 10μ volts up to 600 mc/s. (For frequencies above 100 mc/s a diode mixer was used as the first tube).

Reactance Tubes: Conventional reactance tube circuits were used employing pentodes with an RC phase shifting network from plate to grid. Figure 2 shows a variable inductance, and figure 3 a variable capacitance. The value for deviation frequency is given as follows:

$$\Delta F = F \frac{Lg}{2F} \text{ for figure 2}$$

and

$$\Delta F = F \frac{Tg}{2C} \text{ for figure 3}$$

where F is the oscillator frequency
 g the mutual conductance.
 T the time constant of the phase shifting network.
 L the inductance of the tank circuit in fig. 2.
 C the capacity of the tank circuit in fig. 3.

These formulae show that in both circuits the deviation is proportional to the oscillator frequency. This was undesirable in certain cases. In order to make the deviation independent of frequency, networks were designed and inserted at N (see Fig. 2) to make the time constant of the phase shifting network vary directly with frequency, thus keeping the deviation constant. Simple examples are shown in Figure 4. The curves in Figure 5 show how deviation (with a constant signal in the grid of the reactance tube) is affected by frequency.

These corrections worked well at broadcast frequencies, but in the case of higher frequencies, tube capacities and circuit wiring resistance caused difficulty. For example, in Figure 2 the resistance in the phase shifting network was practically shunting the tuned circuit. This limited the maximum allowable value for this resistance and resulted in a phase error at the grid of the reactance tube. This caused a damping current to flow in the reactance tube. Corrective networks were inserted in an attempt to achieve the 90° phase shift. Similar difficulty was encountered with the circuit of Figure 2. Here, the grid-cathode capacity caused phase shift error and limited the value of signal which could be applied at the grid. This was partly corrected by paralleling an inductance with the grid resistor. With this method it was possible to achieve deviations up to 400 kc/s at frequencies of 200 mc/s using RV 12 P 2000 tubes.

Discriminators: The usual technique of push-pull circuits and double diodes were employed. The one most used is shown in Figure 6. Here it should be noted that there is no magnetic coupling between the two tuned circuits. They are connected by a capacitor which joins the midpoints of the coils, and the return path is provided by another capacitor, C. This second capacitor is very small, and is inserted to obtain a very high reactance, thus producing a current which is in quadrature with the applied signal. This current (normally induced where magnetic coupling is used) established the phase combinations in connection with the tuned circuit to provide the FM discriminator action. Such a method was used because it was the usual practice in radio design not to have magnetic couplings in IF coils. This policy

was brought about by the desire for using standard coil forms in which the IF frequency or bandwidth could be changed.

A similar circuit, shown in Figure 7, was tried in order to use a double diode with a common cathode. Here the return path for the IF signal is provided by the differential capacitor, C_D . The one disadvantage in the circuit is the need for a split inductance in the resonant circuit feeding the diode.

A need for a receiver occupying a very small space led to the development of a magnetically coupled discriminator, using copper oxide rectifiers in place of diodes. The tuned secondary was designed to have a very low dynamic impedance so that the shunting effect of the rectifiers would not be great. The Siemens type "Sirutors" were used as rectifiers. These are about the size of a 1/2 watt resistor. This system worked well up to frequencies of 1500 kc/s.

The general rule used for discriminator design was for the distance between peaks of the curve to be equal to the IF bandwidth. This provided linear demodulation for the greatest deviations, and insured that no FM demodulation could take place in the range outside the correct frequency channel.

Automatic Frequency Control (AFC): When constructing AFC circuits great pains were taken with the tuned circuits in the discriminators to insure good stability and low temperature and humidity coefficient. Coils were wound on a plastic called "LUVIKAHN". This substance has low losses, low dielectric, and melts at about 150°C. Litz wire was used for the windings. The temperature coefficient of the coils was only $+80 \times 10^{-6}$ per °C. They were compensated by ceramic capacitors, using a dielectric called "TEMPA T". The resulting coefficient was kept between limits of $\pm 20 \times 10^{-6}$ per °C. The influence of humidity was reduced by using "MONOSTYROL" to fix and cover the coils. This material will polymerize into "POLYSTYROL" under the influence of light and higher temperature. After this treatment it was found that the most extreme conditions of humidity (simulated by cooking the coils in boiling water) caused a deviation of less than 5×10^{-4} (or 5% of the used bandwidth). Another scheme tried for increasing stability was that of artificial ageing. In this process the coils were heated to a temperature of 80°C, held there for 4 hours, then cooled to -40°C, and held there for the same length of time. The heating was then repeated.

