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THE DEVELOPMENT OF AN AIRWAYS ULTRA-HIGH-FREQUENCY COMMUNICATIONS CIRCUIT

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FOREWORD

The authors wish to acknowledge the cooperation and assistance extended by the commercial organizations which made facsimile and printing telegraph equipment available for comparison tests with the teletype

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The Development of an Airways Ultra-High-Frequency Communications Circuit

SUMMARY

The development of an ultra-high-frequency radio teletypewriter circuit between Washington, D C , and Baltimore, Md , is described in this report This circuit has been in operation on an experimental basis for over 2 years

The radio and terminal equipment which was designed to meet the rigid requirements of the Bureau of Air Commerce communications system is described in detail The propagation characteristics of the 61- and 65-megacycle frequencies in use during the past 2 years are discussed Based on an analysis of the continuous records of received signal at Washington for the period of November 1, 1936, to November 1, 1937, the total outage of the circuit due to fading is estimated at less than 10 minutes Outages due to all other causes have been negligible Previous results obtained in experiments on the low frequencies (284 kilocycles) and later on the high frequencies (3000 to 4000 kilocycles) and on 38 megacycles are reviewed briefly, and it is concluded that these frequencies are not suitable for a communications circuit containing a number of automatic repeater stations, due to fading, atmospheric noise, and reflected sky waves

Experiments with other forms of record printing equipment including facsimile are discussed and comparisons made with teletypewriter These tests have shown that in its present state of development, commercially available facsimile equipment is not suitable for Bureau of Air Commerce communications The teletypewriter was found superior to the other printers tested

Multiple channel radio teletypewriter and simultaneous voice transmission experiments are also described with special reference to the use of such a system for ground station and ground-to-aircraft communications

Comparative costs estimates indicate that for two or more communication circuits, multichannel radio teletypewriter is more economical than land wire teletypewriter and further offers the possibility of a ground-to-aircraft voice and teletypewriter service at a negligible increase in cost

INTRODUCTION

The teletypewriter communication service of the Bureau of Air Commerce, by means of which weather information and other necessary data are disseminated over the civil airways, now extends over 23,000 miles The teletype circuits are further supplemented by point to point radio telegraph in sections of the country where land lines are not available or would be prohibitive to construct The cost of leasing land lines for this service now amounts to over $700 000 annually In an effort to reduce land line charges, the Bureau of Air Commerce undertook a series of experiments in the summer of 1930 to determine the practicability of using radio as a medium of transmission for teletypewriter circuits in place of land lines These tests were conducted between Buffalo, N Y , and Bellefonte, Pa , on a frequency of 284 kilocycles Due to very high static levels, particularly in the summer months, these tests did not prove successful In the latter part of 1932, tests were conducted between Salt Lake City, Utah, and Idaho Falls, Idaho, on a frequency of 4070 kilocycles, and later between Washington, D C , and Baltimore, Md , on 2960 kilocycles Although these tests proved moderately successful, it was apparent that three limiting factors enter into the operation of a fully reliable radio record printing system, namely noise fading and multi-path propagation. Following the tests on 2960 kilocycles, attention was directed to the use of ultra-high frequencies (above 30 megacycles) since these frequencies appeared admirably suited for communication over relatively short distances such as are encountered between airways weather-observing stations, primarily due to their freedom from high noise levels and absence of the reflected sky wave. Accordingly, tests proceeded on a frequency of 38 megacycles between Washington and Baltimore, the frequency being later shifted upward to the band between 60 and 65 megacycles, when police radio and amateur communications revealed that considerable sky wave remained on up to 40 or 45 megacycles, but was absent at higher frequencies. The tests in the 60- to 65-megacycle band also indicated lower noise levels. Considerable development work was done on the transmitters, receivers, and teletypewriter terminal equipment, resulting in a very reliable radio teletypewriter circuit, against which other commercially available forms of printing apparatus and facsimile were compared. These tests showed that the teletypewriter is far superior in performance to present available facsimile, and lends itself more readily to multi-channel high-speed operation. The Bureau of Air Commerce radio teletypewriter circuit has now been in operation on an experimental basis for over 2 years. Early in 1937 a voice channel, and more recently another teletypewriter channel were added, to operate simultaneously on the same frequency with the intention of determining the feasibility of a voice and one printer channel for communication to aircraft, and two or more channels at 60 words per minute each for ground station communication to provide much needed higher speed weather and airway traffic communication channels.

It is the purpose of this paper to report the investigations made to date and describe the Bureau of Air Commerce Washington-Baltimore radio teletypewriter circuit and equipment.

REQUIREMENTS OF THE BUREAU OF AIR COMMERCE COMMUNICATIONS SYSTEM

The major communications traffic handled on the Bureau of Air Commerce teletypewriter circuits consists of weather sequences, so called because the information is collected at various weather observing stations along an airway and placed on the circuit at definite scheduled times during each hour of the day. Each station on the airway places the local weather data on the circuit in sequence starting from one of the terminal stations. At the end of the sequence, all stations on the circuit have a complete copy of the entire weather sequence for the airway. Such a chain communications system places a severe requirement on the operations of the circuits by radio, and differs markedly from ordinary point-to-point and intercity circuits in that transmissions must originate at either terminal or any intermediate station on the circuit, and copies must be received simultaneously at all stations including the originating point. In addition, it is required that the same printer be used for transmitting and receiving and that any station on the circuit be able to "break" transmissions at any time. Further requirements are those encountered in any other communications system, namely reliability, accuracy, simplicity of operation, and speed. Radio and terminal equipment are required to run on an essentially unattended basis. Absolute accuracy is essential, since a great many symbols and abbreviations are used in weather communications. The increasing demand by air-line services for more frequent weather information and added material such as weather forecasts and upper air reports, has placed a heavy load on the present teletypewriter circuits. Prior to July 1, 1937, 40 w. p. m. (words per minute) was the maximum speed of these circuits. This has since been speeded up to 60 w. p. m., the maximum practicable speed of the teletypewriters. No particular difficulty is encountered in the radio operation of printers at this speed. By increasing the number of tone modulation channels, the effective speed in words per minute can be increased several times, provided the radio circuit is of high quality

The technical obstacles arising in the establishment of a high-frequency record printing communications circuit, where the electrical impulses are no longer guided by wire lines, may be divided into three conditions of radio wave propagation, viz, (1) noise, (2) fading, and (3) multipath transmission The signal/noise ratio required is considerably greater than that needed for aural reception, since the recording mechanism takes the form of some relay or triggering device which does not possess the ability of the human ear to discriminate between static and signal impulses Numerous methods of decreasing noise have been devised, but the most practical known means is by frequency selectivity The noise output of a receiver is directly proportional to the selectivity or band width accepted, and the use of audio-frequency filters has been found very helpful in increasing the signal/noise ratio These filters, however, must have a sufficient band width to pass the tone impulse frequency without appreciable distortion Fading causes wide variations of received signal strength, and the recording mechanism must be designed to operate faithfully under these conditions Multipath transmission or multiple echoes result from signals arriving at slightly different times due to reflected sky wave components, producing distorted impulses, and this must be taken into account in the design of the recording mechanism In other words a certain margin of safety must be allowed for to take care of light or heavy impulses and rounded impulse waveforms Two methods are generally employed to aid in maintaining a constant signal level

(1) The use of automatic gain control, wherein the amplitude of the radio-frequency signal controls the gain of the receiver

(2) The use of a limiter, wherein the rectified marking impulses are made to drive the grid of a tube to cut-off from normal value, so that increases of signal cannot have any further effect

These devices, although helpful, are insufficient under certain fading conditions when the signal drops out entirely To combat this, diversity reception is often employed This consists of mixing the rectified signal outputs from two or more receivers, whose antennas are separated in space It has been found that fading will rarely ever occur at three different points in space simultaneously, even though they may be separated by only a few hundred feet Such systems are complex and expensive, and are economically justified only on long-haul high-speed circuits

HIGH-FREQUENCY TESTS

The first high-frequency tests conducted by the Bureau in determining the practicability of operating teletypewriters by radio were conducted between Salt Lake City, Utah, and Idaho Falls Idaho (a distance of approximately 230 miles), in the latter part of 1932 The frequency assigned for this work was 4070 kilocycles, and standard receivers and crystal-controlled point-to-point c–w telegraph transmitters were used Tests were conducted mainly during the daylight hours, since the frequency of 4070 kilocycles was not suitable for night transmission between the two sites The transmitters had a power output of 400 watts Horizontal half-wave antennas supported between 80-foot poles were fed by means of open wire transmission lines The receivers were the standard type RHM superheterodynes In an attempt to keep the terminal equipment as simple and inexpensive as possible, it was decided to use a single-tone system, which will be described in detail later in this report The chief difficulties encountered were

(1) Extreme fading, much greater than could be handled by the system

(2) High noise levels at both sites, but particularly at Salt Lake City

Much of the noise at Salt Lake City was due to nearby streetcars and the large number of arc lamps used throughout the city Errors in teletype copy varied from a few tenths of 1 percent to over 25 percent The single-tone system used, which is based on transient phenomena for its operation, was particularly susceptible to static.

An improvement was made in the circuit when the method of keying the transmitters was reversed from "white keying" to "black keying." White keying refers to carrier "on" for spacing impulses and "off" for marking impulses. Black keying refers to carrier "off" for spacing impulses and "on" for marking impulses. Using the black keying, the carrier was normally on the air and was broken only by the rapid spacing impulses. This allowed the use of the automatic gain control in the receivers and aided considerably in reducing the effects of fading. Although it seems reasonable to believe that the probability of random atmospheric noise arriving at the receiving antenna in or out of phase with the signal would be about equal, it was found that black keying gave less errors due to noise than white keying. The advantage to be gained by the use of sharp filters could not be realized due to insufficiently stable oscillators in the receivers, which did not hold the beat note within the filter band over long periods of time.

In 1934, when further tests with the same equipment were conducted on 2960 kilocycles between Washington and Baltimore, the results obtained were essentially the same. Over this 40-mile circuit fading was decreased to some extent by employing vertically polarized antennas for both transmitting and receiving. From the standpoint of operating a chain of automatic repeater stations to meet the requirements set forth previously in this paper, the use of high frequencies appeared hopeless, unless each station was equipped with diversity receiving equipment and high-power transmitters with directive antenna arrays. Such a system would be economically prohibitive and could not successfully compete with wire lines.

DEVELOPMENT OF THE ULTRA-HIGH-FREQUENCY CIRCUIT

With the increasing interest in the use of ultra-high frequencies, tests were started in the latter part of 1934 between Washington and Baltimore on 38 megacycles, using the same terminal equipment that had been previously used on 2960 kilocycles. The transmitting antenna at Washington was 125 feet above the ground, and the receiving antenna at Baltimore was 30 feet above the ground. Both antennas were eight-element vertically polarized arrays. The transmitter at Washington was crystal controlled, delivering about 50 watts. Tone modulation was used in these tests. Several types of receivers were used at the Baltimore end of the circuit, including two super-regenerative types and two super-heterodynes, one of which was crystal controlled. These tests proved very encouraging because of the increased signal/noise ratio, and much less fading than was encountered on the high frequencies. The terminal equipment, however, was still found susceptible to noise, particularly ignition noise.

As more data became available on the propagation of ultra-high frequencies, it was noted that police radio and amateur signals in the band 30 to 45 megacycles were being received at very great distances under certain conditions, indicating the presence of reflected sky waves. Equipment was then changed to operate in the 60- to 65-megacycle band. This equipment is described in the following.

Transmitters

The transmitters originally utilized 8.125-megacycle crystals in a tri-tet circuit, and the radio-frequency amplifier tubes were type 852 using conventional coil and condenser tank circuits. Due to the fact that the tri-tet oscillator circuit causes excessive heating of the crystals, the circuit was changed to a crystal-dynatron circuit using a type 57 tube. The crystal current was thereby reduced to a maximum of 35 ma., and the harmonic output was sufficiently strong up to the fourth harmonic to enable the crystal frequency to be dropped to 4.0625 megacycles. The fourth harmonic (16.25 megacycles) is derived directly from the 57 crystal stage, then doubled in an RK–23 tube and again amplified in an RK–23 stage to produce approximately 18 watts of power at 32.5 megacycles, which is sufficient driving power for the succeeding stages even with poor crystals. The crystals used are of the low temperature coefficient type The 852 type tubes, due to their relative inefficiency at higher frequencies, were replaced with type 304–B tubes Following the 32 5 megacycle exciter stage, a 304–B tube doubles the frequency to 65 megacycles, after which one 304–B is used as an intermediate amplifier to drive two 304–B tubes in push-pull in the power amplifier The plate efficiency of the power amplifier is of the order of 60 percent when delivering 100 watts of power at 65 megacycles The high efficiency obtained is partly due to the efficient 304–B tubes and also largely to the type of tank circuits used, which consist of "hairpin" coils and "pie-plate" condensers, simulating transmission line-type tanks The output of the power amplifier is inductively coupled to an open wire transmission line leading to the antenna array

A conventional class B modulator is used to modulate the power amplifier The modulator consists of two type 2A3 tubes feeding two type 838 tubes in class B The modulator input is 600 ohms, capable of being connected to the output of a speech amplifier or tone keyer to be described later Separate mercury vapor rectifiers are used for the radio and audio-frequency stages Power is supplied to the transmitter at 110 volts, 60 cycles, single phase A block diagram of the transmitter is shown in figure 1

