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Title SIGNAL DISTORTION BY DIRECTIONAL BROADCAST ANTENNAS

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A source of signal distortion has been found to exist in directional broadcast antennas, and a study of the effects of the distortion on amplitude modulated waves has been conducted.

A theory is developed which shows that signal distortion should be caused by directional antennas. On the basis of the theory it is found that distortion may be caused in several ways. For each cause an example is shown of the type of distorted modulation envelope waveform to be expected.

Experimental tests with two directional broadcast antenna systems are described. Test signals transmitted by these stations were analyzed with mobile test equipment. The distorted modulation envelope waveforms observed experimentally are found to be similar to the theoretical waveforms. A large number of experimental waveform photographs are shown.

It is shown that the audio frequency response of a directional broadcast station is not the same in all azimuth directions. Experimentally the difference in response amounts to several decibels for 5 kilocycle sinusoidal modulation. Audio frequency response curves are given for many receiving locations. The high frequency audio components transmitted are most subject to the change in response. In some directions the high audio frequency components are increased in amplitude with respect to the low audio frequency components; in other directions they are decreased in amplitude.

The modulation envelope distortion varies with azimuth angle. The directions of greatest distortion are found to be the null directions. In one case the distortion in the null region was 14% for 4 kilocycle audio modulation while the distortion in the direction opposite the null was less than 4%. Square wave audio modulation was used to show the effect of the distortion on transient behavior. The square wave modulation envelope waveforms show changes in audio frequency response as well as changes in distortion, as the receiving location is moved around the antenna system.

This study points out inherent disadvantages in directional antenna systems. It gives reasons for criticism of present broadcasting practices which necessitate the construction of highly directional arrays at low carrier frequencies.

SIGNAL DISTORTION BY
DIRECTIONAL BROADCAST ANTENNAS

by

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SIGNAL DISTORTION BY DIRECTIONAL BROADCAST ANTENNAS

INTRODUCTION

A source of signal distortion has been found to exist in directional broadcast antennas and a study of the effects of the distortion on amplitude modulated waves has been conducted.

Differences in the signal frequency response characteristics amounting to several decibels for 5 kilocycle sinusoidal modulation are found to exist between the received signal at different azimuth angles from the antenna array. Conditions causing distortion in the receiver are also shown to exist and to be a function of the azimuth angle. A transient response study with square wave modulation shows the existence of unwanted phase modulation and amplitude distortion. A type of overmodulation, with accompanying signal distortion, is possible in some directions while normal conditions exist simultaneously in other directions from the antenna.

This study points out inherent disadvantages in directional antenna systems. It gives reason for criticism of present broadcasting practices which necessitate the construction of highly directional arrays. The distortion is evidently present in all directional arrays in greater or less degrees and is most pronounced at low frequencies.

THEORY

The signal distortion to be described may be attributed to the existence of different response conditions in a directional array for the carrier frequency and each sideband frequency. The directional pattern of the array is a function of the transmitted frequency and is necessarily different at the sideband frequencies from that of the carrier frequency. These radiation pattern differences result in changes in the amplitudes and relative phases of the signal components at the receiving point.

The signal transmitted in a given direction may have either increased or reduced sideband power at the higher audio modulating frequencies where the effect is most pronounced. This causes changes in the audio frequency response characteristics of the antenna at various azimuth angles, and may also cause modulation envelope distortion in the regions of increased sideband power. In some directions the sidebands may become shifted in time phase with respect to the carrier, resulting in large amounts of phase modulation. In some directions one sideband frequency may be nearly or totally cancelled out by the directional characteristics of the array while the other sideband component may be increased. This results in distortion of the modulation envelope at high modulation percentages.

ANALYSIS OF MODULATED WAVES BY VECTORS

The distorted modulation envelop waveforms resulting from the directional distortion effect are most easily understood by the use of vectors. An amplitude modulated (a-m) signal can be represented by a sinusoidal carrier component, or vector, plus a group of sideband components, or vectors, carrying the intelligence.

The transmitted signal in an a-m system for a single sinusoidal audio modulating frequency consists of a carrier component and two sideband components. The vector equivalent of the signal is a carrier vector of carrier frequency and two sideband vectors, one with a frequency higher than the carrier frequency by the frequency of the audio modulating signal, and the other with a frequency lower than the carrier frequency by a similar amount. If f_c represents the carrier frequency and f_a represents the audio modulating frequency, then the angular velocities of the carrier, upper sideband, and lower sideband vectors are $2\ f_c$, $2\ (f_c + f_a)$, and $2\ (f_c - f_a)$, respectively.

It now remains to plot these three vectors on the same polar time coordinates. The carrier component may be plotted as datum at zero degrees. Any other vectors of like angular velocities may be plotted directly on this set of coordinates at their proper time phase angles. The sideband vectors, however, have different angular velocities from each other and from the carrier. Because of this, a vector diagram which contains all three of these vectors can only be valid for a particular instant, and the vector diagram will be different for the next instant.

Amplitude variations in the received signal are responsible for the audio output of the receiver in an amplitude-modulation system. The modulation envelope, then, must remain a true replica of the audio signal to be transmitted if distortion is to be avoided. The modulation envelope is determined by the peak amplitude reached by the sum of the carrier and sideband components during each half cycle of carrier frequency. With sinusoidal modulation the peak amplitude reached by the received signal voltage during each half cycle of the radio frequency carrier must vary sinusoidally at the audio rate.

The magnitude of the modulation envelope can also be determined at any instant by taking the sum of the carrier vector and the sideband vectors in their proper phase positions. Analysis of the vector diagrams of Figure 1 shows this to be true. Stated differently, the vector sum of the carrier and sideband vectors produces a resultant which may be considered as changing in length at the audio rate, and the magnitude of this resultant determines the magnitude of the modulation envelope each time the resultant rotates with its time axis to a maximum positive or negative value.

When a large number of audio modulating frequencies are present, as for complex speech or music, the a-m signal contains a pair of sideband components for each modulating frequency. The resultant transmitted signal is the sum of all of the individual sideband components plus the carrier component.