The figure of merit used in measuring the effectiveness of an AFC circuit was called the "correcting factor". It was defined as a ratio of the maximum deviation AFC to that existing with AFC operating. Factors having a value between 10 and 20 were considered sufficient in most cases. The discriminators used had an output of about 20 volts at the peaks of their

selectivity curves. Thus for a 40 kc/s bandwidth an output of 1 volt per Kc/s was achieved.

The time constant in most AFC circuits was chosen to be 100 milliseconds. Attempts to use a much shorter time constant in order to investigate negative frequency feedbacks were not successful.

Limiters: Conventional circuits, limiting by grid current and plate saturation were used. The value of C, shown in Figure 8-a was from 20 to 100 pF, and the value of R between 10,000 and 100,000 ohms. In a number of circuits the preceding IF stages were designed to accomplish a certain amount of limiting on stronger signals. It was found that a large amplification preceding the limiter was necessary to obtain the best signal to noise ratios. An input of about 10 volts was required at the grid of the limiter. The limiter circuit shown in Fig. 8-b was often used where it was desired to have the receiver operate on either FM or AM. The output from the diode (formed by the grid and cathode of the limiter tube) could be used either as an AVC voltage or as the detected AM signal.

III. FREQUENCY MODULATED EQUIPMENTS

Early Transmitters: The first FM broadcast transmitter on the Continent was built at Eindhoven in January 1941. It operated on wavelengths of 6.7, 3 and 1.1 metres and had a peak output of 8 kW. Known by the code name of "Dora", it was used for measurements in connection with propagation tests and for voice transmission. Another smaller transmitter, only 500 watts, was operated on 6 metres for test purposes. This one was known as "Cesar".

Fu Sprech K: The Fu Sprech K was designed as a vehicular FM transmitter and receiver containing 400 channels in the band from 20 to 40 mc/s. It could also be operated on AM so that it could work into existing nets. The set was contained in one metal box measuring roughly 12" x 8" x 7", and weighed 34 lbs. It required a 12 volt battery for its power source, using a vibrator unit to provide plate supply voltages. In order to conserve drain on the battery, the vibrator unit supplied only 150 volts DC when receiving. The voltage on transmit was 250 volts.

Other characteristics were:

Power required	12 volts (5 amps on transmit-2 on receive)
Transmitter Power Output	10 watts on FM, 2.5 watts on AM
Max. Dev. Freq. on FM	± 10 KC (AF 300 to 2500 cycles)
IF Bandwidth	35 kc/s

IF Frequency	3 mc/s
Tubes used	12 ea RV12P 2000
	1 ea L 54 (RF power amplifier)
Range	12 miles on level ground
Selectivity	1 to 100,000 for 50 kc/s off.
Receiver Sensitivity	0.3 μ V (for 60 ohm input)
Audio output	600 milliwatts for 4000 ohm load

The circuit, as an FM receiver, contained two RF stages, a mixer, local oscillator, AFC tube, three IF amplifiers (which acted as limiters on strong signals), limiter (which also provided AVC voltage), discriminator and output stage.

As an FM receiver, the limiter grid was used as the diode detector, and the discriminator provided only AVC control voltage.

When on transmit FM, the switches in the circuit converted the first two RF amplifiers to reactance tube and master oscillator respectively. The oscillator signal was applied to the power amplifier (L 54), the audio-output tubes were used for monitoring, and all the remaining tubes were used to provide an AFC arrangement, keeping the transmitter at the same frequency as that of the received signal.

When on transmit AM, the audio output tubes were used for speech amplifiers.

Further circuit details can be obtained in EEIS report No. 9-19.

An interesting feature on this set is the tuning dial which consists of a strip of 35 mm film 4 metres long. The marks for the 400 frequency channels are 1 cm apart on the film and are illuminated by a small lamp as they pass in front of the small window in the front panel. The film rotates between two spring loaded drums, and is driven by a small sprocket coupled to the tuning shaft, which contains the alignment of variable inductances.

Each individual film strip is calibrated independently; the entire process takes only 5 minutes for one strip. Figure 13 shows a block diagram of the procedure. The unexposed film is inserted in the receiver under calibration. The output of the receiver feeds a mixer, which also receives signals from a crystal controlled multivibrator having a 50 KC fundamental. This provides an audio frequency beat signal which disappears each time the receiver is tuned to the same frequency as one of the multivibrator harmonics. The audio signal is amplified and rectified to produce a negative DC bias, which normally keeps a thyratron tube at cut off. The receiver is automatically tuned

starting from one end of the band. Each time a zero beat occurs, the negative bias will disappear, thus allowing the thyatron to conduct. This initiates two other functions: First a mercury vapour lamp in series with the thyatron will be struck and glow for 10 micro-seconds. This illuminates the standard calibrating film and projects a marker line (also the correct frequency designation) on the film under calibration. Simultaneously, the thyatron energizes a relay which controls the receiver tuning mechanism and the receiver is tuned to the next zero beat, where the process is repeated. While under calibration the film passes into a machine where it is automatically developed, fixed, washed, and dried.