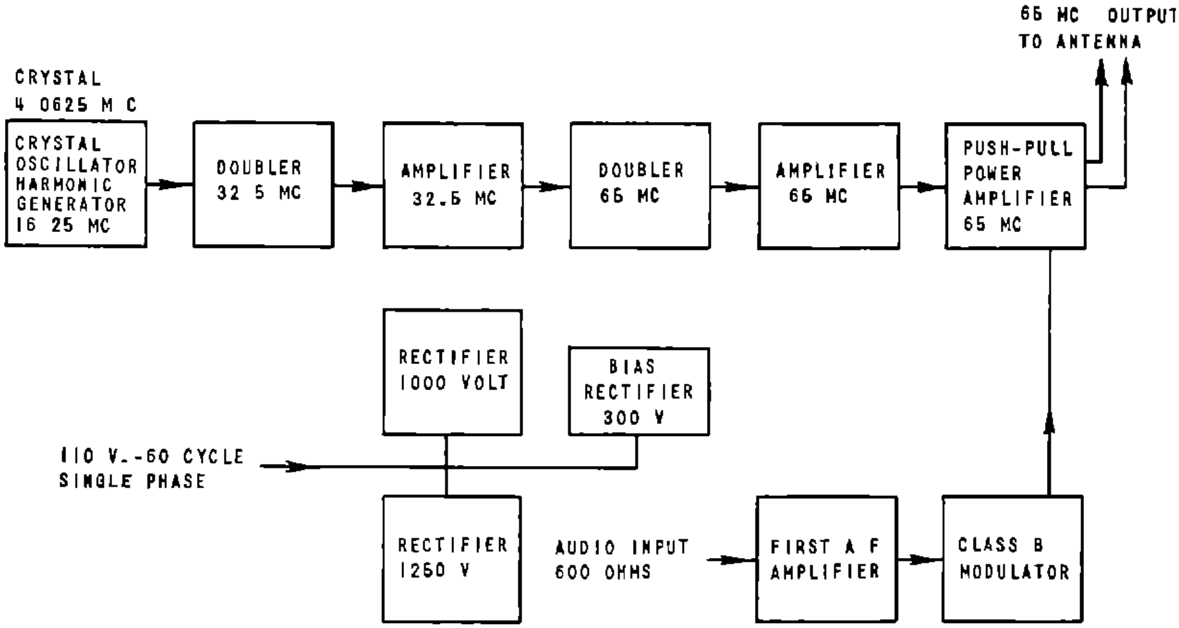

Figure 1—Block schematic of the ultra high-frequency transmitters

Receivers

The first receivers used were of the superregenerative type These supplied signals of sufficient amplitude to operate the terminal equipment, but since this type of receiver is not generally suitable for unattended operation, commercially available crystal-controlled superheterodyne receivers were obtained The sensitivity of these receivers, at 61 megacycles was sufficient to give a usable signal although they were operating far from the a g c (automatic gain control) region At 65 megacycles, the sensitivity was so low that no signals could be heard at the Washington station Provision was made in the receivers to make the beating oscillator self-excited, giving an increase in sensitivity This increase was insufficient to permit their use at 65 megacycles The crystal controlled receivers were rebuilt using the original intermediate-frequency amplifier and audio system A double concentric line input is used with a 954 tube as a radio-frequency amplifier The plate of the

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radio frequency amplifier uses a conventional coil and condenser. The use of sections of concentric line loaded with a capacity for the tuned circuits provides a high Q circuit, which is self-shielded and mechanically rugged. The first detector is a 954 type tube, the heterodyne voltage being introduced in the cathode circuit. The frequency of the heterodyne oscillator is controlled by a low temperature coefficient crystal. The fundamental frequency of the crystal is such that the sixth

Intermediate-frequency selectivity—60 kilocycles wide at 3 db down from resonance. (See fig. 3.)

Image response—85.3 db down.

Figure 4 is the a. g. c.-noise output curve. This curve was obtained by measuring the output of the receiver with and without modulation for various input signals. A modulation of 30 percent with 400 cycles was used. This curve gives a measure of the utility of the receiver.

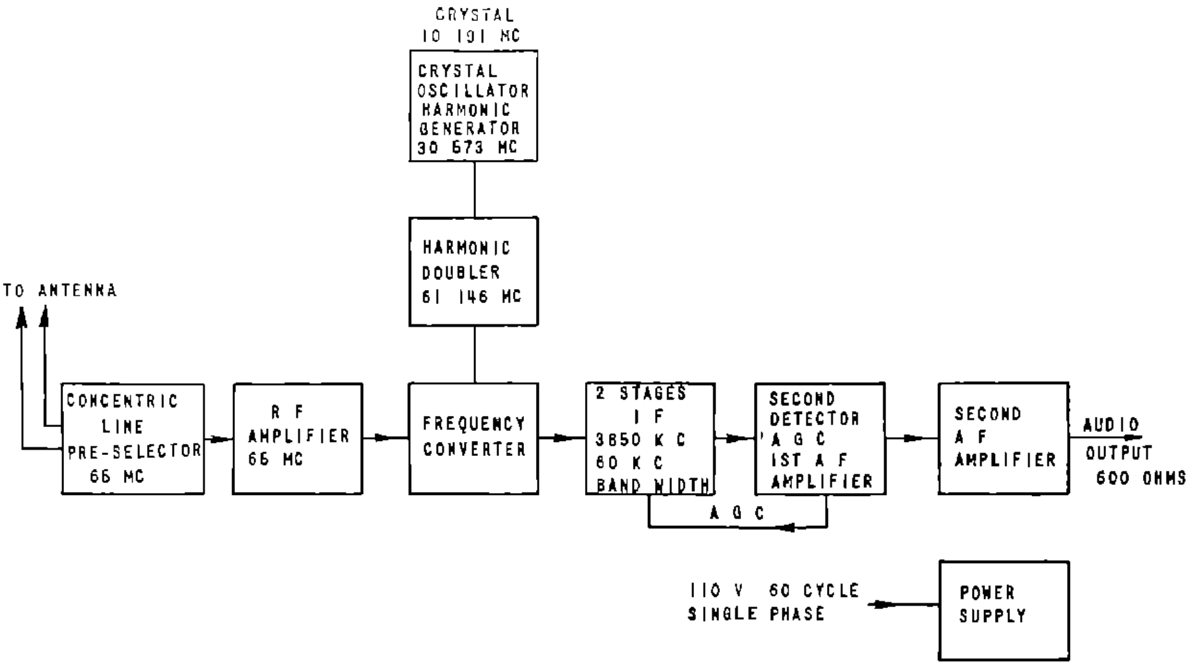

Figure 2.—Block schematic of the ultra-high-frequency receivers

harmonic is 3850 kilocycles less than the signal frequency. Two types of heterodyne source are being used. In one type, a 954 tube acts as a frequency multiplier feeding the third harmonic to the cathode circuit of the detector. The other type uses an extra stage of amplification operating as a frequency doubler, feeding the sixth harmonic to the first detector. The latter adds an extra tuning control. A block schematic diagram of this receiver is shown in figure 2. The performance characteristics of the receiver are as follows:

Sensitivity—3 microvolts through a 50-ohm resistance for zero db output.

Antennas

The first antennas used were Sterba arrays, using vertical polarization. They consisted of two vertical one-half wave sections spaced horizontally one-half wave apart, for the top three tiers, with a similar quarter-wave section at the bottom. A similar bay placed one-quarter wave behind the antenna was used as a parasitic reflector. The antenna was fed by a two-wire open line at a current maximum. The transmitting and receiving antennas were alike and erected on 65-foot wooden poles. This type of antenna gives a gain of about 10 db over a single half-wave radiator.

New transmitting and receiving antennas were designed and erected later on 125-foot steel towers The transmitting antenna uses four horizontal one-half wave elements spaced one-half wave apart in the vertical plane, fed in-phase, with a similar unit placed one-quarter wave behind the antenna used as a parasitic reflector The construction is a modified "turnstile," using no insulators A two-wire open line feeds the antenna, and a stub matching section is used near the antenna to remove standing waves from the line

Horizontal rhombic antennas are used for receiving These are erected on top of 125-foot steel towers, each side of the antenna being two wavelengths long Unidirectional characteristics are obtained by terminating the forward end in a resistance The transmission line to the receiver is of the two-wire open type

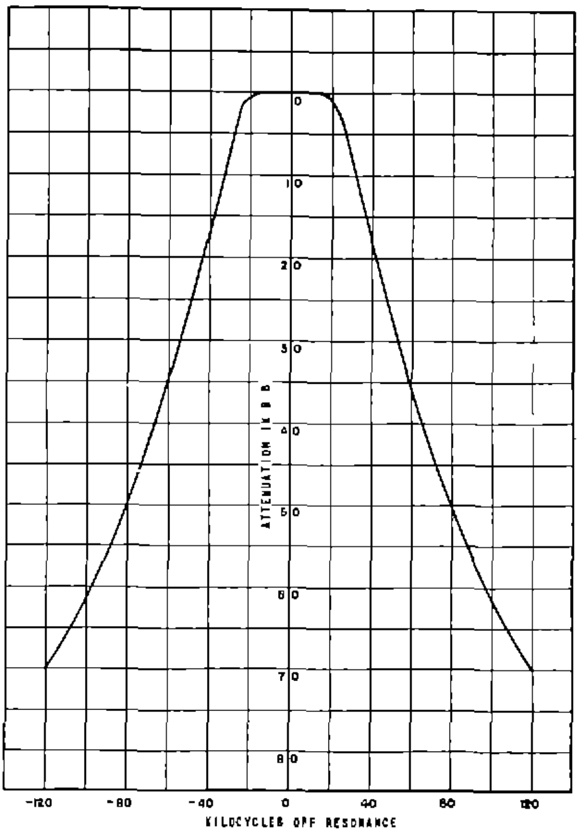

Figure 3—Intermediate-frequency selectivity curve of the ultra-high-frequency receiver

TERMINAL EQUIPMENT

When the electrical impulses of a telegraphic communications system are no longer guided by wires, it becomes necessary to provide apparatus to change the d c impulses of the teletypewriter into a form which can be transmitted by radio, and at the receiver be translated back to the d c impulses with the same original characteristics The simplest system would consist of keying the carrier with the teletypewriter impulses, then rectifying the received carrier and operating a relay from these impulses Direct keying of the carrier has two main objections

(1) Multi-channel operation is difficult and resort must be made to some form of time division multiplex principle, with its attendant complex terminal equipment and necessity for automatic synchronous transmission

(2) Without complicated circuits, the a g c action of a receiver cannot be used to keep received levels at a constant amplitude Consequently, tone modulated carriers were used on this circuit

Figure 5 illustrates a simple form of equipment required for use in operating a visual recorder or printer by radio Assume that marking impulses consist of signal "on," and spacing impulses are signal "off" For convenience this will be referred to as a single-tone system The output of the receiver (either modulation tone or c-w beat note) is fed into a rectifier, which converts the marking impulses to d c impulses suitable for actuating the signal winding of the receiving relay, thereby closing the circuit to the printer magnet or recorder During spacing impulses, no signal is rectified, hence the receiving relay armature is held to the spacing side by the biasing winding In this system, there is no constant relation between the force tending to throw the armature to the marking position, and the restoring force produced by the bias The restoring force is constant, whereas varying signal levels produce variations in the signal actuating force Such a system is said to be "biased"

Engineers of the Bell Telephone Laboratories have devised a scheme whereby the restoring current of the receiving relay is caused to vary approximately in accordance with the strength of the received signal by using the so-called two-tone system. One tone is used for the marking impulses and another tone is transmitted for the spacing impulses. The two tones are thereby subjected to similar attenuations of the radio circuit, except in cases of selective fading. This system however, requires two filters and two rectifiers, one for each tone on a one-way circuit. Figure 6 is a diagram reproduced from a paper by Bailey

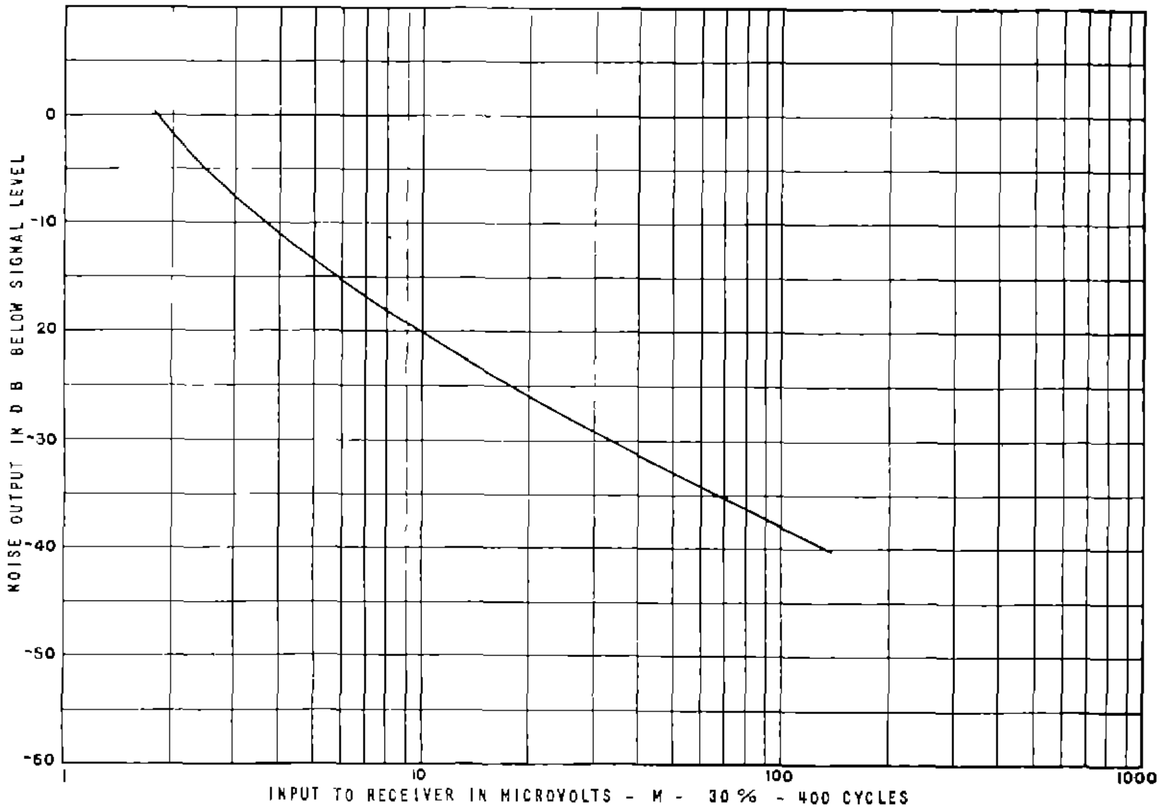

Figure 4—Receiver noise as function of input signal. Noise expressed as decibels below combined output level of noise and modulation. Modulation *30 percent at 400 cycles*

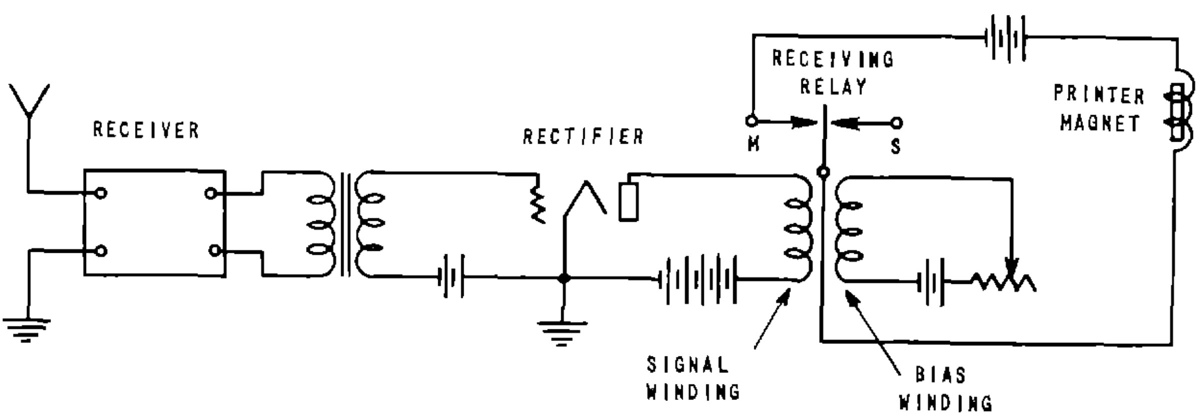

Figure 5—Fundamental circuit of a single-tone fixed bias printing telegraph system

and McCann, illustrating the variations of the radio circuit that can be tolerated by both the single-tone method with fixed bias and two-tone method of transmission. These curves show the relation between received current and the limits of printer margin within which correct operation is secured. The ordinates of the curves as given by Bailey and McCann have been converted to read in percent of the maximum margin obtainable by the particular printer used (which was assumed to be 85 considerably higher if the circuit noise had been lower. This system was used on a long wave trans-Atlantic circuit, and noise level limited operation to levels between plus or minus 7 db of the normal zero shown on the curve, whereas the single-tone fixed bias system limited operation to levels between plus and minus 3 db.