The analyses of phase modulation (p-m) and frequency modulation (f-m) emissions for low amounts of deviation are quite similar to the analysis of the a-m emission. The carrier component must be shifted 90° from its phase position with respect to the sidebands in the a-m case. This is the method employed for producing phase modulation (or frequency modulation with proper audio compensation)

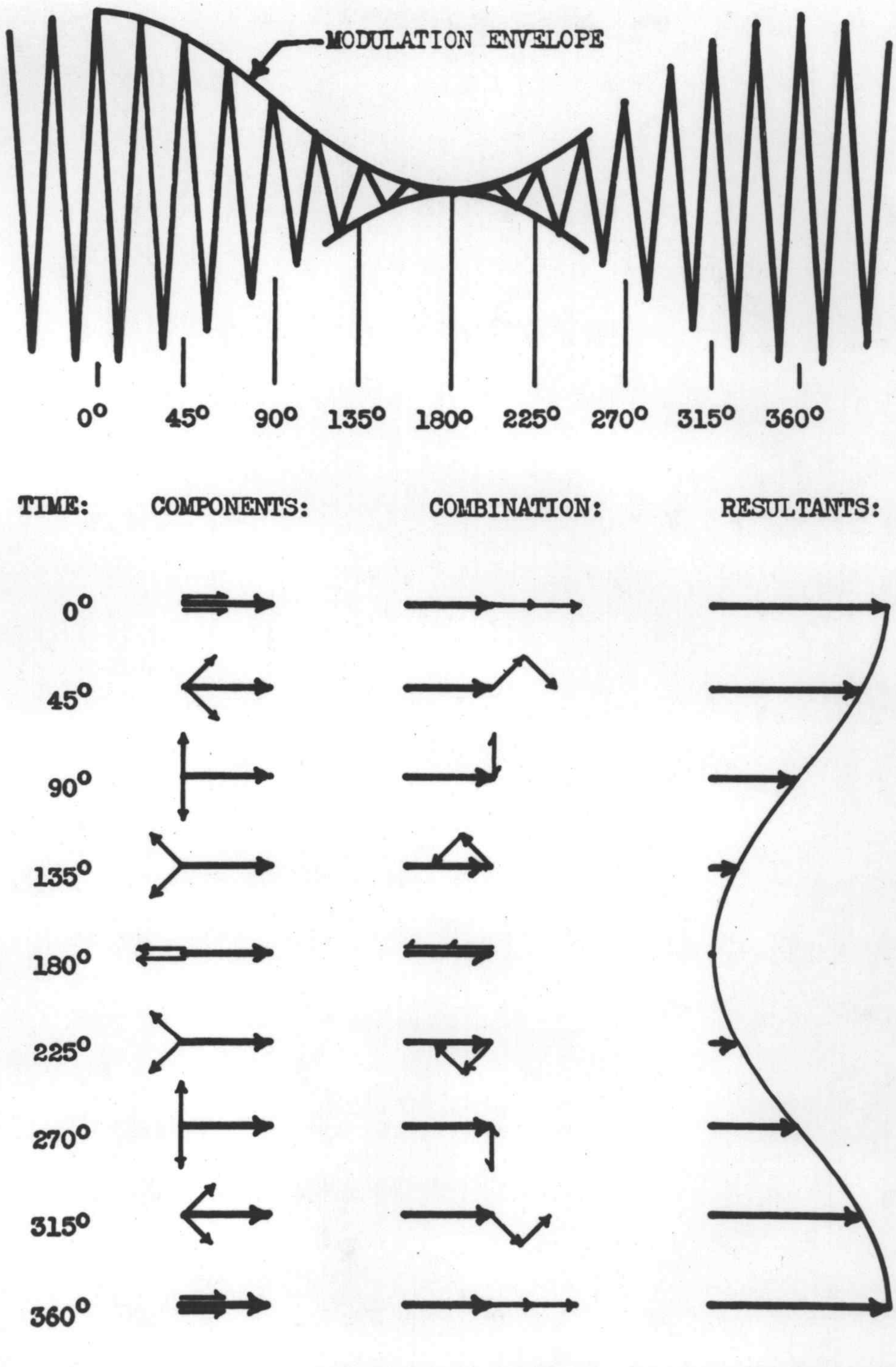


Figure 1. Analysis of an a-m signal by vectors for one audio modulating tone and 100% modulation. The modulation envelope has been drawn through the tips of the radio frequency waveform.

in the Armstrong system of f-m (1, p. 496-497). The deviation must be low enough to produce only two significant sideband components for a single modulating frequency for a simple analysis to be made. Figure 2 shows the analysis of the carrier and sideband components of an f-m or p-m signal for low deviation as required above. Higher deviation requires that more sideband components be considered and the analysis is somewhat more difficult to make.

THEORETICAL CAUSES OF FREQUENCY DISTORTION AND MODULATION ENVELOPE DISTORTION

Because the pattern of an array is a function of the transmitted frequency and phase shifts occur between the sideband and carrier components in a signal transmission, it is possible to predict that distortion and audio response changes should exist in particular transmitting directions. It is also theoretically possible to predict the directions of most severe distortion and greatest response changes at high audio modulating frequencies.

For a directional antenna system with a deep null and one or more maximum radiation lobes at the carrier frequency, it is reasonable that the null will probably not remain as deep for the sideband frequencies as for the carrier frequency if the sidebands have frequencies considerably different from the carrier frequency. In the null region, therefore, it would be expected that the high frequency audio response should be increased. This is by far the most probable condition, but it may not always obtain. It is also