Infantry Pack Set "Torn Fu D4": The requirements for this equipment were brought about because the sets in existence were either too heavy or had too small an operating range. The specifications called for a very light weight FM pack set capable of transmission and reception at the same frequency, and having 70 channels. The maximum operating range required was 15.5 miles over a level surface. Simultaneous development was started at Telefunken, Lorenz and Stransfurter*. The information gives here pertains to the laboratory models built by the Stransfurter* firm. There is no indication of any use in the field, or of the existence of production models. *Stassfurter?

The characteristics of the set are as follows

Dimensions :	Roughly 12" x 9" x 5"
Weight:	About 27 lbs.
Material:	Lightweight steel (type used in airborne equipment).
Power Supply:	Edison type 2.4 volts storage battery (15 ampere hours, weight about 2 lbs.
Operating time of battery:	29 hours (without recharge).
Frequency:	20.7 to 23 mc/s. in 70 channels.
Selectivity:	1 to 100,000 for 50 Ic/s off.
Modulation:	FM, Max. Dev. ± 10 kc/s; Audio Freq. Range 300-2500 cycles.
Transmitter Power:	1.5 watts (60% efficiency).
Receiver sensitivity:	0.15 μ V for 35 ohm input (to provide intelligibility of "2" for ± 10 Kc/s deviation)
Audio output:	9 milliwatts for 4000 ohm load.
Antenna:	Flexible steel, mounted on set, 6 feet long "Button Call" system available.
Number of tubes:	10(8 ea RV2.4P700 and 2 ea RL 2.4P2).

The set is mechanically divided into three sections: i.e., R.F. vibrator, and IF, the latter including the audio circuits.

Fig. 14 gives the functional diagram for the entire circuit. The RF oscillator tube T2 is used for local oscillator when on receive, and as master oscillator when transmitting. Since transmission and reception are accomplished on the same frequency, the oscillator frequency must be shifted by an amount equal to the IF when changing from one to the other. This is accomplished by relay contacts S1 and S2 which vary both components in the tank circuit. For tuning a slip contact type of variometer is employed. The components of this circuit are carefully designed to provide good frequency stability. The reactance tube T, serves as modulator when on transmit, and AFC for the receiver. In the case of the latter it will handle a frequency shift of + 10 kc/s. For modulation, a peak audio voltage of + 0.7 volts at its grid will cause a deviation of + 10 kc/s.

The audio voltage applied to its grid is limited by two copper oxide rectifiers connected in opposite directions in series with a resistance across the output of the microphone transformer. It was found necessary to prevent the audio voltage from exceeding a certain level because stronger signals tended to increase the deviation beyond the bandwidth of the receiver, causing distortion and increased noise level. Tests with this audio frequency limiter indicated that it had no noticeable influence on intelligibility and that it actually increased the range of the set.

The microphone is the carbon granule type, strapped to the operator's throat. Pushing the mike button energizes relay Ryl which operates contacts Si and S9, thus changing the circuit from transmit to receive. In order to save on current consumption, an interlocked type of relay was used for Ryl. With this type, each time a switch over is made, the current drain in the relays lasts only about 5 milliseconds.

The output of the oscillator T2, when transmitting, is fed to the RF amplifier T3 by means of magnetically coupled tuned circuits. These circuits are broadbanded, so as to cover the entire operating range of the set. T3 acts as a video amplifier, having an inductive plate load. It is magnetically coupled to the antenna feeder which includes a tuneable inductance for increasing the electrical length of the antenna and a thermal meter. Neutralization is used to prevent oscillation in the RF amplifier stage T3. The simplicity of tuning should be noted. Thus, when shifting to another frequency channel, only the oscillator tank circuit and the antenna inductance is changed. For receiving, the RF amplifier tube T4 employs the inductive plate load of T3 for its input circuit. The benefits of a tuned circuit here were sacrificed for simplicity. The coupling between T4 and the mixer tube T5 consists of a four circuit band-pass filter (20.7 to 23 megacycles) which is used to

provide the desired image rejection. This filter has a very high impedance, and is roughly temperature compensated. Mixing of local oscillator and received signal is done at the grid of T5.

The IF section consists of four amplifiers: T6, T7, T8 and T9, the last three of which serve as limiters. The first limiter T7 provides AVC voltage which is fed to the grids of the RF amplifier and first IF. This provides a constant output over an enormous range of input level, (even when the transmitter is 3 feet from the receiver) and prevents distortion due to overloading.