Obviously, an unbiased system is desirable and for the sake of simplicity a single-tone system is to be preferred. A modification of

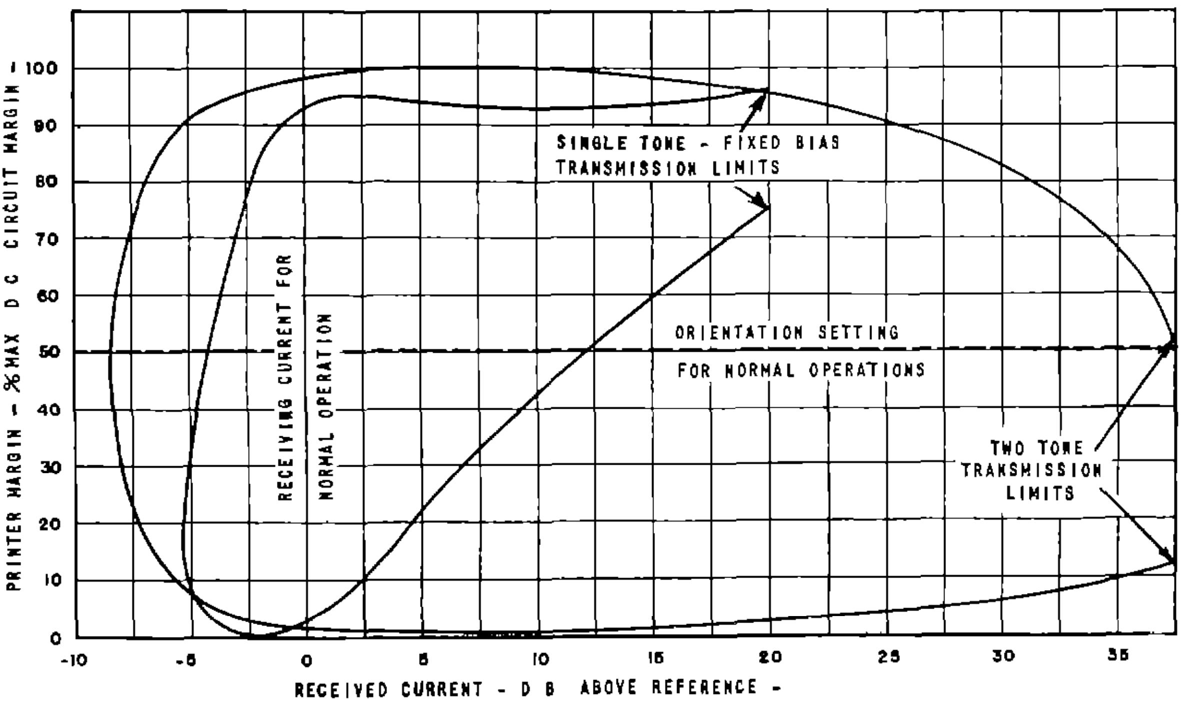

Figure 6.—Margin characteristic showing relation between received current and printer operating margin for the two-tone and single-tone fixed biased methods

points, the maximum margin obtained with the two-tone system in their tests). For a certain minimum signal for each method of transmission, the upper and lower limits of printer margin meet, indicating complete failure to print. With increase in signal level, the limits of printer margin are not affected as seriously in the two-tone method as in the single-tone fixed bias method. It is apparent then that the ideal margin characteristic to be desired is a rectangle. The normal receiving current level is shown 7.5 db above the point of printer failure, and could have been raised

the simple circuit of figure 5 is shown in figure 7, which is a single-tone system modified to

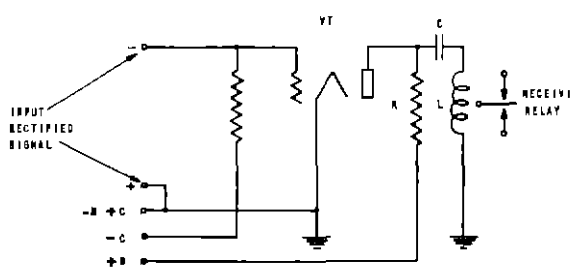

Figure 7.—Schematic circuit of vacuum tube relay, single-tone system used in high-frequency tests

eliminate the fixed bias. In this circuit, a high speed Creed relay is operated through the charging and discharging of the condenser C in the plate circuit of tube VT_1. The constants R, L, and C are chosen such that they constitute a dead-beat oscillatory circuit. Changes of the plate current in VT_1, caused by the rise and fall of the rectified signal impulse, cause momentary surges of current to flow through the relay winding in one direction for increasing plate current and in the opposite direction for decreasing plate current. Thus the device operates on the rate-of-change of amplitude rather than on the magnitude of the rectified impulse, and is essentially independent of the variations in signal strength. Figure 8 shows the operating margin characteristic obtained with this system. It will be noted that the improvement over the single-tone fixed bias system is considerable, and the relay was able to operate well for variations of signal of about 14 db. The normal operating current was set about 4 db below the upper limit, to allow for more fading. Furthermore, the tube VT_1 of figure 7 was connected so that a marking impulse would drive it to cut-off thereby providing a degree of limiting. This system, although removing the objection of the biased system, was susceptible to static since it is essentially a transient operated device. This type of relay was used in the previously described high-frequency tests.

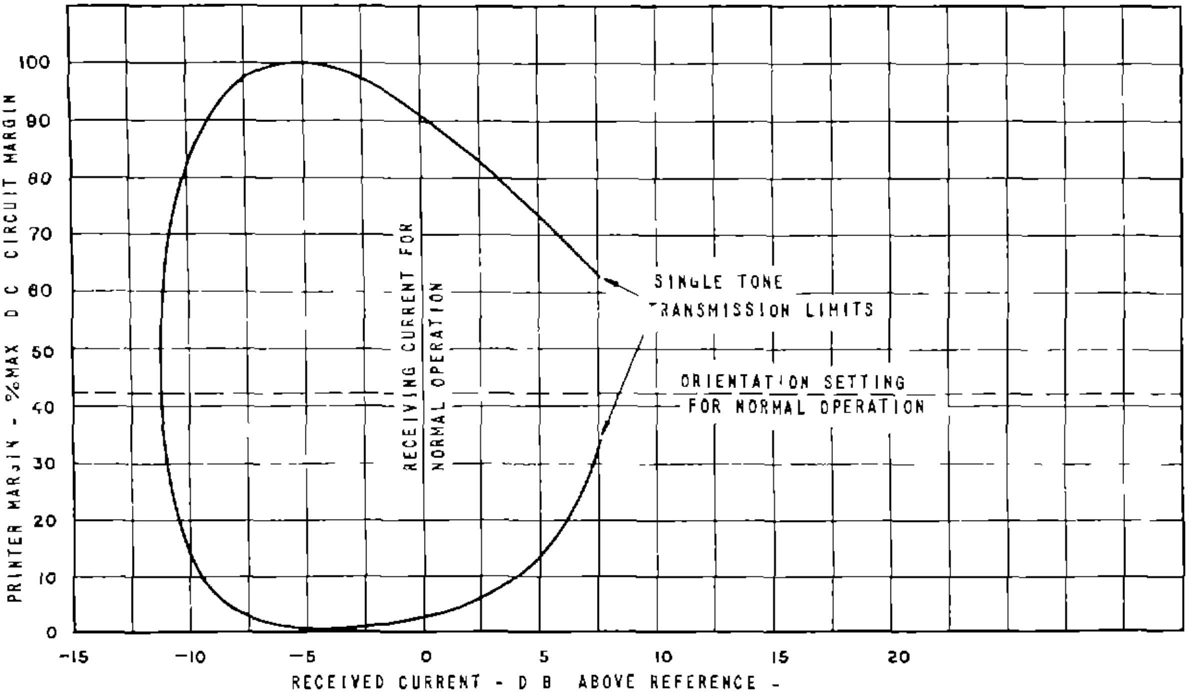

Figure 8.—Operating margin characteristic of the single-tone system shown schematically in figure 7

The gas discharge tube relay

In an effort to obtain a system which would be more free from effects of static and interference and obtain a margin characteristic whose shape is rectangular, resort was made to the 885 type of gas discharge triode. The circuit is shown in figure 9. During spacing impulses the gas discharge tube VT_1 is ionized and draws plate current which can be adjusted to the desired value by resistance R_1. At the same time VT_2 is biased below cut-off and is not ionized. Condenser C is then charged to a potential, such that A, figure 9, is plus 15 volts to ground (which is approximately the drop across VT_1 when it is ionized) and B is at full plate potential above ground, say plus 100 volts. During marking impulses the grid of VT_2 is driven positive, causing it to become ionized and draw plate current of constant value, depending on the value of R_2. This changes the potentials at A and B. Potential B decreases from plus 100 to plus 15 volts, while A drops by the same amount, or 85 volts, from plus 15 volts to minus 70 volts. Since the plate and grid of VT_1 have gone negative, the tube no longer is ionized and draws no plate current. Thus, marking and spacing impulses trigger the two tubes oppositely, thereby operating the polarized receiving relay, and the relay current is independent of the triggering applied voltage, giving an unbiased system.

The best triggering of the gas discharge tubes obtains when the control grid current, under ionized conditions, is at a minimum. This grid current can be either a flow of cur-

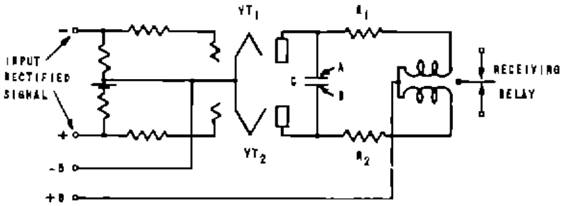

Figure 9.—Schematic circuit of gas discharge tube relay, single-tone system.

rent from the grid to the cathode or from cathode to grid, depending on which element is at a positive potential with respect to the other. This is true since the conduction of current in this type of tube is by means of an ionized gas. If the grid potential is not sufficiently negative, the tubes will oscillate just as they trigger off, resulting in a chattering of the relay and poor margins on the teletype machine. When the grid potential is excessively negative, then there is too great a difference in the instantaneous voltage necessary to make the tubes trigger off. By reference to figure 9, it is seen that when no rectified signal voltage is present VT_1 is ionized since its grid is at zero potential. VT_2 is not ionized and its grid is at a negative potential equal to the bias voltage. As the rectified signal voltage is increased from zero, the grid of VT_2 finally reaches a potential such that the tube breaks down and extinguishes VT_1. As the rectified signal voltage is again decreased VT_1 again breaks down and extinguishes VT_2, but, when the fixed bias is too great, the value of rectified signal voltage required to trigger the tubes will not be the same when increasing as when decreasing. There is, of course, a critical grid potential at which the on and off potentials are the same, but since a less negative potential will cause chattering of the relay, it is desirable to operate with a bias slightly more negative than the critical value. An excessive negative bias will result in a material reduction in the range of input signal which will give perfect printing. Figure 10 is a schematic diagram of a unit incorporating the gas discharge tube type of relay. A d. c. amplifier of the phase inverter type is used as a source of potentials to operate the grids of the gas discharge tubes. This type of amplifier simplifies the power supply requirements and permits the use of an impulse rectifier, wherein a positive bias is applied to the cathode of the rectifier tube to act as a noise threshold control. In order to prevent a change in the length of the impulses it is desirable to keep the input to the impulse rectifier within reasonable limits. Perhaps the simplest method of accomplishing this is by the use of a peak limiting amplifier feeding the impulse rectifier.

The printer magnet of the teletype machine is connected directly in the plate circuit of one of the gas discharge tubes as the simplest method of obtaining the d. c. impulses. This unit gives printing over about a 26-db range of input signals. The margin characteristic of the unit is shown in figure 11. This characteristic was taken on received signals over the Washington-Baltimore radio circuit and represents operating conditions. The desired rectangular-shaped characteristic has been obtained and shows a great improvement over previous methods.