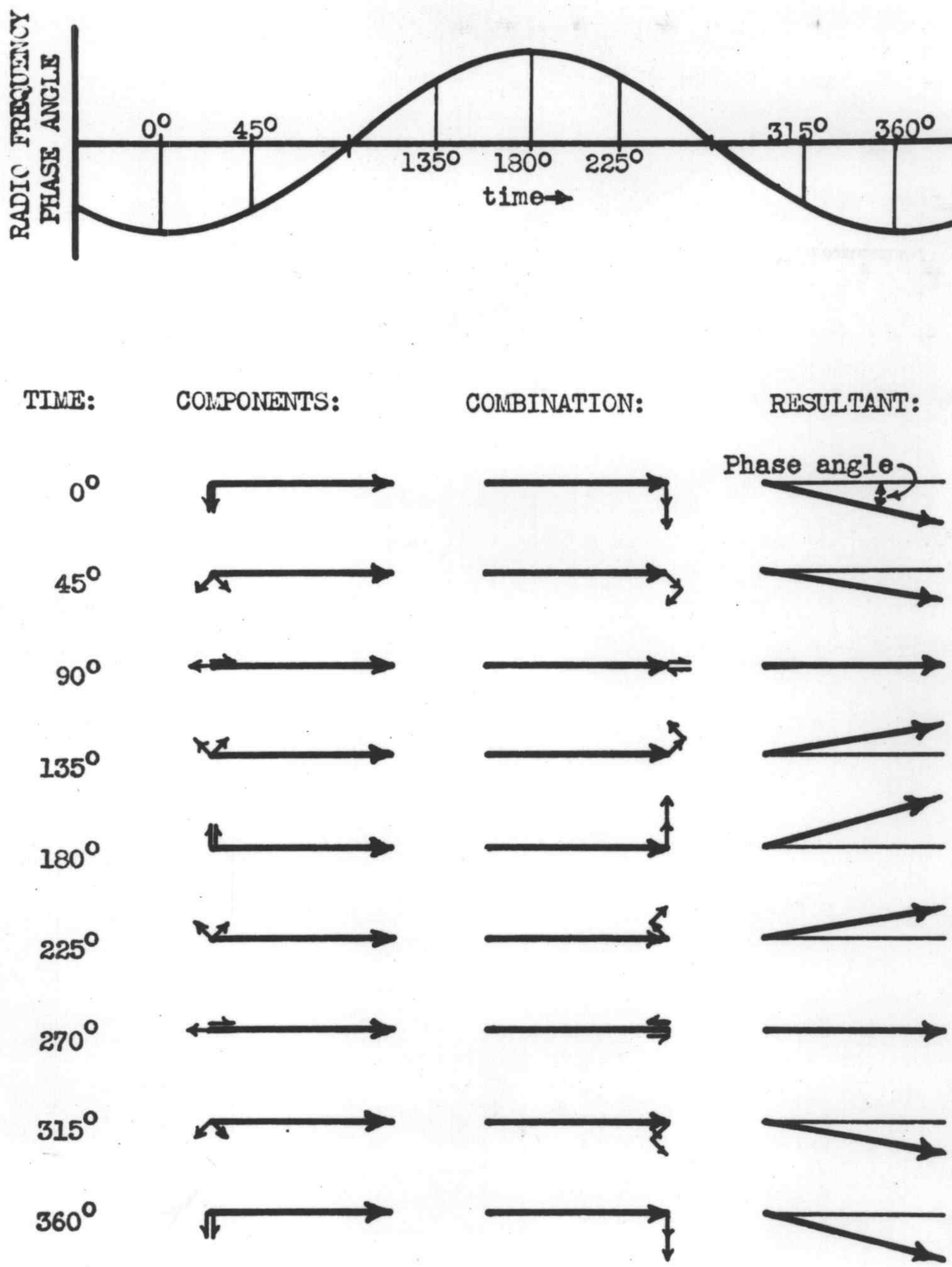


Figure 2. Analysis of a p-m signal by vectors for a single audio modulating tone and low deviation resulting in only one pair of significant sidebands.

highly improbable, but nevertheless theoretically possible, that the carrier component in the null region should suffer less destructive interference by the array than the two sideband components. In this event the high frequency audio response would be decreased instead of increased. It is also possible that the response might first decrease, then increase, or vice versa, with increasing frequency of the modulating signal.

In the maximum radiation directions it is probable that as the transmitted frequency changes from the carrier frequency to which the array is tuned the power output should decrease. At frequencies slightly different than the carrier frequency it is likely that a reduced power gain should exist than a power gain above that obtained at the carrier frequency. The transmission of high audio modulating frequencies in the maximum radiation directions is therefore most likely to be reduced.

Several distinct types of modulation envelope distortion are found in directional arrays. In general, for all types the percentage of distortion will be highest for high audio modulating frequencies and high modulation percentages.

One type of envelope distortion is caused by a phase shift between the carrier and sideband components. The resulting modulated wave can be resolved into a-m signal components and p-m signal components. At low percentages of modulation the p-m components adding in quadrature with the carrier produce essentially no change in the amplitude of the modulation envelope and therefore result in lack of output in the receiver. At high percentages of modulation the p-m signal sidebands are large and result in a distorted receiver output. The p-m signal contains only the first order sideband components so actually becomes angle modulation in this case. An analysis of the transmitted signal for a 100% modulated a-m signal which has become an angle modulated signal due to phase shifts in the signal components is given in Figure 3. The resultant audio signal in the receiver for envelope distortion of this type contains only harmonics of the original modulating frequency. This type of distortion is most likely to exist in the null regions because the destructive interference in the null represents a balance between strong forces and the small resultant is subject to radical change in phase and amplitude with change in frequency. This distortion becomes more objectionable with the increased sideband amplitudes expected in the null region.

Another type of distortion results when the amplitude of one sideband component approaches zero due to the directivity of the array while the carrier and other sideband are transmitted. In this type, as before, the distortion is worst at high levels of modulation. At lower modulation percentages, however, this type of signal becomes less distorted and for extremely low modulation percentages may result in negligible distortion. The signal can then be analyzed as a single sideband signal with a reinforced carrier and the distortion is low, as evidenced by the use of this type of transmission in telephone carrier systems. If the carrier amplitude is low at the single