The discriminator is the conventional type using magnetic coupling, but employs copper oxide rectifiers instead of diodes, thus saving the drain required for filament currents. The discriminator provides a DC correction voltage for the AFC tube, and the audio signal which is applied to the AF amplifier, V 10. This tube uses negative feedback to give improved fidelity and reduce distortion. When the call button is pushed the tube is connected as a 1 kc oscillator feeding the modulator tube. For this operation the effect of the AF limiter is removed so that a large frequency shift is obtained (± 20 kc/s.)

The power supply section contains a vibrator which operates on 2,4 V DC requiring 3 amperes. It provides a negative bias voltage as well as the required plate voltages, 110 volts when on receive and 200 volts for transmitting. In either case the efficiency is 80%, which includes the losses in the filter choke. The choke is provided with a secondary winding which is used to compensate for hum voltage in the negative bias supply. High capacity, low voltage filter condensers are used in the filament and bias supplies.

IV. CONTROL DEVICES FOR GUIDED MISSILES:

General Developments: The fear of radiated jamming caused the designers of the circuits in the guided missiles to utilize FM for control signals. In most cases it was simply square wave switching from one audio frequency to another. The discriminators contained resonant circuits for the various audio frequencies, and associated rectifiers to produce DC square wave outputs. These are described in detail in reports on the STRASSBURG and STRASSBURG F control receivers for guided missiles. The range of frequencies used for the tones varied from 50 cycles to 100 kc/s.

For very low frequencies (5 to 50 cycles) a mechanical type of discriminator was developed. The operation of the circuit is as follows (see Figure 10): The low frequency FM signal is applied across a polarized relay A causing its armature to make contact at a and a' respectively for equal periods of time. The

same W signal is applied across the moving coil of a galvanometer B. Due to its inertia and the presence of the springs, the coil represents a mechanical resonant circuit. The constants are designed so that it is resonant at the centre frequency of the modulated signal. Thus the phase of its mechanical oscillation is shifted 90° at the centre frequency. It will lag at lower frequencies and will be advanced at higher frequencies. The oscillating armature causes contact to be made at b and b' respectively with equal time intervals, but the phase of these "make and break" movements with respect to those at a and a' will depend on the deviation of the frequency of the applied signal from the central value. This will vary the amount of time for each cycle that the circuit is completed for the flow of DC in a given direction. The result is that the DC output is proportional to the frequency deviation of the applied FM signal, and the polarity indicates whether the signal is instantaneously at a higher or lower frequency than its central one, the latter case resulting in no DC output.

This system was tried for the control of a guided missile which was connected to the control transmitter by two steel wires each 0.2 mm. in diameter. The wire unwound as the missile was projected until a length of 10 km was reached. The nature of the problem made it undesirable to use either DC or high frequency AC for the control signal.

A pulse discriminator was developed for the purpose of obtaining extremely high sensitivities to frequency deviation. The circuit, as shown in Figure 11, was capable of detecting phase shifts equal to $1/3$ of a degree, or frequency deviations of 1 part in 20,000. The disadvantage of the scheme was that it was limited to frequencies below 20 kc/s. Operation of this circuit is as follows. The applied FM signal is split into two channels. The first goes to the limiter tube V1. The second passes through a three-circuit phase shifting network having a phase characteristic proportional to frequency and designed so that at the central frequency the shift will be 180° . The output of the network feeds the limiter V2 which is identical to V1. The outputs of the two limiters are applied to the primaries of the pulse forming transformers T1 and T2. The bridge rectifier systems in the secondaries eliminate the pulses of undesired polarity so that only positive pulses appear at the grids of V3 and V4. The instantaneous frequency of the FM signal will determine, during each cycle, whether the pulse applied to V3 will occur before, after, or simultaneously with the pulse at V4. Since the tubes are arranged as a DC multivibrator, the one receiving its pulse first on each cycle will conduct heavily and completely "take-over" until the frequency changes enough to cause its pulse to lag that of the other tube, during which time the conditions will reverse, and the tube will become completely

cut off. The output-versus-frequency characteristic is shown in Figure 12.

Tests with Kehl-Strassburg System: In the spring of 1942 equipment was built to test the relative vulnerability of FM and AM to jamming signals as applied to the remote control of guided missiles. The normal system for AM transmission, known as KEHL-STRASSBURG, consisted of an AM transmitter modulated by control signals containing two sets of audio tones. Each set continuously switched from one tone to the other. The receiver, as shown in Figure 15 consisted of a super-heterodyne AM receiver, having AVG and AFC. The audio circuit had four resonant filters in the plate circuit of T10. This formed two discriminator systems for the audio tones and, in conjunction with the rectifiers, produced square waves on the grids of the DC amplifiers T11 and T12 to operate the control relays.