The level controlled amplifier

In the circuit as operated between Washington and Baltimore, it has been found that

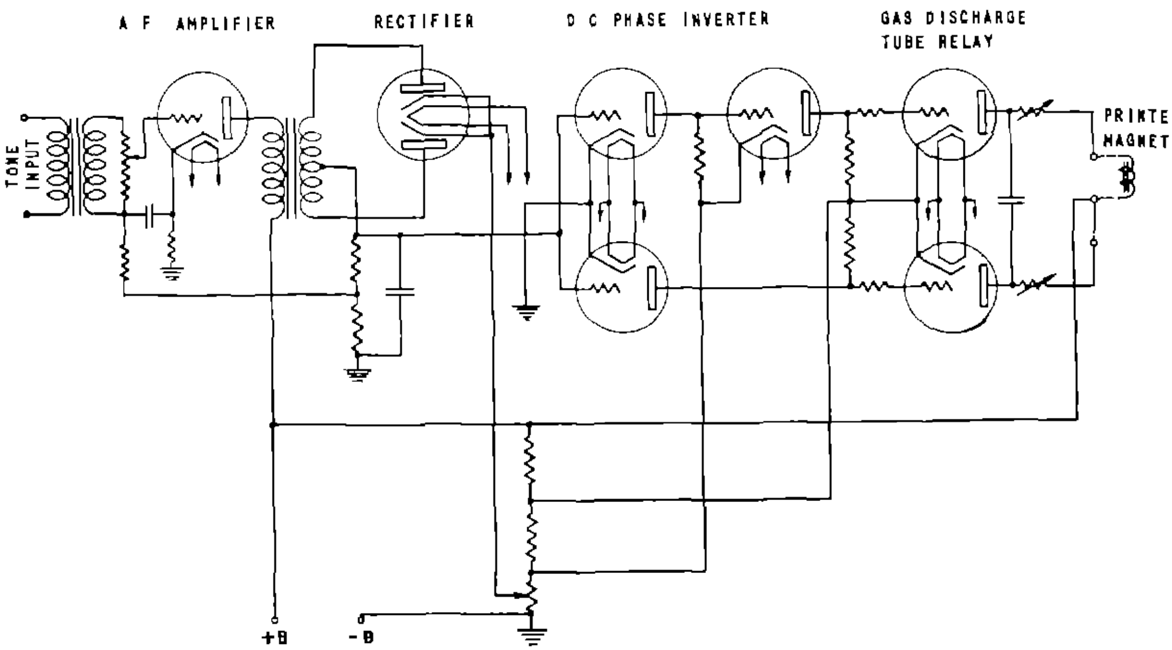

Figure 10—Schematic circuit of gas discharge tube relay, incorporating phase inverter, one stage of audio-frequency amplification and rectifier are also shown

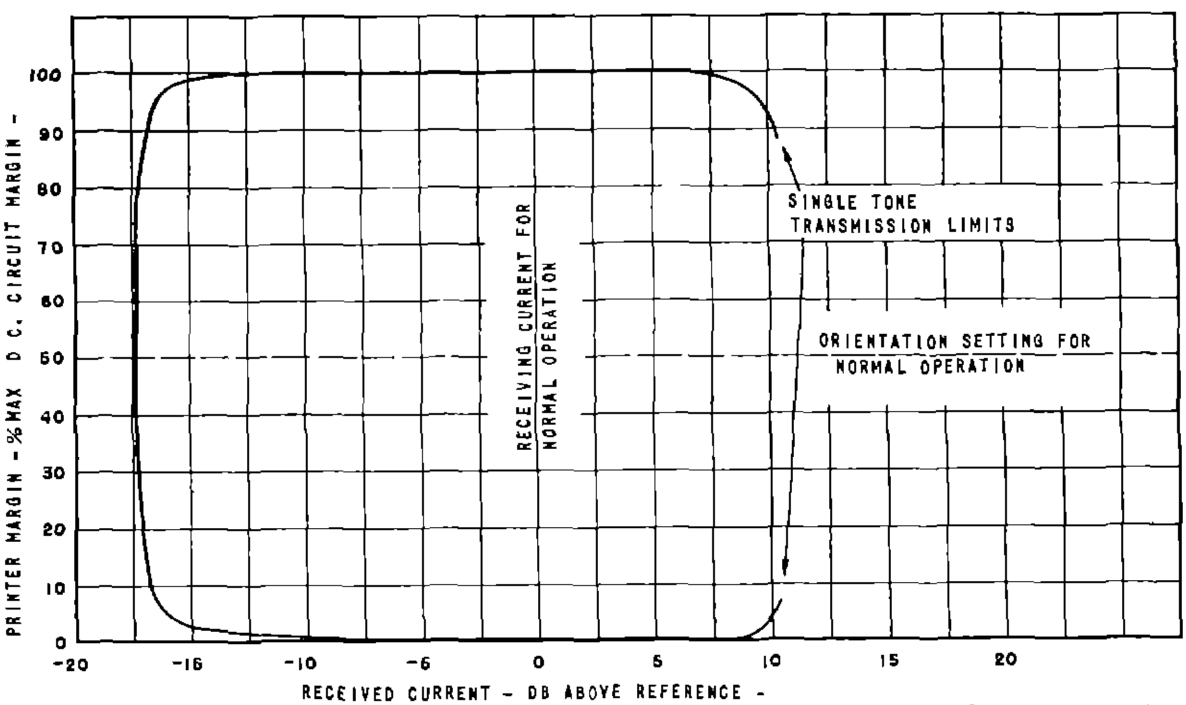

Figure 11—Operating margin characteristic of the circuit shown in figure 10, taken under actual operating conditions

a fade which reduces the audio output of the receiver to about minus 35 db is apt to cause errors in printing due to noise A relay which would print with signals from minus 35 db up would then allow printing over the usable range of signals

The relay described above operates over a 26-db range, or 9 db less than the usable range of signals experienced on this circuit In order to extend this range a level controlled amplifier was developed This makes use of a bridge circuit in which the plate resistance of a vacuum tube is used as the variable arm The plate resistance is controlled by the rectified output of the bridge and gives an amplifier whose output is relatively constant Figure 12 is a schematic diagram of the complete amplifier and relay A receiving relay has been added to permit operation of the teletype machine over a wire line, remote from the terminal equipment, in the case of an automatic repeater station As the input signal to the bridge is increased, there is an increase in output which, when rectified by the diode, furnishes a control voltage to the grid of the control tube and brings the bridge more nearly to a balance The upper limit of input which can be accommodated by the bridge and control circuit is determined by the design of the bridge and component parts and is well above the overload limits of the first audio amplifier tube supplying the bridge

The teletypewriter circuit as operated uses black keying or tone on for marking The normal condition for the circuit is with a steady tone applied A spacing impulse removes the tone and the tendency is for the control tube to throw the bridge farther from balance and increase the effective gain of the amplifier For this reason the load circuit of the control tube rectifier, RC, must be designed so that the gain of the amplifier is not changed rapidly enough to follow the changes in signal level caused by keying and give a constant tone level output

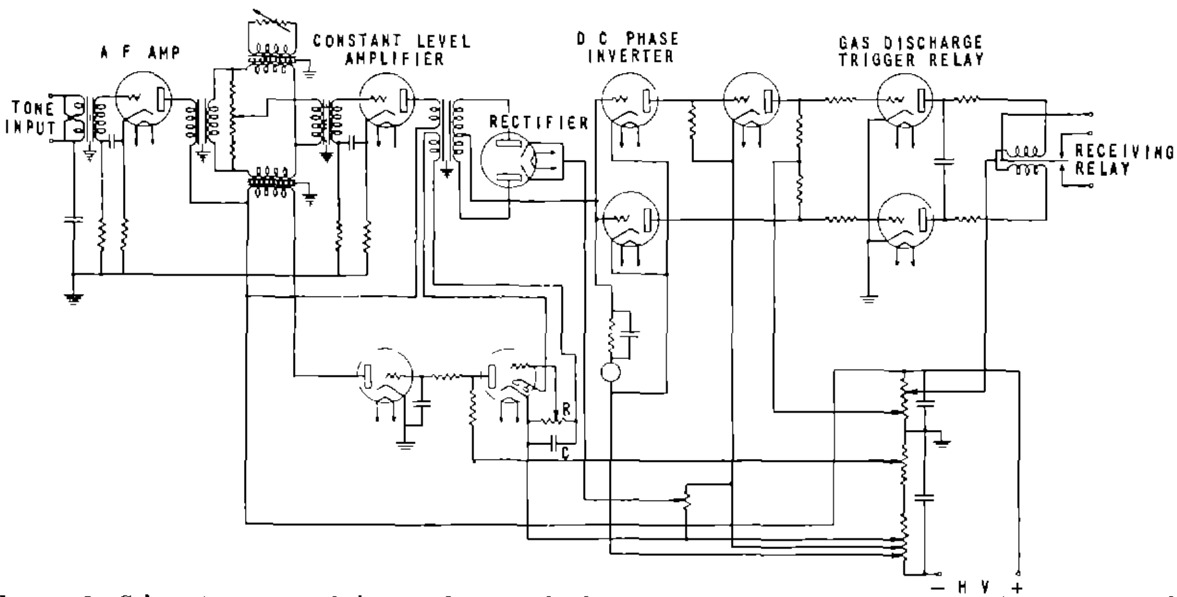

Figure 12 —Schematic circuit of the complete gas discharge tube relay with phase inverter and level controlled amplifier as used on the Washington Baltimore ultra-high-frequency circuit

It must be fast enough, however, to follow the changes in level caused by fading, etc Since black keying is used, the condenser C is normally charged and the time constant involved is that of RC or is the decay time of the circuit The rapidity with which the gain of the amplifier is reduced due to increasing average signal is primarily determined by the time constant of the circuit composed of C, the internal resistance of the rectifier and the impedance of the source

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The characteristics of the amplifier are shown in figures 13 and 14. With inputs up to minus 6 db the distortion is a minimum but increases for higher levels due to overload and limiting action in the first audio amplifier feed-

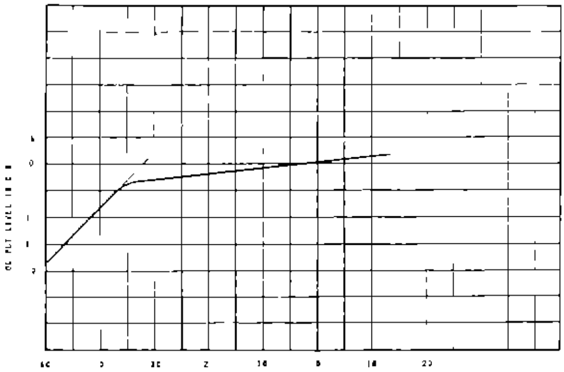

Figure 13.—Gain characteristic of the level controlled amplifier

ing the bridge. The distortion due to this limiting action does not appreciably change the rectified teletype impulses and increases the useful range of the unit. Figure 15 shows the teletype margin characteristic obtained under circuit operating conditions and covers the requirements of a rectangular shaped margin curve and operation over the usable range of signals. The normal operating point is with

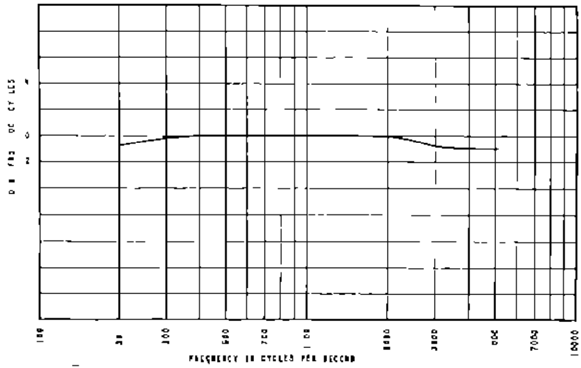

Figure 14.—Audio characteristic of the level controlled amplifier

an input of about zero db which allows the signal to drop to about minus 35 db before the circuit becomes inoperative. The audio-frequency filter used with the relay unit overloads with levels higher than this and places the

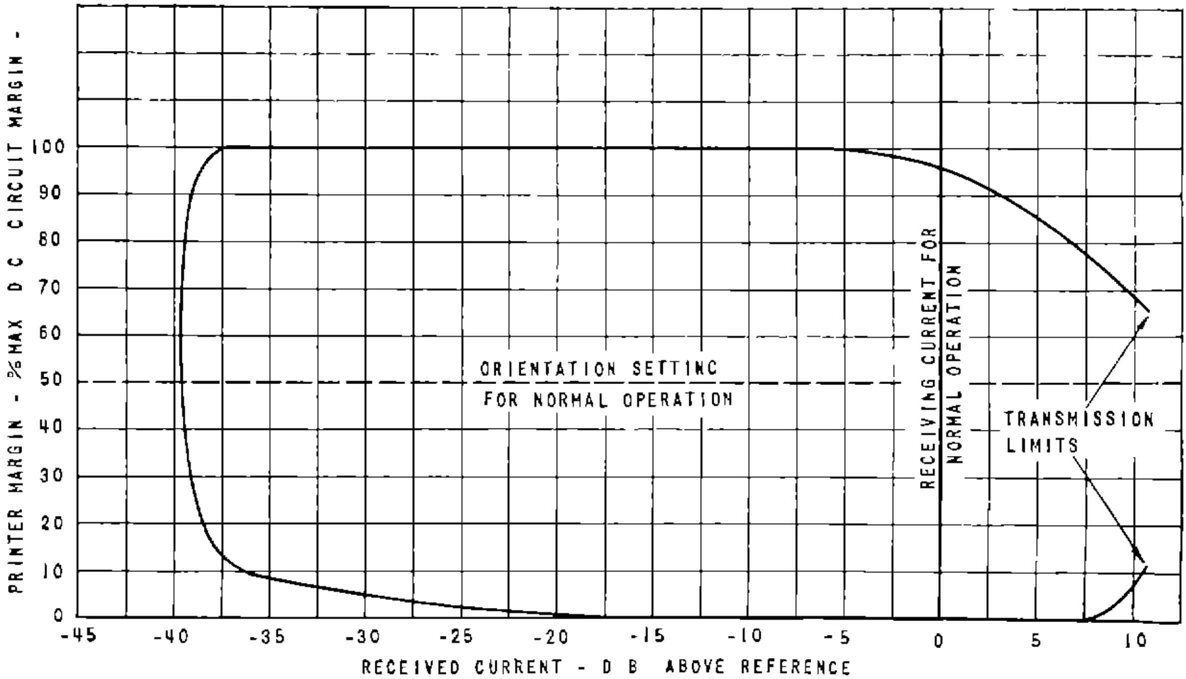

Figure 15.—Operating margin characteristic of the relay (fig. 12) taken under actual operating conditions on the Washington Baltimore ultra-high-frequency circuit

operating point at about zero db, although the relay unit is capable of operating at higher levels, thus increasing the range. With the receiver operating well in the a. g. c. region it is apparent that a fade of considerable extent can be handled without disrupting service. The average signals received are such that the signal can decrease approximately 30 db before the receiver is out of the a. g. c. region. This, added to the 35 db of the relay unit, indicates that signal variations of approximately 65 db may be handled on this circuit without printing errors. These are average conditions and are reduced at times by the presence of increased noise levels. The range could of course be extended by increasing the power of the transmitter.