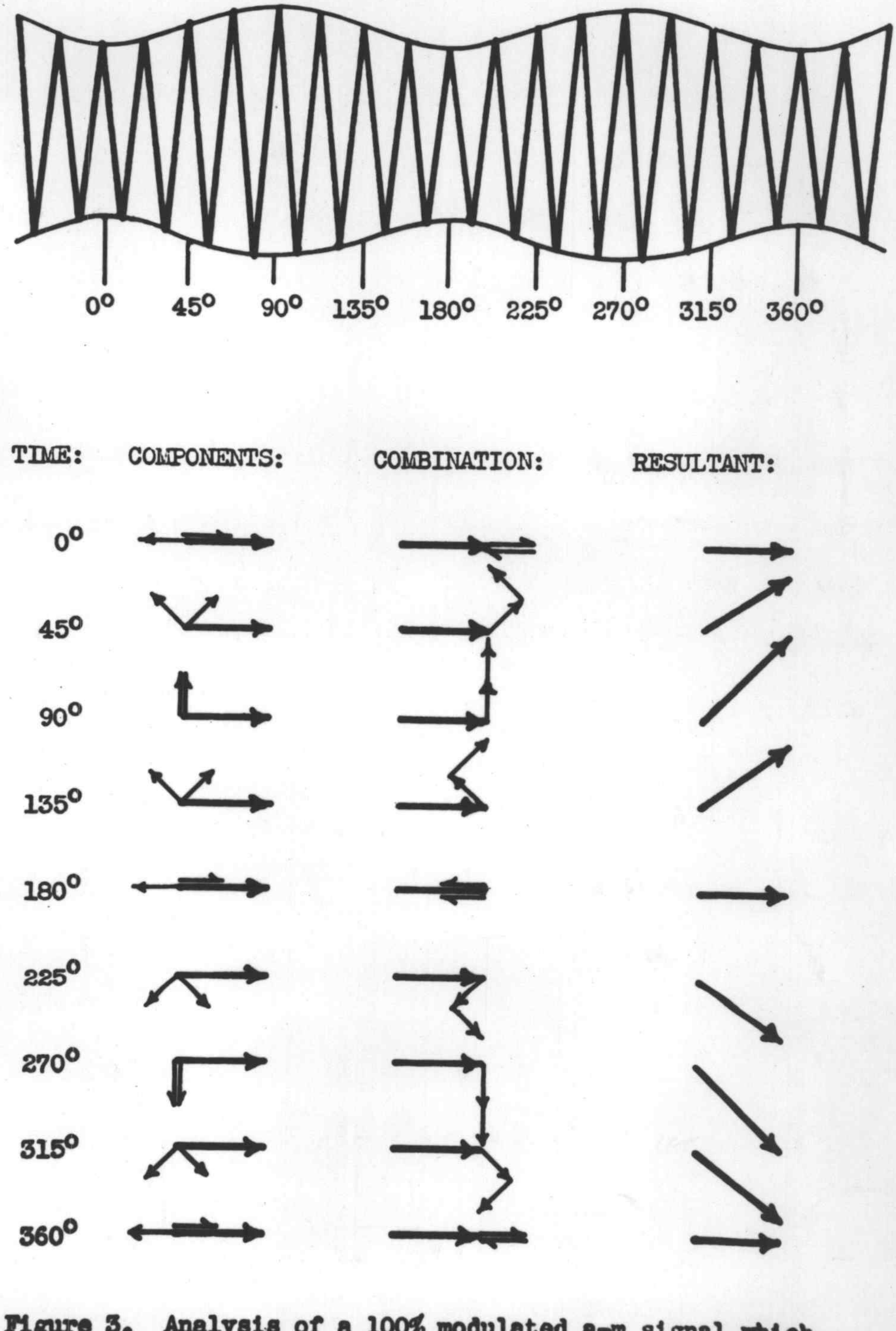


Figure 3. Analysis of a 100% modulated a-m signal which has become angle modulated by phase shift in the signal components without attenuation. The modulation envelope is not sinusoidal and contains no component of the fundamental modulating frequency.

sideband receiver, distortion results, as in the case of high modulation percentages in the present problem. If one sideband is cancelled out and the other becomes twice its normal amplitude then the resulting transmitted signal conditions for 100% modulation are as shown in Figure 4. This type of distortion may be less pronounced, and in less severe cases may be merely an unbalance in the amplitudes of the two sidebands. This type may exist simultaneously with the p-m type previously discussed.

When a signal with high modulation percentage is transmitted by a directional broadcast array, another type of distortion is possible. The increased sideband power in the null region due to increased response to high audio frequencies may cause a type of overmodulation. If a transmitter is overmodulated by excessive audio signal, new frequencies are produced in the process of distortion and the peak excursions of the modulation envelope appear to be clipped. The overmodulation distortion due to the array has quite different features, however. If there are no phase shifts in the sideband components but their amplitudes are increased, the analysis of the signal will be that shown in Figure 5a. This waveform is entirely different than the overmodulated signal waveform originating in an overmodulated class C amplifier, given for comparison in Figure 5b.

This type of modulation envelope distortion may occur in conjunction with p-m envelope distortion and the analysis of one possible resultant signal is given in Figure 6.

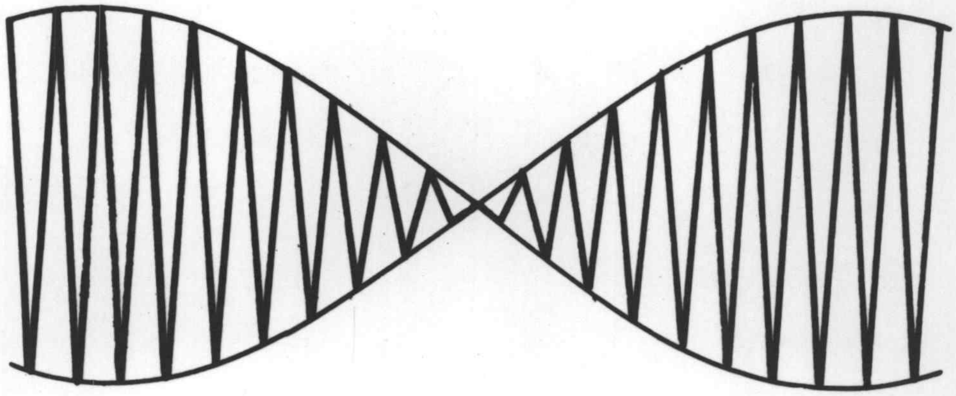


Figure 4. Modulation envelope conditions existing for only one transmitted sideband having a magnitude equal to the carrier magnitude. The vector conditions for this waveform are similar to those of figure 1 except only one sideband is present.