In order to modify the receiver for tests with FM transmission the AFC output from the discriminator was changed and fed to an audio amplifier, and the IF circuit changed to provide more limiting.

Two types of jamming signals were used. The first contained a modulation signal at the same frequency as one of the control tones. In this case the FM system was found to be superior. In the other case the audio frequency produced by the jamming was not the same as any of the control signals. This time the FM proved more vulnerable. For this reason, the use of AM remained, since it was felt that with AM the possibility existed for the exploitation of super-regenerative detection.

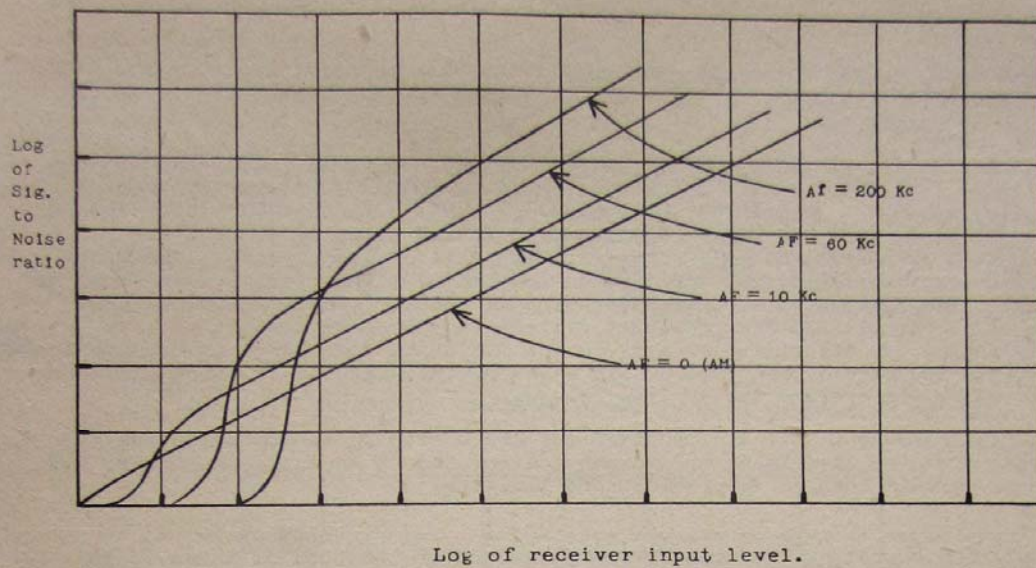


FIG.1. - Receiver performance with varying frequency deviations.

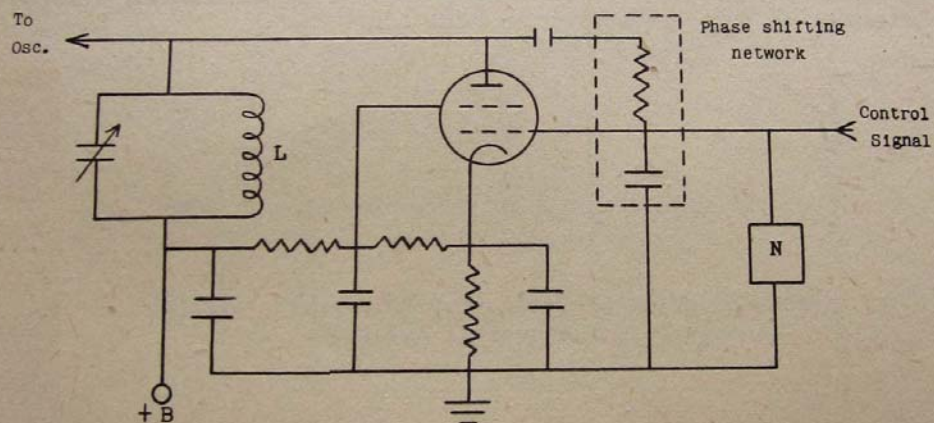


FIG.2. Variable inductive reactance.