There is another advantage in using a level-controlled amplifier over a peak-limiting type, aside from the increased signal range. Figure 16 has been drawn to illustrate the effect of noise on the two types of amplifier-relay. While the figure is not a true picture since the actual impulses are somewhat rounded due to filters, etc., it will illustrate the effects encountered. Let (A) of figure 16 represent the keyed signal, (C) would be representative of the same signal with a small or normal amount of noise, (B) is the same signal with an appreciable increase in noise. The noise threshold control has been adjusted in each amplifier-relay to a value X, such that during spacing impulses no noise will be rectified and the resulting rectified signal will be represented by (D). The potential represented by the distance Y is the potential to which the signal must fall to cause the gas discharge tubes to trigger off. It is apparent from (D) that for either amplifier, the rectified signal will be such that perfect keying will result. If the noise level increases,

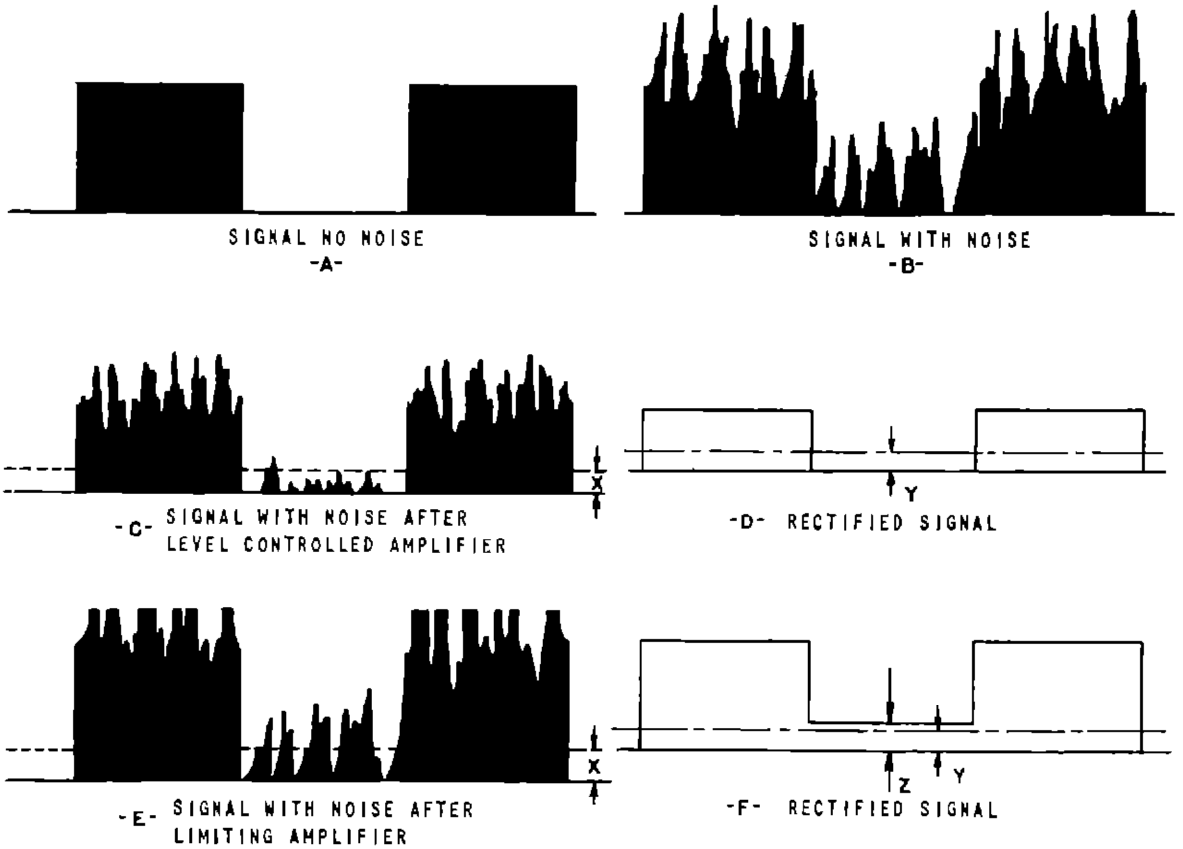

Figure 16.—Illustrating the effects of noise on the level controlled amplifier and peak limiter

while the tone signal remains the same, a signal similar to (B) would result. Since the average amount of energy over a period of time is greater than before the condenser C of figure 12 will be charged to a higher potential and the control tube will bring the bridge closer to balance and reduce the gain of the amplifier. This reduction in gain then will give an output signal from the amplifier which would closely approach (C), reducing the amplitude of both noise and signal by the same amount and correct keying is obtained. In the peak-limiting type of amplifier, however, the gain is not changed appreciably but the peaks are cut off, resulting in a reduction of the peak value of signal but no reduction in amplitude during spacing impulses, as shown in (E) of figure 16. The net result in this case will be that an appreciable amount of noise is rectified during the spacing impulse, giving a rectified signal Z as in (F), in which the rectified signal potential does not fall low enough for the gas discharge tubes to trigger and a false marking impulse is received instead of a spacing impulse.

On clean signals with no noise or with noise of a constant and low value such that the noise threshold can be adjusted to take care of it, either type of amplifier-relay will give perfect printing but when noise conditons vary and signal-level variations are large, the advantages of the level-controlled amplifier-relay justify the additional equipment.

Filters

In order to increase the frequency selectivity of the receiving equipment beyond the limits which can be accomplished practically in the radio-frequency portions of the receiver, audio-frequency filters have been incorporated in the terminal equipment.

The start-stop printers operate at 60 w. p. m. corresponding to a keying frequency of 21 cycles per second. In order to reproduce reasonably square-topped signal impulses, the pass band of the filters must be sufficiently wide to accommodate at least the third harmonic of the keying frequency, or about 126 cycles. The attenuation characteristic of one of the filters used is shown in figure 17. The band width at 3 db down from mid-frequency is approximately 160 cycles and the insertion loss is 7.5 db. The filters are designed for a maximum input of 4 volts r. m. s.

In a single channel the filters are primarily used as a means of increasing the signal/noise ratio. For multichannel operation on the same carrier their use becomes a necessity and serves the double purpose of separating the several channels and of increasing the signal/noise ratio.

Keyers

Since tone modulation is to be used, it is necessary that the d. c. impulses of the teletype machine be converted to tone impulses. This

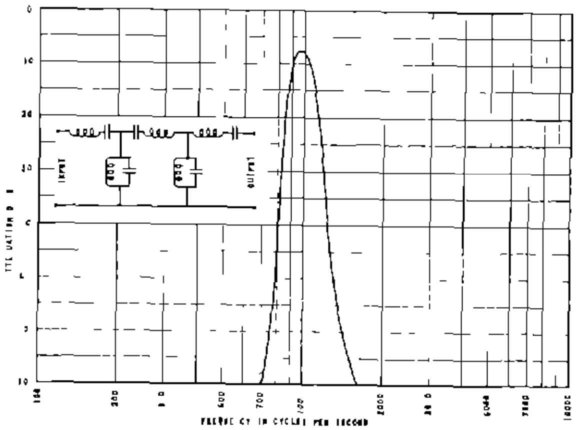

Figure 17.—Attenuation characteristic of band pass audio-frequency filter and schematic diagram

can be accomplished by the use of a relay, but it was felt that an electronic keying device would eliminate a mechanical relay and be more reliable.

A push-pull amplifier, with the keying potential applied to the bias, would tend to reduce key clicks and other transients in the keying due to the fact that the grids would be in parallel and the plates in push-pull to any disturbance introduced in the grid-bias supply. The schematic diagram of the keyer is shown in figure 18.

The station at Baltimore can operate either as a repeater station or a terminal station. When operating as a terminal station, it is necessary that the signals received print on the teletype machine but not be retransmitted It is also necessary to transmit from the keyboard and provision must also be made for automatic transmission from a perforated tape using a transmitting distributor simultaneously with reception

For terminal station operation the distributor is connected between terminals 2 and 3 R_1, biasing the amplifiers below cut-off When ionized, the 885 tube oscillates but, since the amplifiers are well below cut-off, this oscillation is not carried through to the output The condenser C_1 further reduces the a c voltage across R_1 The time constant of R_1C_1 must be low enough to prevent rounding of the impulses These two factors in addition to the cancellation due to the push-pull plate

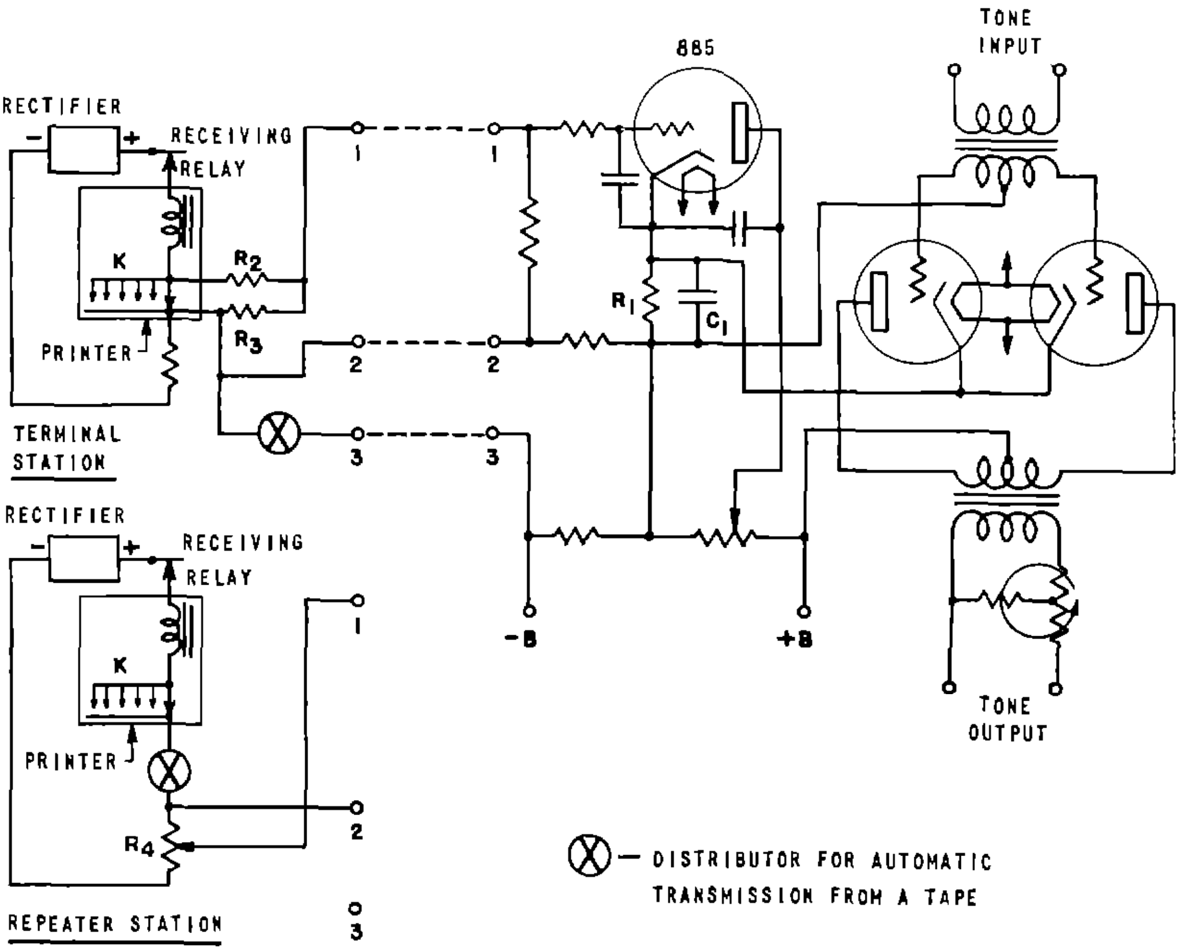

Figure 18—Keyer circuits used on the Washington-Baltimore ultra-high-frequency radio circuit

In the marking condition, the distributor circuit is closed and the grid of the 885 tube assumes a negative potential of 35 volts In spacing condition the distributor circuit is open and the grid assumes a zero potential, thus breaking down the tube Plate current limited by the resistance in the plate circuit and the potential, increases the drop across circuit eliminate all output during spacing impulses

In order that the keyboard be used, the distributor must be stopped (a normal condition) When the keyboard contacts K are closed (marking) no potential exists across the terminals 1 and 2 and the amplifier is normal If the contacts K are opened, the no-load potential of the rectifier appears across them. The keying potential is taken from the potentiometer R_2–R and is sufficient to ionize the 885 tube (from 30–50 volts). The normal negative potential of the grid of the 885 tube must be enough to prevent ionization and also such that, when the plate voltage becomes a minimum (due to oscillation) the tube will de-ionize.

A further advantage in the use of a gas discharge tube to supply the keying voltage is that it does not act as an amplifier and any ripple or "hash" in the teletypewriter circuit will not be passed on to the amplifier tubes.

For repeater station operation the drop across the resistor R_4 in the teletypewriter circuit is used for the keying potential. Terminals 2 and 3 are open, and the grid of the 885 tube assumes zero potential. The drop across R_4 is adjusted to 35 volts. Thus when the teletypewriter circuit is closed the bias on the 885 tube is enough to prevent ionization and tone is transmitted. The distributor is then also in series with the teletypewriter machine for automatic transmission when no other signals are being received. When the circuit is opened by the receiving relay, the keyboard contacts or the distributor there will be a loss of potential across terminals 1 and 2, and the 885 tube will become ionized, biasing off the amplifier and making a spacing impulse.