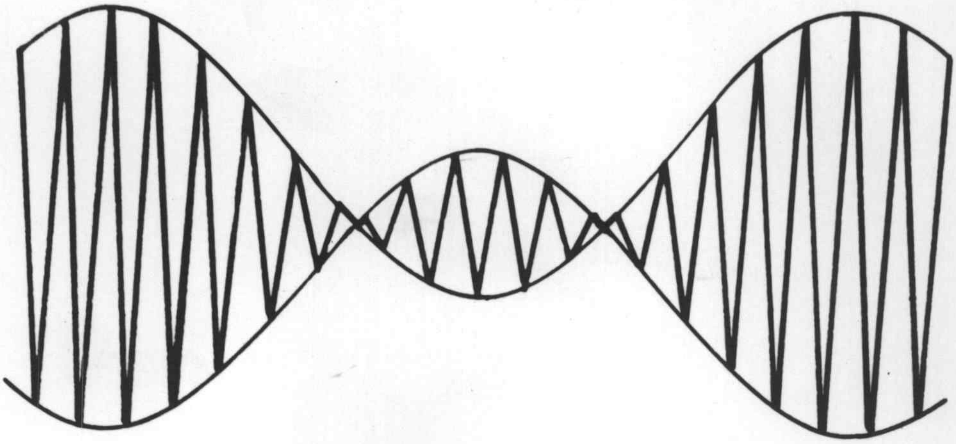


Figure 5 a. A type of overmodulation pattern resulting from increasing the sideband amplitudes with sinusoidal modulation above their values at 100% modulation.

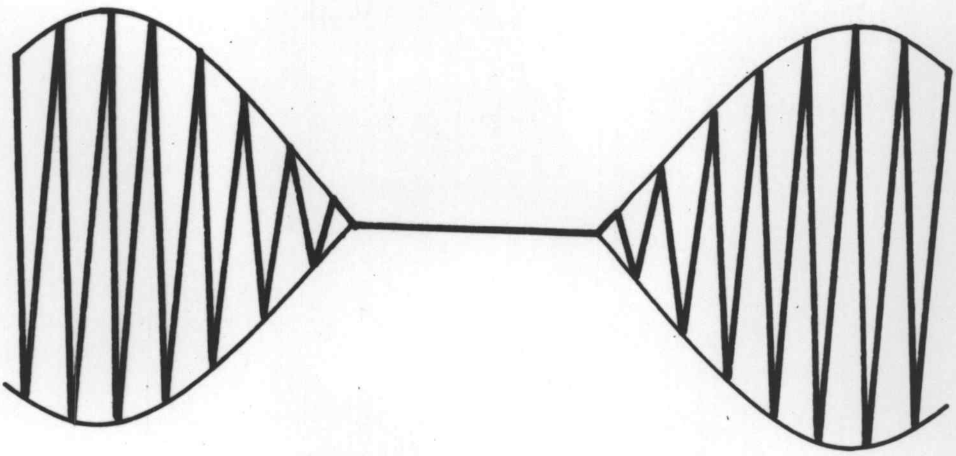


Figure 5 b. Modulation envelope conditions for an overmodulated transmitter.

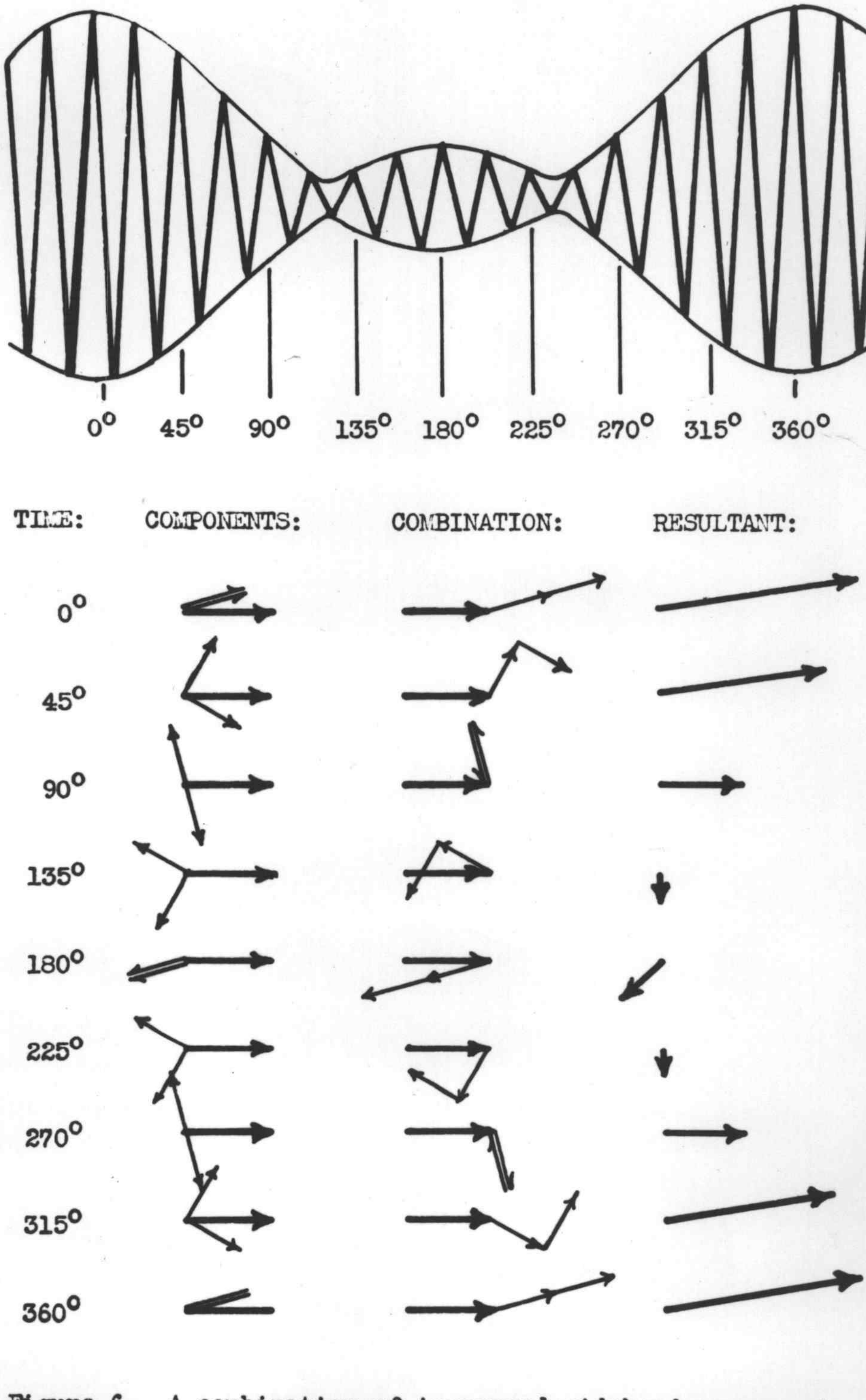


Figure 6. A combination of increased sideband power and phase shifts for sinusoidal modulation.