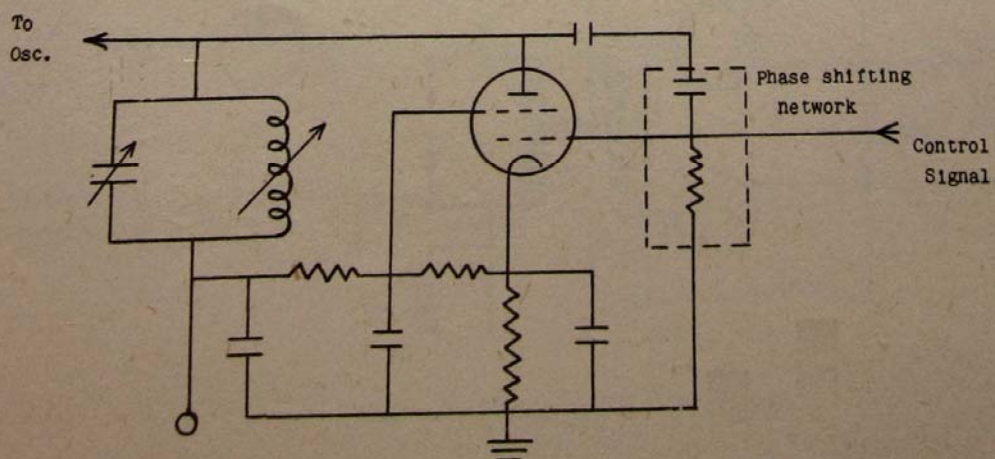


FIG.3. Variable Capacitive Reactance.

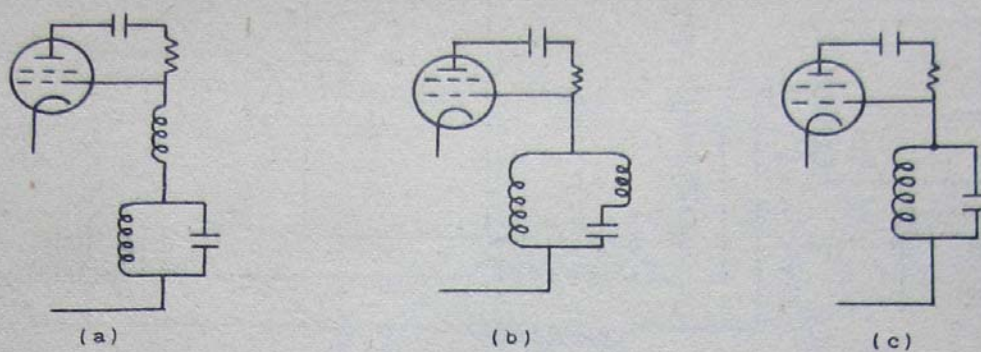


FIG. 4 - Corrective feedback networks used to produce variable time-constant.

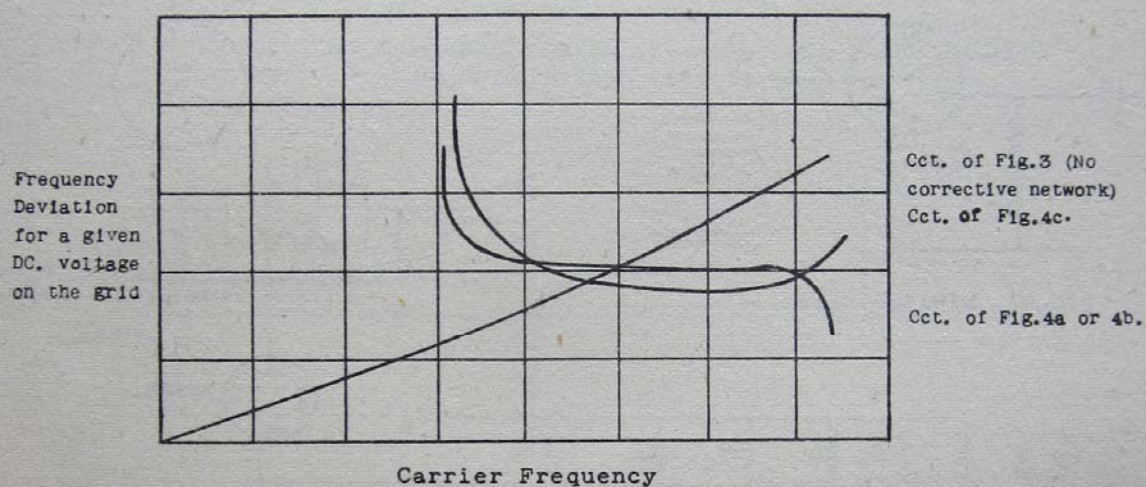


FIG. 5. Effect of corrective networks in making deviation independent of frequency.