This type of keying (in repeater condition) is a form of regenerative keying tending to correct the pulses at each repeater station rather than add up the distortions as would be done by retransmitting the received audio signals.

The Washington station operates as a terminal station, and the keyer is used as in the terminal-station condition, except that the distributor is in the teletypewriter circuit.

Operating characteristics

The terminal equipment was designed so that operation of the teletypewriter machine would be exactly similar to wire-line circuits, and so that standard machines could be used. With the Baltimore station operating as a repeater, this condition is exactly simulated. Transmissions originating at Washington are received at Baltimore and printed and the impulse shape is corrected and automatically transmitted back to Washington, where they again print on a separate machine from the one on which the transmission originated. This is in effect a three-station circuit with one station acting as an automatic repeater. Transmissions originating at Baltimore print locally, and are transmitted to Washington, with the normal provisions for breaking the circuit as in wire lines. The same machine is used for transmitting and receiving. The Washington station always operates as a terminal, and wire-line conditions are simulated at all times.

The accuracy of the system is dependent largely on the radio circuit, and is equal to or better than the average wire-line circuit. The noise levels encountered are low, and the range of the equipment is such as to take care of the useful range of signals as experienced on this circuit, with a large safety factor to allow for unusual conditions.

Voltage regulators of the static type have been included in the design of the terminal equipment to provide constant supply voltages with variations in line voltage from 80 to 140 volts, and in order to insure long life from the vacuum tubes the maximum plate voltage has been limited to less than 225 volts.

It was the aim to provide equipment which would be simple in operation, easy to maintain and capable of unattended operation. Few adjustments in the apparatus are critical and these are very stable having once been set.

A block schematic diagram of the terminal apparatus is shown in figure 19.

DISCUSSION OF RESULTS OBTAINED ON THE ULTRA-HIGH-FREQUENCY RADIO TELETYPEWRITER CIRCUIT

Recordings of the strength of the received signals have been made during most of the time this circuit has been in operation. The early records taken at Baltimore (when the antennas at both sites were on 65-foot poles) were of the rectified audio signal since the signals were low and the sensitivity of the receivers did not permit recording of the carrier strength In February 1936 horizontally polarized antennas were erected at both ends of the circuit on 125-foot steel towers, doubling the antenna heights These new antennas had approximately the same gain as the old ones This resulted in greater signal strengths which, with more sensitive receivers, permitted the recordings to be made in terms of carrier strength directly rather than the rectified audio output of the receivers

The increase in the height of the antenna above ground produces two effects, (1) an increase in signal, and (2) a decrease in the amplitude of the fading

(1) Effect of antenna height on signal intensity

With the center of the receiving antenna 60 feet above ground (vertical polarization) an increase in height of the transmitting antenna from 60 to 120 feet resulted in an increase of approximately 10 db in the received signal Likewise with the transmitting antenna 60 feet above ground, increasing the height of the receiving antenna from 60 to 120 feet produced a 10 db increase in the received signal Raising the second antenna to 120 feet produced approximately 8 db increase in signal

(2) Effect of antenna height on fading

With the receiving antenna 60 feet above ground (vertical polarization), the amplitude of the fading was about 8 db for a transmitting antenna height of 60 feet This amplitude was reduced to about 6 db by increasing the transmitting antenna to 120 feet above ground Figure 20 is a copy of the recording from which the above data were obtained While the absolute amplitude of the fading would hold only for this one case, the record is indicative of the general reduction in fading with increased antenna heights

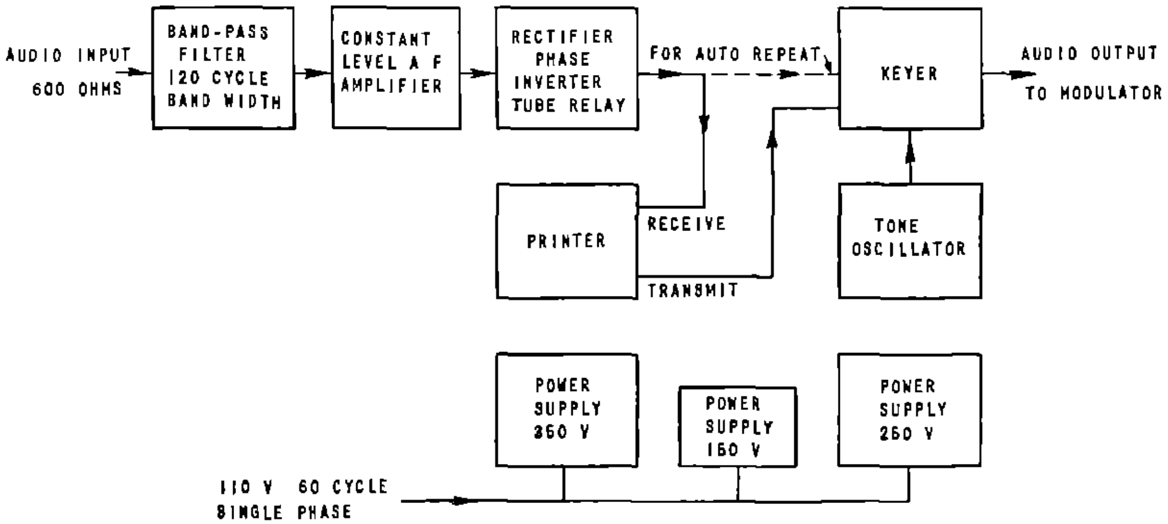

Figure 19—Block schematic diagram of the terminal equipment

Fading

Using the low antennas at the transmitter and receiver, the amplitude of the short-period fading varies from practically nil to more than 20 db The day-to-day, or longer, period trends show even greater variations Figure 21 is a recording of the rectified audio output of the receiver taken at Baltimore on November 6, 1935, and is representative of many of the records taken which show the rapid changes that occur in the type of fading Up until about 0120 E S T, the signals are quite steady with a slow, long-period variation, with the fading amplitude of about 4 db Between 0120 and

0140 a change is taking place and by 0145 the amplitude has increased considerably, reaching amplitudes of from 12 to 16 db On other records the type of fading may change several times during a day, the changes being very

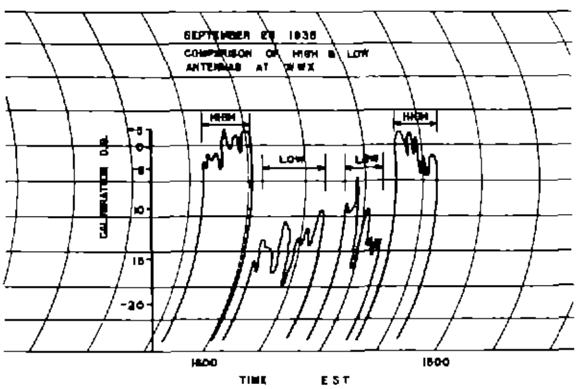

Figure 20.—Recording, showing effect of transmitting antenna height on signal intensity and amplitude of fading

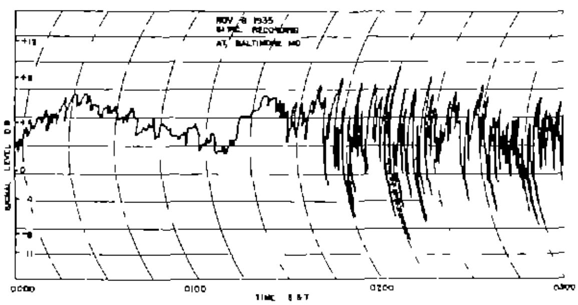

Figure 21.—Sample taken from many similar recordings illustrating rapid change in type of fading

abrupt at times and at other times gradually changing from one type to another

Figure 22 is part of a recording taken at Washington on July 24 1937 (horizontal polarization, height 125 ft), and is included to show the rapidity with which the signals change It is a record of the carrier strength and represents signals many times stronger than those of figure 21 For 24 hours previous to and following these fades signals had been very steady This recording illustrates the extremely rapid nature of the fades On several occasions these deep fades have been watched, and with the teletype apparatus capable of following variations of the order of 60 db or more automatically, an additional 20 db has been followed manually (by removing attenuators in the receiver output) still to have the signal drop below operating levels which indicates a complete loss of signal or a "drop-out" These "drop-outs" seldom last more than a few seconds

Due to the inertia of the pen of the recorder a very sudden drop in signal causes an overshoot of the trace In cases where the signal has dropped so that the receiver is out of the a g c region, and there is an overshooting of the trace, this has been called a "drop-out" Such "drop-outs" are in most cases instantaneous, and the low signal end of the trace becomes a line In the recording in figure 22, the limit of a g c was a fade of about 30 db The fade at 0840 represents a variation of approximately 30 db, while the overshoot of the pen indicates the fade at 0915 to have been of a much greater amplitude, and probably a complete loss of signal for a few seconds Figure 23 is a chart showing the distribution of fades which were similar in nature to "drop-outs" This data covers the period from November 1, 1936 to October 31, 1937 The dots on the chart represent quick fades of less than 30 db and more than 20 db amplitude The crosses represent quick fades greater than 30 db, some of which were total loss of signal More than 50 percent of these fades were of the instantaneous type, lasting only a few seconds Approximately 84 percent of the fades occurred between 2200 and 0900 E S T the following day, and 20 percent of the fades occurred between 0800 and 0900 E S T Three-fourths of the "drop-outs" marked by crosses occurred between July 24 and August

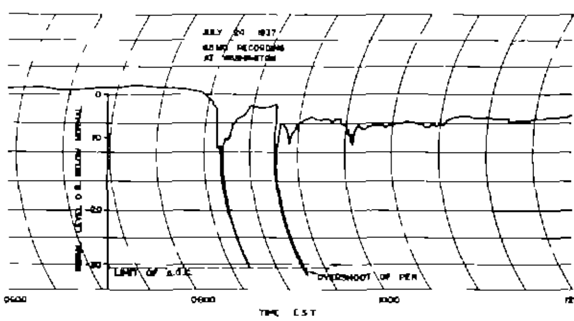

Figure 22.—Recording illustrating deep, rapid fades of "drop-out" nature

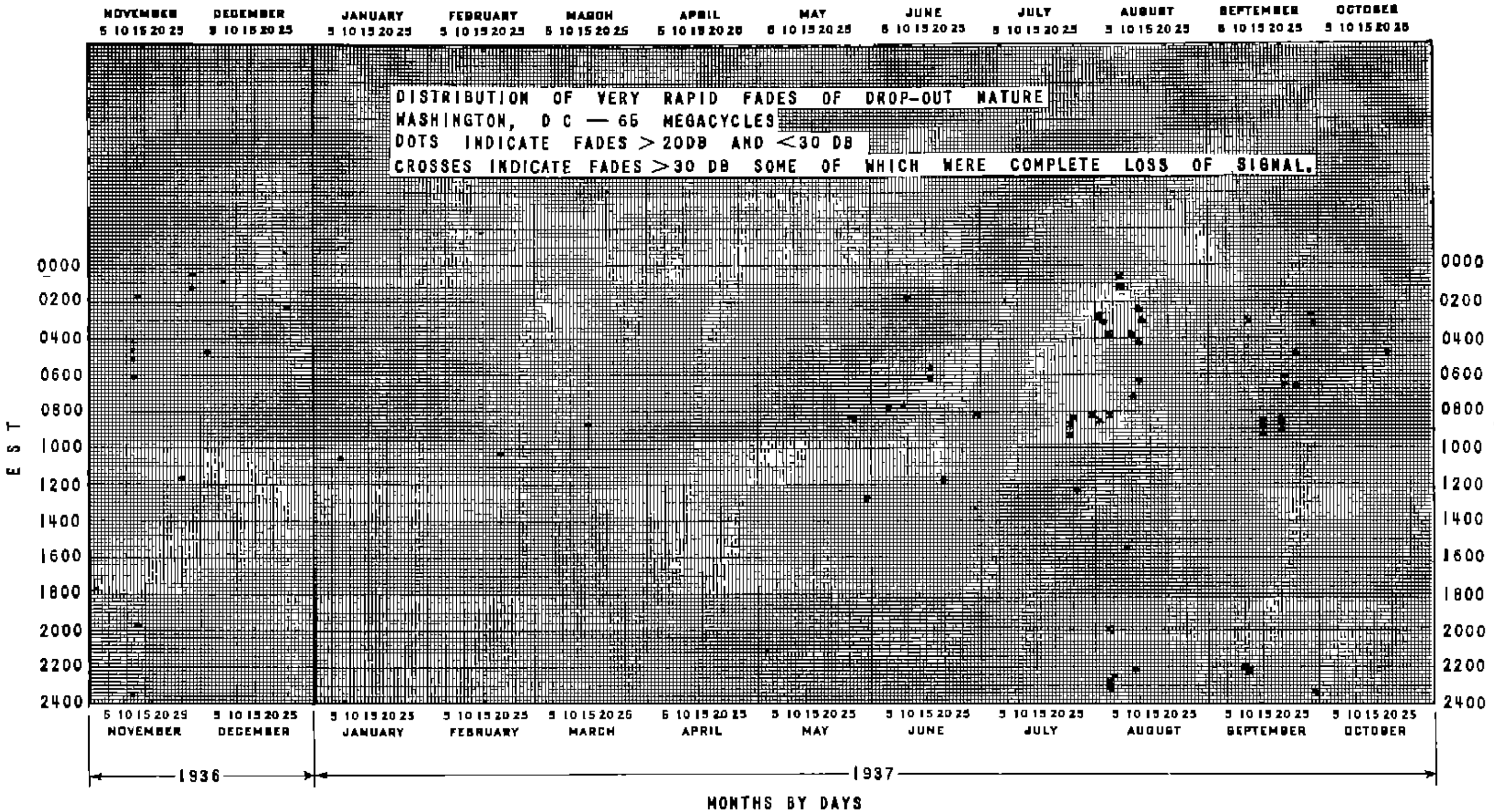

Figure 23 —Chart showing occurrence of rapid, deep fades and "drop-outs" for Nov 1, 1936, to Oct 31, 1937

6 If 30 seconds were allowed for each "drop-out" (and this is ample, based on those "drop-outs" which have been followed manually) the total outage of the circuit from November 1, 1936 to October 31 1937, would be about 8.5 minutes