It is very significant that although audio distortion may be found in the receiver output when modulation envelope distortion exists, the array itself does not introduce new frequency components in the transmitted signal but merely alters the amplitude or phase of the existing components. The transmitted signal bandwidth with antenna distortion is the same as for distortionless operation. The receiver second detector is responsible for the addition of the large number of distortion components found in the receiver output.

MAGNITUDE OF MODULATION ENVELOPE CHANGES

The exact nature and magnitude of the modulation envelope distortion in a particular direction from a multi-element directional broadcast array is a function of many things. The directional pattern, tower types and heights, ground system, antenna tuning network components, method of feed, transmission lines, and phasing and matching units at the point of common feed are the important things which effect the distortion. These factors influence the tuning of the array and the nature of the frequency sensitivity, both in phase and amplitude, of the field radiated from each tower. If all of the electrical constants were known for a particular array it would theoretically be possible to calculate the resulting envelope distortion characteristics of the array in any direction by a laborious point by point solution. It is a formidable task, however, to evaluate the operating constants of the usual directional array due to the presence of tower mutual impedances, distributed constants in the matching and phasing networks, and mutual impedances between inductors in the antenna tuning units. The resulting circuit is so complicated that many approximations must be made to reduce the calculations to reasonable proportions. Also, since months are required to tune some arrays there is a danger that in working with the networks the tuning may be accidentally upset and the station might suffer financially through lost operating time and tuning expenses. These factors make it inadvisable to attempt a theoretical analysis of an existing broadcast array for the purposes of this paper.

It appears at first that a model antenna system could be constructed and that the required measurements could be made on the model. The model would have to be small enough to allow economical erection of reasonably small towers, perhaps 50 to 60 feet tall. This would place the operating frequency in the 3 to 4 megacycle region, the exact frequency depending on the specifications of the array. It becomes increasingly more difficult to make accurate radio frequency bridge measurements as the frequency is increased, and the problems of measurement at 3 or 4 megacycles are rather severe. If shorter towers were used this problem would become more acute. Assuming that measurements could be made, however, it would require months of calculating and adjusting to tune the model array just as for a full-scale station. In addition experimental audio measurements would be difficult because of the audio modulating frequencies would have to be scaled to the new carrier frequency. Commercially available audio distortion measuring equipment would not be suited for study of the higher modulating frequencies. Unless some means were found to avoid these difficulties the use of models would not simplify the process of obtaining measurements.

EXPERIMENTAL PROJECTS

Due to the size of the project of analyzing a typical array for the magnitudes of envelope distortion and audio response changes, other means of obtaining typical experimental data were employed. Two standard broadcast stations permitted testing of their directional antenna systems to observe the signal distortion directly.

PRELIMINARY EXPERIMENTAL TESTS

The first tests of station A were exploratory and qualitative in nature and served only to verify the existence of the envelope distortion and audio frequency response changes. Square wave audio modulation was selected for the first tests because many frequency components are present in a square wave and the phase as well as amplitudes of the signal components could be observed in the received signal waveform.

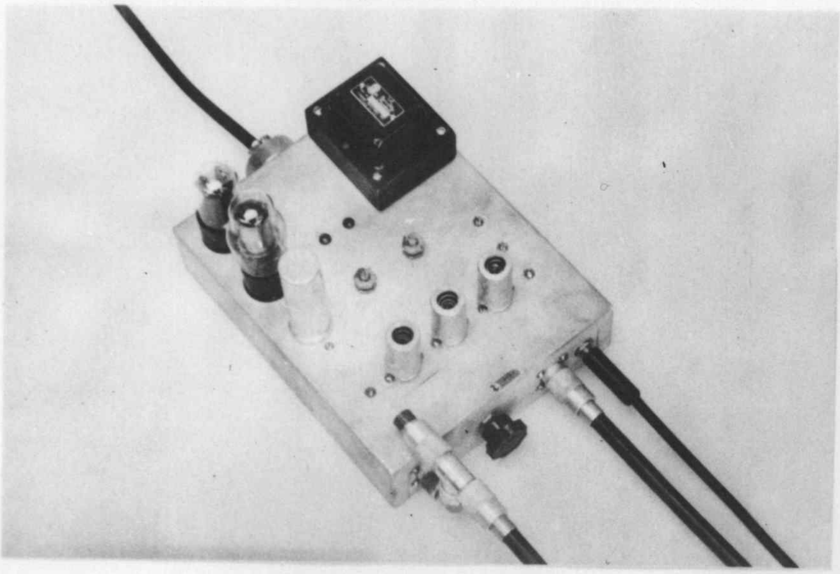
A 2 kilocycle fundamental was chosen for the square wave as a matter of convenience in interpreting the results. A higher fundamental frequency would have been more subject to frequency distortion in the null region than the 2 kilocycle fundamental; a lower fundamental frequency would have produced lower magnitude harmonics in the audio frequency band being explored.