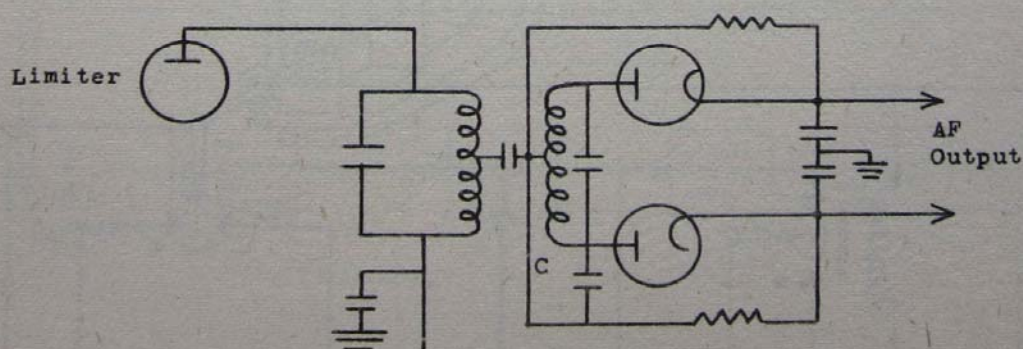


FIG. 6. Discriminator Circuit.

Section
(15 Contd.)

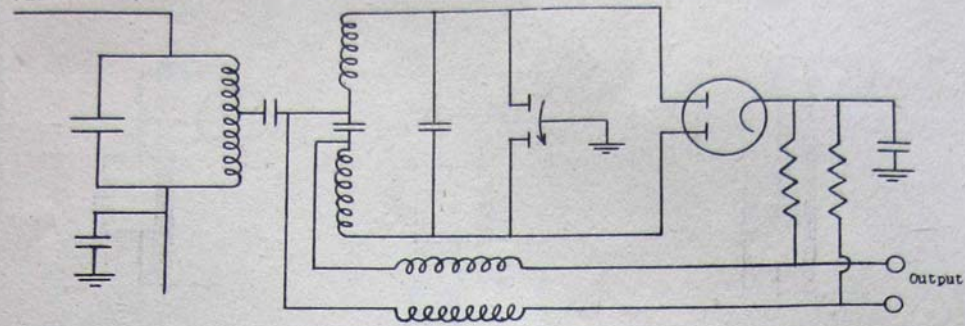


FIG.7. Discriminator using common cathode.

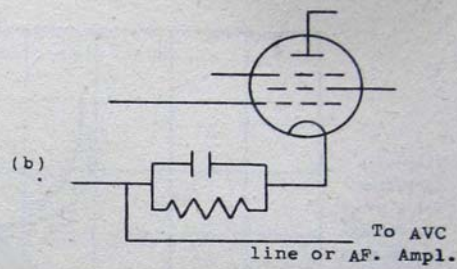
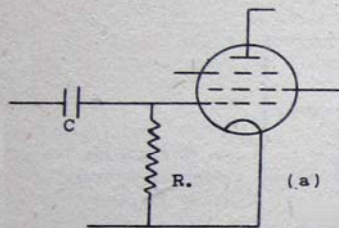


FIG.8. Limiter Circuits.

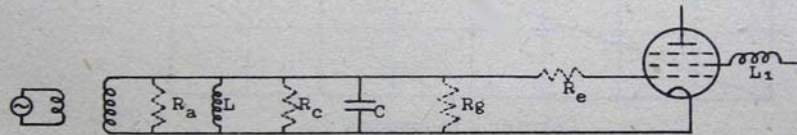
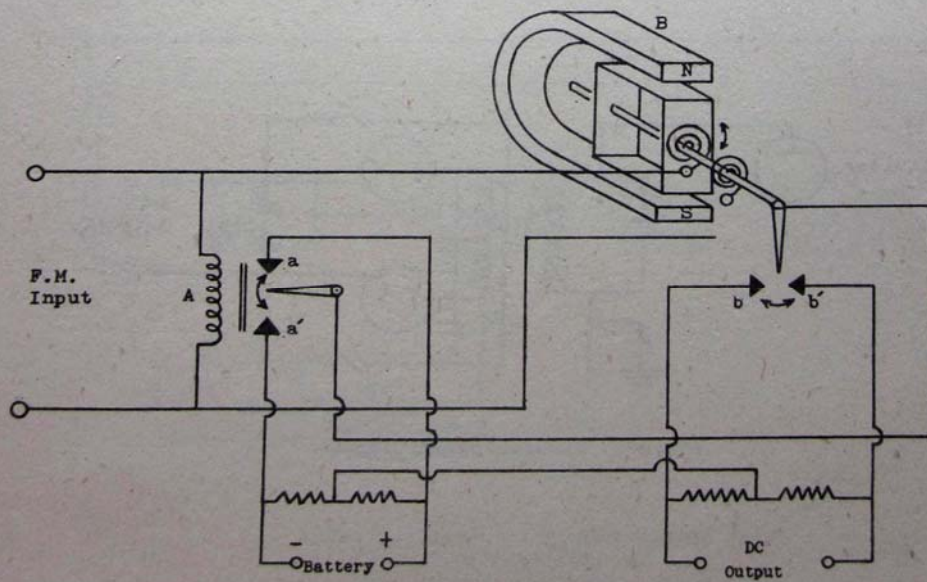


FIG.9. Equivalent circuit of first RF. stage.