A chart showing the seasonal fading which occurred over the Baltimore-Washington radio circuit is shown in figure 24 These data were

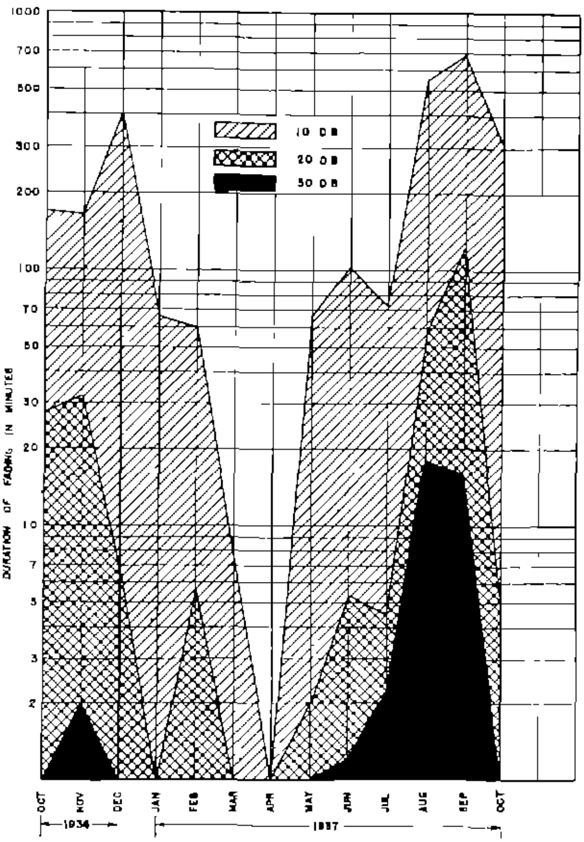

Figure 24—Chart showing seasonal variations in fading from Oct 1, 1936, to Oct 31, 1937

taken from the recordings of carrier strength at Washington from the Baltimore transmitter on 65 megacycles, and indicate the total number of minutes during which the signal was a given number of decibels below the normal signal

The most severe fading of the order of 30 db, occurred during July, August, and September

It should be noted that on this radio circuit, no diurnal regularity in the fading has been observed Attempts at correlation of the propagation with temperature barometer, humidity, or temperature inversion have proved futile, and no doubt all play an intricate part in the amount of diffraction and refraction of the ultra-high frequencies over any given nonoptical path

Figure 25 is a profile map of the Washington-Baltimore circuit, showing the antenna heights (125 feet) now in use at both sites In this profile the scale of the radius of the earth is multiplied by a factor of 50 and the scale of the elevations divided by the same factor, giving a true relation for the optical range From figure 25, it is seen that each station is approximately 180 meters (594 feet) below line of sight If the radius of the earth were increased by a factor 4/3 to account for normal refraction, the stations will still be below line of sight Suffice it to say that although optical paths are desirable, their necessity appears to have been overemphasized for the frequency band tested and the amount of normal diffraction and refraction in the lower atmosphere is sufficient to maintain a reliable communication service over nonoptical paths as in the present case

While this circuit has provided a communication channel in which the effect of fading, diurnal and seasonal variations are of minor importance, other factors such as interference, both man-made and natural, must be considered

Noise and errors.

The most serious noise is that from automobile ignition systems, due to the proximity of the stations to the highways Due to the fact that the beam of the Baltimore station falls along a heavily travelled road, more ignition noise is picked up at that station This noise pick-up is not noticeable from vehicles over a quarter of a mile distant A careful choice of the site would greatly reduce this type of interference The general atmospheric level is very low The circuit noise is more than 30 db below the signal level measured at the input to the audio filter This circuit noise includes receiver noise, hum from both transmitter and receiver, and external noise It should not be inferred, however, that the existing noise is of sufficient amplitude to cause errors, as perfect operation has been maintained even with low percentage of modulation as used in the multi-channel tests of which more will be said later It is safe to say that printing errors have not been due to these noise levels as experienced at the two stations

While static is at a very much lower level in these ultra-high-frequency bands, it does exist in practically all of the forms found at the lower frequencies The normal noise level during storms does increase, but only such crashes as are caused by lightning discharges in the immediate vicinity of the receiving station have caused printing errors During times when the circuit is idle (marking) the static discharge often causes the receiving relay to click, but the pulse is of too short a duration to cause a print on the teletype machine Even severe crashes cause only a single character to print This is, of course, increased when the circuit is in operation to an occasional single-character misprint for normal discharges A severe crash may drop the machine out of synchronism and cause several false characters before it again synchronizes itself

In general it can be said that the errors caused by fading, man-made and natural noises, and all other propagation causes have been too few to be expressed in any useful percentage of transmitted characters During the entire operating period there have been no periods (other than caused by "drop-outs" of a minute or less) during which communication has not been possible due to any causes other than failure of equipment or power

The ultra-high-frequency transmissions are in general most satisfactory when approximate line-of-sight conditions exist This distance of course is dependent on the topography and the available antenna heights Noise levels are inherently lower than on the lower frequency bands which, as in all communication circuits, permit the use of lower power to provide an equivalent signal/noise ratio Proper choice of sites practically removes fading and permits the use of a single frequency for day and night and all seasons

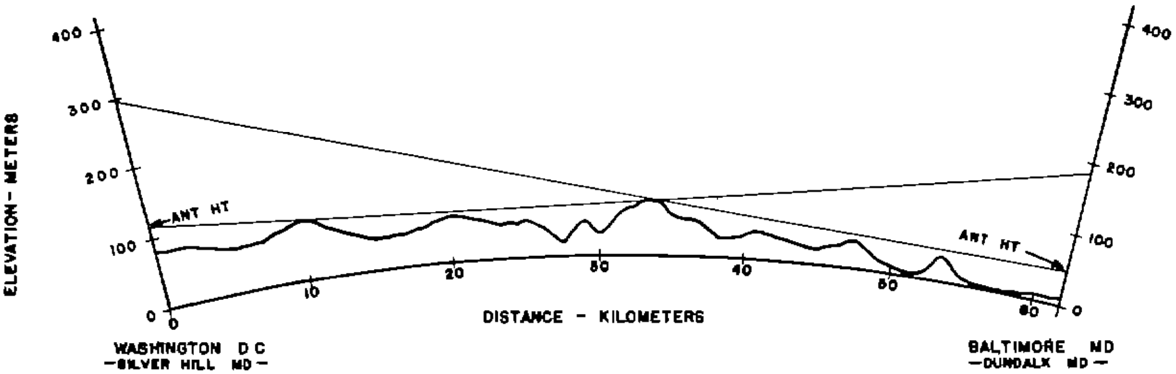

Figure 25—Profile map of the Washington-Baltimore radio circuit

It has been established that transmissions are made up of several rays, the direct ray and various reflected rays This is in effect a multipath transmission, but the delays thus encountered are too small to have any noticeable effect on the received impulses even though they consist of a single cycle (1600 cycles per second fundamental)

AUTOMATIC REPEATER AND MULTI-CHANNEL TESTS

Tests have been conducted to determine the reliability of the circuit, both with each station acting as a terminal and with Baltimore acting as a repeater station Much of the success of the repeating tests has been due to the type of repeated signal As explained above, the keying for automatic-repeater operation is of the regenerative type tending to reconstruct the received signals and send them out in true form and without noise The normal margin tests give average margins within 5 points of that obtained on locally generated signals

In April 1937 a voice channel was added to determine the possibilities of multichannel operations with about 10 percent modulation, the remaining amplitude being used for the voice circuit

In order to further study multichannel operation, another teletypewriter channel was added in July 1937 Available equipment was used for the second channel, and although the band pass filter had its pass band at 1020 cycles, and the first tone source was used, the results were very encouraging The filters at

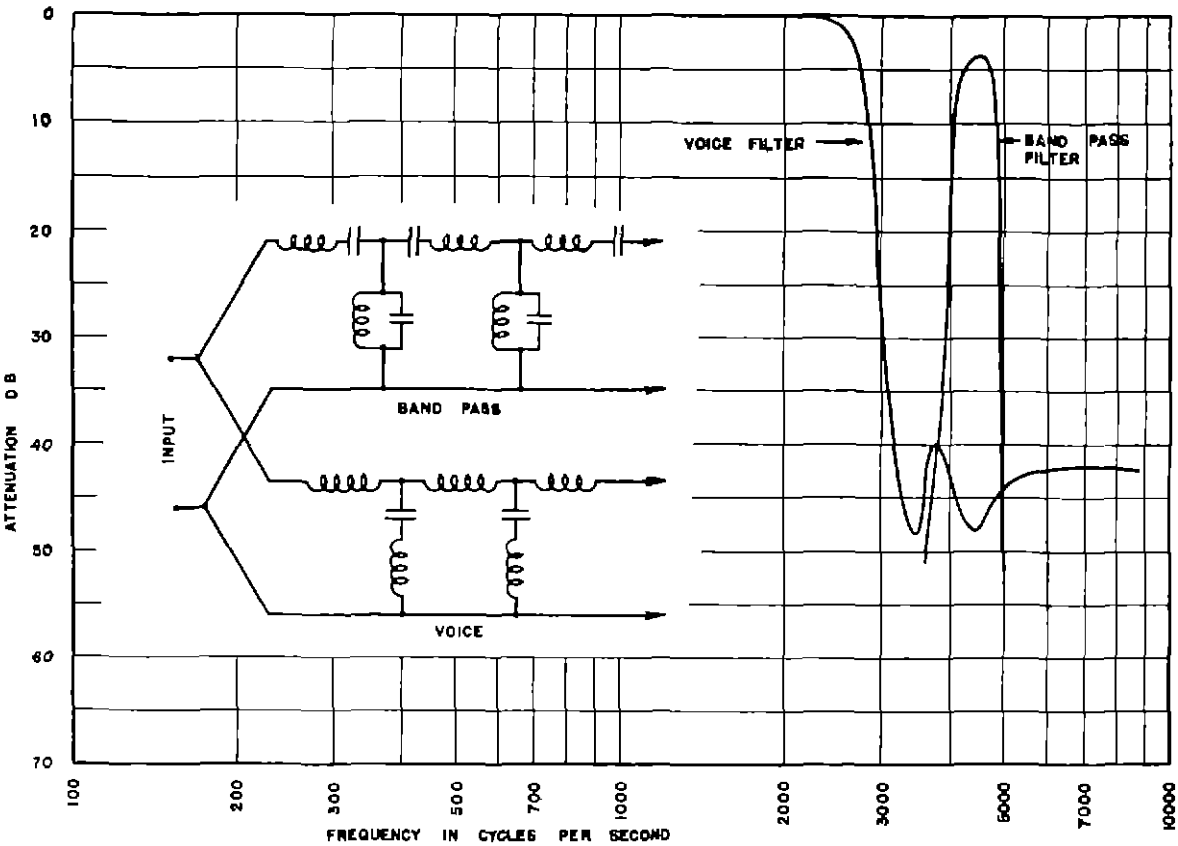

Figure 26—Attenuation characteristics of voice and band pass filters used in multi-channel tests

operation This required a low pass filter on the voice channel to cut off below the teletypewriter channel For this test the teletypewriter channel was put on 4300 cycles Figure 26 shows the characteristic of the filters used at the receiver to separate the channels Although no band pass filter was used at the transmitter, the key clicks were negligible Successful operation of the teletypewriter circuit could be maintained under normal conditions

the transmitter then included a low-pass voice filter, a 1020-cycle band elimination filter, and and a 1020-cycle band pass filter The receiving equipment used a 4300-cycle band pass, 1020-cycle band pass, and a 1020-cycle band elimination filter The 1020-cycle band pass filter at the transmitter greatly improved the circuit from the standpoint of key clicks, since the low or keying frequency component was eliminated Successful operation of the three channels was accomplished with a peak modulation of the teletypewriter channels of approximately 20 percent

OTHER PRINTING METHODS TESTED

Facsimile.

Numerous tests have been made to compare radio facsimile and radio teletypewriter This comparison is a difficult one because of the inherent differences in the two systems The best copy from the facsimile cannot compare with the teletypewriter printed copy, whether it be carbon or ink printing of the facsimile, because the elements of the separate letters are broader or heavier, and are made up of groups of lines or dots printed at different times A comparison might be made to the differences between newsprint pictures and photographs in the matter of picture definition In order to improve the facsimile copy, it would be necessary to increase the definition, which would mean an even broader frequency spectrum

As was stated previously, in a weather transmitting service, as maintained by the Bureau of Air Commerce, full advantage of the circuits must be taken to transmit the volume of information that is needed For that reason the messages are coded It is absolutely essential, therefore, that each character stand fully on its own merit and not depend on its association with other characters for its intelligibility For example in straight copy, one or more letters may be omitted from a word, and in many cases a whole word, without losing the intelligibility of the sentence In any coded message, an error may change the entire meaning regardless of the type of transmission, but an error caused by misinterpreting a character is eliminated from the teletypewriter copy In the unretouched photograph, figure 27, are shown samples of facsimile to illustrate the effect of noise on intelligibility It is apparent that there are many characters which if taken by themselves might easily be interpreted differently by two persons, but taken as a whole the words are quite clear

Late in 1934, a commercially available radio facsimile equipment using photoelectric tape scanner and carbon tape recording was made available to the Bureau for tests The receiving equipment was set up at a site approximately 126 miles from Silver Hill, Md The 400-watt transmitter at Silver Hill, Md, was used for transmitting on 2960 kilocycles Teletypewriter equipment developed to that date (circuit of fig 7) was also set up for comparison

The results of these tests brought out three things

(1) Teletypewriter equipment gave perfect copy over a signal variation of 17 db, while facsimile was capable of withstanding only a 10 db change in signal level