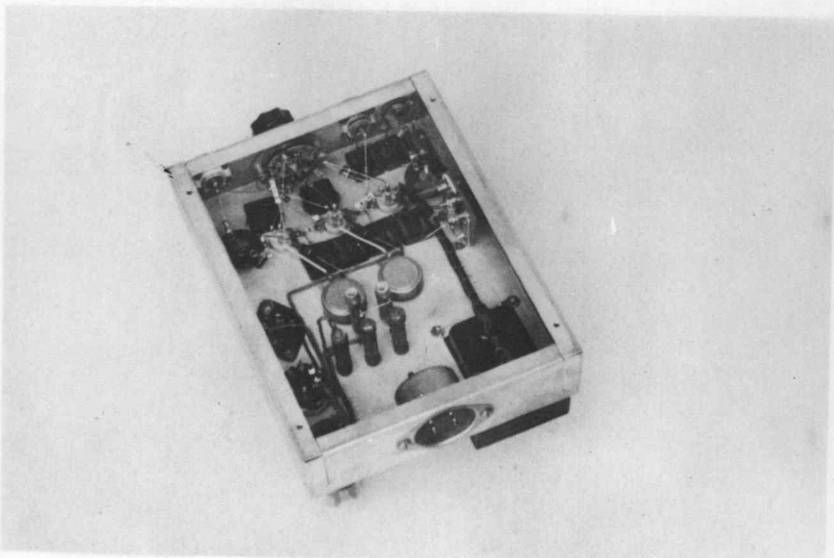
The transmitter was modulated 50% by the square wave, as indicated on the station modulation monitor. This percentage was chosen to allow a few decibels below 100% modulation for audio response increases in the null directions, yet produce sufficient modulation to cause observable distortion.

An 8 foot whip antenna for sampling the transmitted signal was installed on a truck and the modulation envelope was observed and photographed with a Tektronix model 511-AD oscilloscope. The truck was driven around the array and the signal was observed while in motion. Photographs were made with the truck standing still. An amplifier was constructed for the mobile receiving unit to provide sufficient gain for ample deflection on the oscilloscope with the weakest signal. It consisted of a two stage broad-band amplifier and one stage combined output cathode follower and detector. The detected signal provided triggering for the Tektronix oscilloscope which was operated with driven sweep. Details of the construction and performance of the mobile amplifier are given in Appendix I and photographs are shown in Figure 7.

The first tests provided information about experimental techniques and definitely showed that envelope distortion and variations in frequency distortion were present. These results, however, will not be shown because more reliable data were obtained in later tests. One important observation in the preliminary tests was that much more severe distortion often resulted when the receiving antenna was directly under telephone lines or guy wires than when it was located outside these regions. It was found that a true sample of the transmitted signal could only be obtained if the receiving antenna were entirely removed from local distortion sources.

Figure 7





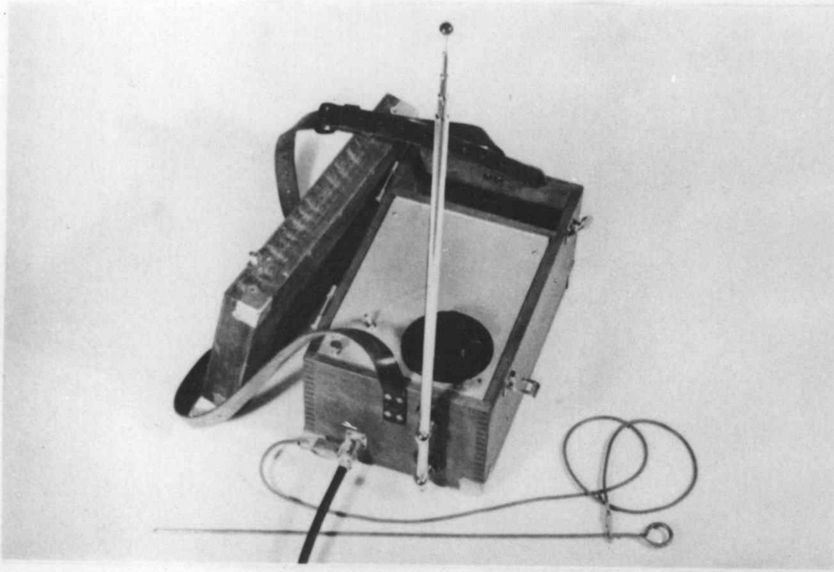
Top and bottom views of the mobile amplifier.

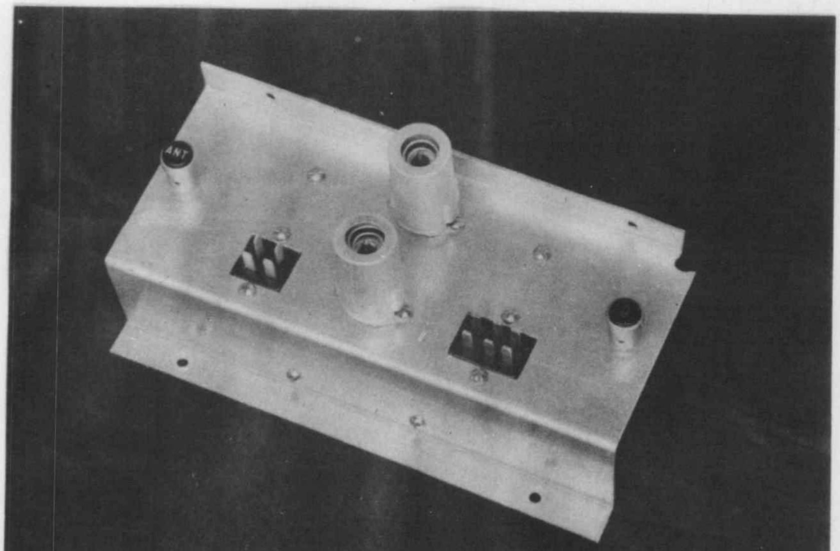
EXPERIMENTAL PROCEDURE

In order to examine the response characteristics of the antenna systems of the two test stations it was necessary to travel around the arrays on existing roads with measuring equipment. It was also necessary to stay sufficiently far from each array to minimize errors due to tower induction fields and lack of a point radiation source. These effects become significant within about a 1 mile radius of the antenna, the exact distance depending upon the allowed error, the characteristics of the array, and the carrier frequency. To minimize these errors and to stay on existing roads it was sometimes necessary to take measurements many miles from the antennas. All tests had to be made during the standard broadcast test period of 1 A.M. to 6 A.M.

A portable battery-powered broad-band preamplifier with a collapsible 8 foot whip receiving antenna was built to satisfy the need for an antenna located away from overhead wires and local distortion sources. The portable preamplifier was carried into open fields and connected to the truck by about 300 feet of coaxial cable. The cable carried the amplified signal from the antenna to the truck where it passed through the mobile amplifier and then to the oscilloscope or distortion meter. About 250 feet of cable was reeled out from the truck for each measurement and the antenna was always extended to full length. A course gain adjustment was provided on the preamplifier to prevent overloading of the output cathode follower in regions of strong signal. Photographs of the battery preamplifier chassis and of the complete amplifier and antenna are shown in Figure 8.