Section 2.1
(15 Contd.)

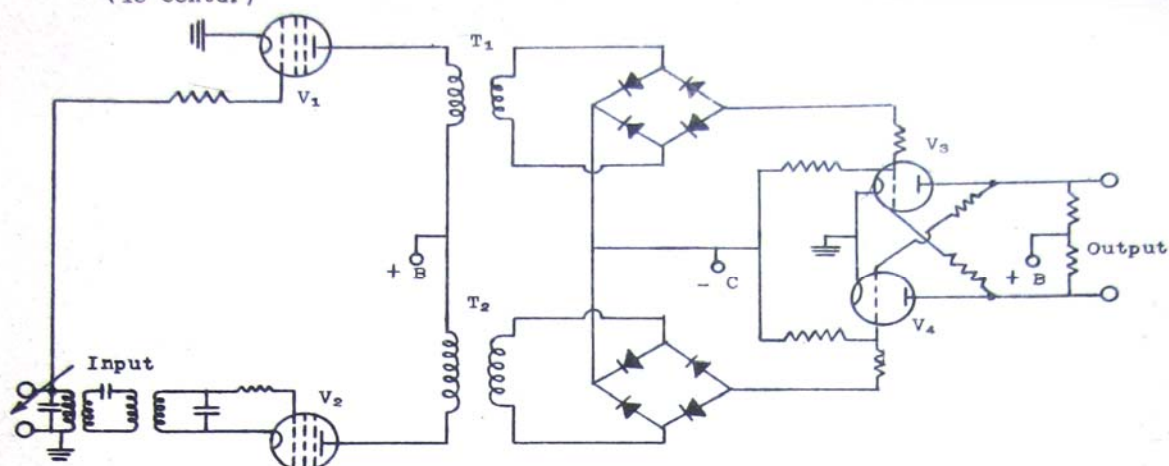


FIG.11. Low frequency (Pulse operated) discriminator with high Deviation sensitivity.

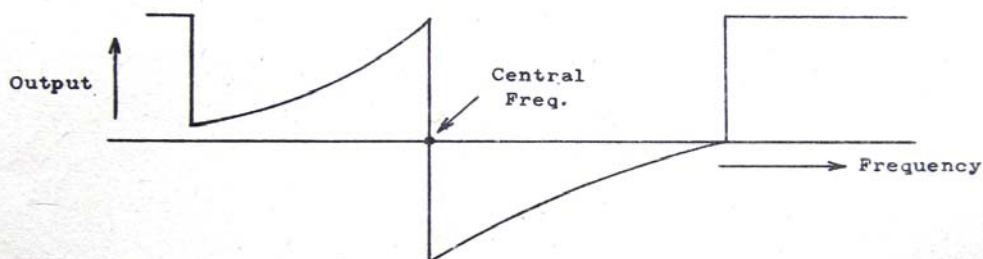


FIG.12. Characteristic for pulse type Discriminator.

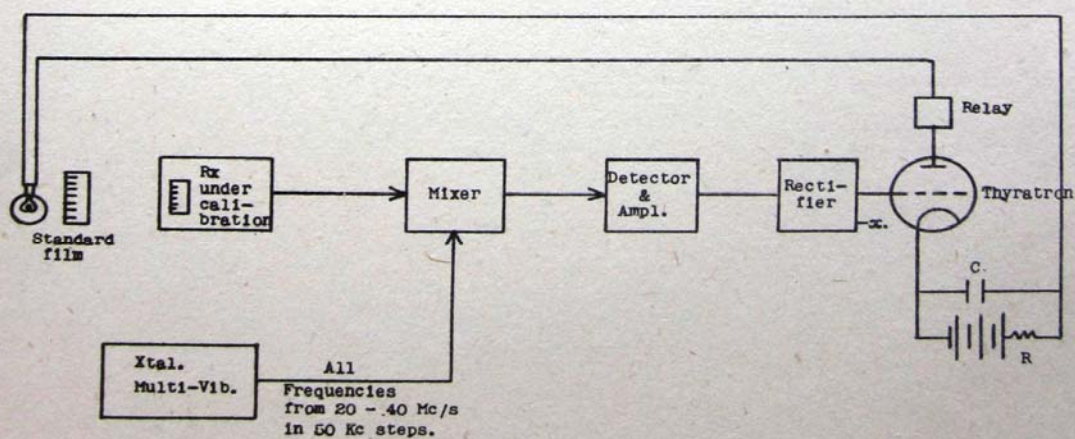


FIG.13 - Process for calibrating film dial in FUSRECH K.