(2) Due to the wide transmission band resulting from the high keying speed of

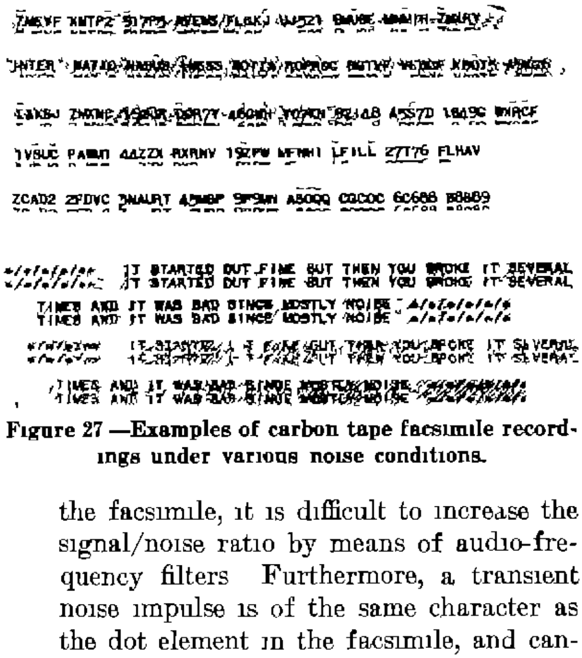

Figure 27 —Examples of carbon tape facsimile recordings under various noise conditions.

the facsimile, it is difficult to increase the signal/noise ratio by means of audio-frequency filters Furthermore, a transient noise impulse is of the same character as the dot element in the facsimile, and cannot be removed by simple methods For the same speed in words per minute the keying frequency of the teletypewriter is very much lower and a similar noise impulse can easily be removed without destroying the intelligence The practical result is that the teletypewriter system can operate with a much lower signal/noise ratio, and perfect copy can be received long after the intelligence of the facsimile copy is lost through extraneous noise spots This was amply demonstrated in these tests

(3) Multiple path signals caused double image characters to be printed on the facsimile copy, while under the same conditions the teletypewriter copy was not affected The speed of transmission on both equipments was 60 w p m The effects of multipath transmission on facsimile were more serious than on teletypewriter because of the higher keying frequency required for the same number of words per minute transmitted

Later in 1935, tests were again conducted on a similar but improved form of facsimile apparatus The teletypewriter terminal equipment by this time had also been improved by use of the gas discharge type of relay These tests were carried on between Washington and Baltimore on 61 and 65 megacycles The signal range of the facsimile had been increased to cover about 15 db, while the teletypewriter range extended over about 26 db Conclusions similar to those of the previous tests were arrived at, namely

(1) Teletypewriter equipment was capable of operating over a greater change of signal level

(2) Interpretation of characters on facsimile copy, when covered with noise spots, was extremely difficult, disproving the common fallacy that facsimile copy can be read even though covered with noise spots Single characters are often rendered completely unintelligible by the addition of a few spurious noise spots

(3) Double-image copy was not observed on 61 and 65 megacycles, indicating that no multiple path transmission took place Nevertheless, facsimile characters were often spread out when the printer bar bore too lightly or too heavily on the carbon tape

In addition to the above, other serious disadvantages of facsimile are apparent

(1) In a chain communication system, where repeated retransmissions are necessary the noise can be more readily removed from the teletypewriter signal than from the facsimile signal The lower keying frequency of the teletypewriter permits the use of sharper filters and much less complex signal correcting circuits or regeneration Rescanning of facsimile copy is the most undesirable procedure as found by actual test, and even in simple retransmission the noise distortion adds up rapidly over several repeating stations

(2) No method of storing a message at a terminal station for future retransmission is provided with facsimile, other than rescanning of the received copy Teletypewriter signals, on the other hand, may be used to reperforate a tape at the same time the received copy is being printed

(3) Facsimile requires a band approximately 1000 cycles wide for 60 w p m —100-line definition, whereas teletypewriter requires about a 120- to 130-cycle band width for the same speed At least three and possibly four 60 w p m teletypewriter channels could be inserted in the spectrum required for facsimile with a corresponding effective increase in speed to 180 or 240 w p m

A high-speed printer

In the latter part of 1936 and again early in 1937, numerous tests were conducted on a commercially available high-speed printer over the Washington-Baltimore ultra-high-frequency circuit

Essentially, this system depends for its operation on the use of combinations of eight single sine wave impulses derived from a common oscillator and phase-splitting networks For example, the first impulse is used for synchronizing, and the fourth impulse is used for shifting from lower- to upper-case figures, leaving six impulses for combinations in a 6-unit code

An eight-phase voltage is applied to the plates of eight vacuum tubes through the selector magnets of the printer The received impulses are applied to the grids of these same tubes in the proper sequence so that if the received impulse unbiases the tube at the time the plate voltage is applied, the tube will then conduct current and close the armature Four to six groups of pulses are necessary to close the magnet Each armature operates a code bar and causes the printer to operate

Exact synchronism is essential between the received pulses and the plate supply to the several tubes

These printers were capable of operation up to 120 w p m with a short wire line connection, but it is anticipated that considerable difficulty would be encountered when working over telephone lines or cables of any great length due to distortion of the transient impulses Since the printing of each character necessitates about six groups of impulses, it would appear that static would have little effect, as it is hardly probable that random noise would be sufficiently regular over six groups of combination impulses to cause a false character to print It is entirely possible, however, that a periodic recurring interference such as ignition noise might cause false printing

The radio tests disclosed the following results

(1) The impulses used in the system are highly transient in nature, and it was found highly susceptible to noise

(2) A very high quality circuit is essential to transmit and receive the impulses without undue distortion Calculations revealed that a frequency spectrum approaching that required for broadcast purposes would be necessary to reproduce the impulses sufficiently well The increase in speed over 60 w p m teletypewriter is not warranted, since the teletypewriter speed by use of multiple channels could easily exceed 120 w p m with much less difficulty

(3) The printer could operate faithfully for less than eight db variation of signal level

(4) The frequency of the oscillators in the apparatus must be held to about 1 part in 100,000

RESULTS

The results obtained in more than two years' operation of the Washington-Baltimore radio teletypewriter circuit have shown that the necessary requirements of reliability, accuracy, simplicity of operation, and speed have been met by the use of ultra-high frequencies and the development of suitable terminal equipment

The earlier work on 284, 4070, and 2960 kilocycles has shown that frequencies in these bands will not meet the requirements of the Bureau of Air Commerce communications system, due principally to extreme fading, high noise levels, and reflected sky wave components The propagation characteristics of the ultra-high frequencies below about 45 megacycles, as reported by many investigators, also indicate considerable sky wave reflection The characteristics of 61 and 65 megacycles over this path, however, indicate that a high quality radio circuit suitable for multi-channel services can be obtained over distances in excess of the optical path Such fading as exists can be taken care of by proper design of terminal equipment as has been done on this circuit by means of the gas discharge tube relay and level controlled amplifier, since noise levels on the circuit are very low

The investigation of commercially available carbon tape facsimile has shown it, in its present state of development to be unsuitable to Bureau of Air Commerce communications traffic Comparison tests with teletypewriter have shown conclusively that the teletypewriter is much to be preferred

ECONOMIC CONSIDERATIONS

The choice between land line and radio teletypewriter circuit operation, aside from purely technical considerations is largely dependent on two other factors, namely, the type of service required and cost The present land line teletypewriter facilities of the Bureau of Air Commerce extend over approximately 23,000 miles The cost of leasing wires for this service amounts to nearly $700,000 annually

In order to make a comparison between land line and radio, cost estimates were made up for a 600-mile circuit (Washington, D C to Nashville, Tenn) consisting of 9 drops The radio circuit included 13 intermediate stations of which 9 were drops The circuit represents average conditions for the radio teletypewriter since it includes both level and mountainous country and at least average conditions for land line teletypewriter

The location of the radio teletypewriter sites was made on a line of sight basis as far as practical, the maximum deviation being only 150 feet below line of sight Line of sight was calculated using the actual radius of the earth It has been quite well established by other investigators that normal refraction would permit the radius of the earth to be multiplied by a factor of 4/3 which would make all sites within optical range Actual distances ranged from 28 to 64 miles depending on the terrain covered The estimate included duplicate transmitting equipment with automatic change-over in case of failure, spare receiving equipment, auxiliary power supply, buildings, towers, additional qualified maintenance personnel, and miscellaneous other items

The land line estimate included only the cost of teletypewriter machines, installation maintenance, and line charges No construction costs were necessary on this particular circuit due to existing facilities

Figure 28 is a cost estimate for the Washington, D C, to Nashville, Tenn, airway communication circuit, showing a comparison between land line and ultra-high-frequency radio teletypewriter service Operators' salaries were not included in the estimate since they would be the same for either type of circuit It is found that with a reasonable number of years allowed for obsolescence of equipment, a radio teletypewriter circuit is economically justified using two or more channels This is true since increasing the number of simultaneous channels does not greatly increase the cost of the radio circuit

In addition, a radio teletypewriter circuit can provide a service which cannot be furnished by wire lines namely a ground to aircraft voice channel and a ground to aircraft teletypewriter channel simultaneously with two ground station teletypewriter channels at a small increase in cost as shown by the curves of figure 28

CONCLUSIONS

In view of the results obtained it is concluded that a high quality radio repeater circuit suitable for multichannel services along the airways is feasible in the band 61 to 65 megacycles Such a circuit could provide for a ground to aircraft voice channel, a ground to aircraft teletypewriter channel and two ground-station teletypewriter channels One

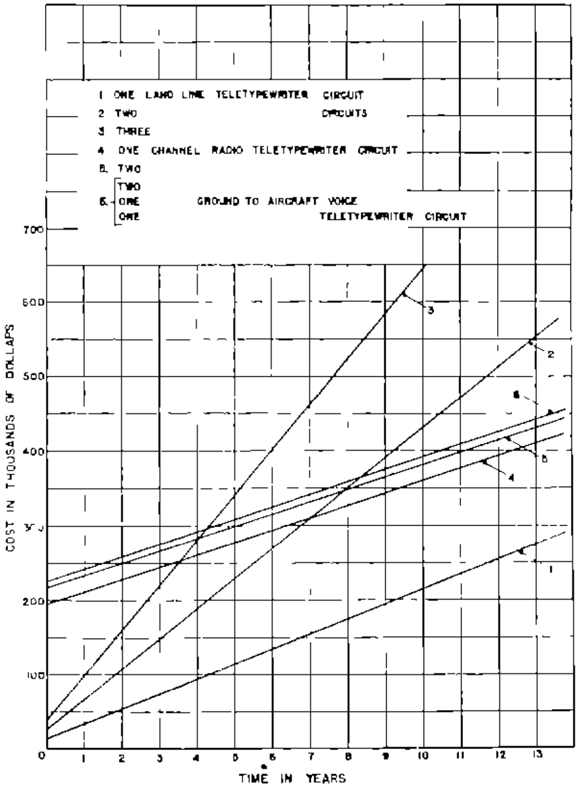

Figure 28—Cost estimate for the Washington, D C, to Nashville, Tenn, airway communication circuit, showing comparison between land line and ultra-high-frequency radio teletypewriter service Operators' salaries are not included

ground-station channel would be provided for all communications now handled on the land lines, the second to be made available for use in connection with air-traffic control All teletype channels would have a speed capability of 60 w p m The ground to aircraft teletypewriter channel would provide direct printed copy of weather information and other communications to pilots in flight, the ground to aircraft voice channel could be used for air traffic control

APPENDIX

In order to adapt ultra-high-frequency radio teletypewriter to a chain of stations along an airway, it is necessary to locate intermediate stations at weather observing points Most of the intermediate stations along an airway are separated by relatively short distances, making the ultra-high frequencies particularly well adapted for this purpose It is desirable also to obtain radio station sites as high above intervening ground as is practicable to obtain an approximate line-of-sight transmission path Present beacon sites in most cases lend themselves admirably well for this purpose, and power is already available at such sites In a relatively few cases, due to intervening mountains between station sites in rugged terrain, it would be necessary to erect automatic repeater stations to get "over the hump"

In such a communication chain it is desirable to have a directional transmission of messages with a minimum of equipment As an example, let us assume a circuit composed of four stations, A, B, C, and D Stations A and D are the terminals, and B and C are intermediate stations, one of which may be an automatic repeater station Any one of the stations must be able to originate a message and all others receive copies of it Thus, a message originating at A must be repeated through B and C to D, or a message originating at station C must be repeated through B to A and also go to D This can be accomplished by the use of two transmitters and two receivers at each repeater station Unidirectional antennas would be employed However, in an attempt to reduce the amount of equipment necessary, the same result can be accomplished with but one transmitter and bidirectional antenna and two receivers with unidirectional antennas at each repeater station

Referring to figure 29, assume that a signal originates at station A It is transmitted at frequency F_1 modulated at a frequency M_1 This is picked up at B on a receiver tuned to F_1 and further provided with a filter for M_1 The signal operates the printer at B and also a keyer, putting M_1 on the transmitter at B The signal is then retransmitted at F_2–M_1 This is picked up at station C on a receiver tuned to F_2 and filtered for M_1 and again retransmitted to D in a manner similar to that at B At the same instant the signal from B is picked up at C, however, it will also have gone to A, but since the receiver at A rejects M_1 by filter, the signal is dead-ended and no singing can result The same anti-singing characteristics will hold at the other stations, since all signals going

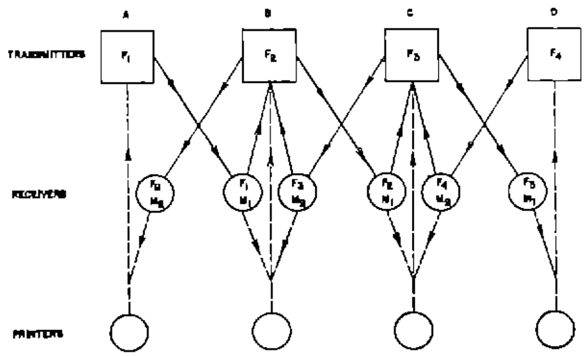

Figure 29 —Block diagram illustrating operation of a chain of radio teletypewriter stations.

from A toward D are modulated at M_1, while those going in the direction D toward A are modulated at frequency M_2

If station B originates a message, it is transmitted at F_2, but modulated with both M_1 and M_2 In this case the receiver at A will pick up F_2–M_2, while station C accepts only F_2–M_1, and retransmits it as F_3–M_1 to D Thus the desired result is accomplished with but one transmitter and transmitting antenna, instead of two transmitters and two antennas

Transmission in other directions may be accomplished, if necessary, by including additional receivers, correct filters and changing the directional field pattern of the antennas to include the additional stations

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