Figure 8





Preamplifier chassis and carrying case.
Antenna is shown collapsed.

Further information about the design and operation of this unit is given in Appendix II.

A crew of three to five men was required each night to operate the transmitting and test equipment efficiently. One licensed operator and occasionally an assistant were required at the transmitter at all times. At times the assistant was needed to help with the test program while the licensed operator cared for the station. At least one helper was needed in the field to reel cable in and out, set up the preamplifier, operate communications equipment, and drive the truck while another operated the test equipment and recorded and photographed data.

Radiotelephone communications equipment was installed in the truck and at each station under test in order to allow the operators in the truck to change the nature of the transmitted test program without loss of time. This permitted a great saving in actual testing time over that required by using prearranged test programs. The communication equipment was operated in the amateur bands.

A Hewlett Packard type 330-B Noise and Distortion Meter was coupled to the output of the preamplifier through a 75 micro-micro-farad capacitor for measuring the received signal distortion for sinusoidal modulation. In this instrument the received signal is detected and the detected audio signal is then analyzed. The transmitter was modulated 50% and audio distortion was measured at several frequencies at each test location. Frequency distortion was also measured with this instrument. A reference frequency of 200 cycles was first transmitted by the station and the received audio amplitude at this frequency was assigned a value of zero decibels. It was assumed that no serious antenna effects were present at 200 cycles. Actually it will be seen that no appreciable effects were obtained until a modulating frequency above 1 kilocycle was employed. The response at higher modulating frequencies was then recorded and a response curve was obtained for each measuring location.

It was necessary to correct all frequency response data for the frequency response error of the Hewlett-Packard noise and distortion meter. The correction information is given in Appendix III. The distortion data could not be corrected for this error.

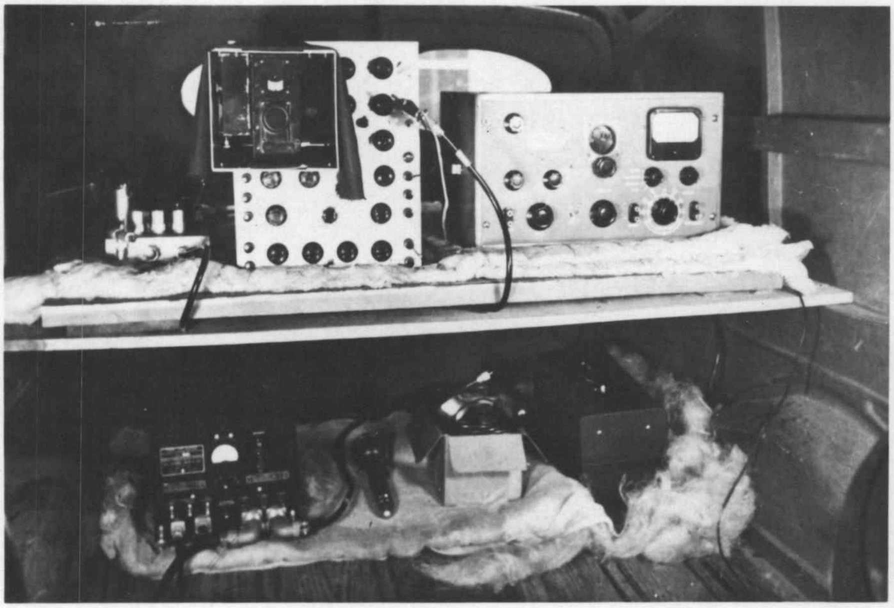
The power requirements of the equipment in the truck were quite high and had to be met reliably at any time or location. Therefore a 1500 watt 60 cycle portable gas driven generator was mounted in a trailer and used to supply continuous power. The trailer also carried the reel of coaxial cable for the battery preamplifier. A photograph of the truck and trailer ready for a test run is shown in Figure 9. A view of the test equipment in the truck in normal operating condition is given in Figure 10.

A grounding stake connected to the portable amplifier chassis was driven about 16 inches into the ground at each receiving location in order to reduce the magnitude of the ground circuit impedance and guard the antenna from stray pickup carried by the coaxial cable. Also, since the cable was long and capacitively loaded by the truck

Figure 9

Complete mobile test unit.

Figure 10



Test equipment installation in the truck.

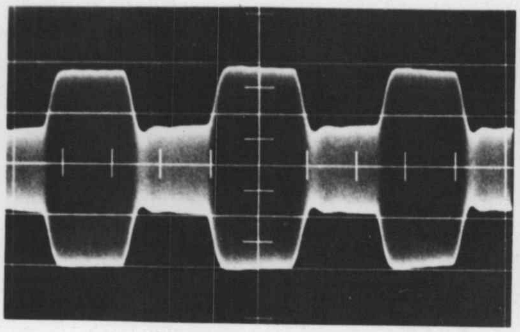
and trailer it was necessary to ground the coaxial cable at the truck to eliminate a resonant circuit from the truck through the cable sheath to the ground at the portable unit. Without a ground at the truck such a resonant circuit might transmit radio energy from local distortion sources in the vicinity of the truck to the portable unit. The grounds were always made in the dampest spots available, usually under water or in water-saturated soil.

RESULTS

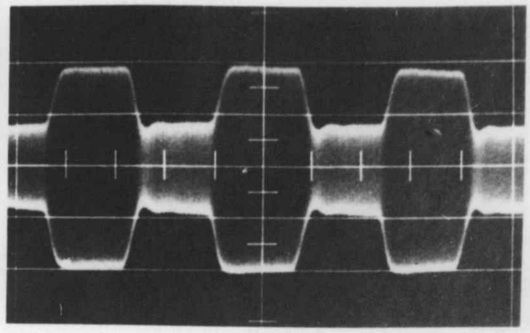
The equipment and measuring techniques employed for studying the radiated field at various azimuth angles were designed specially for this problem. It was therefore very desirable to provide a check on the performance of the equipment in actual operation. A sample radius having a large number of points accessible by existing roads was chosen for this purpose at station A. Theoretically the signal passing any point on the radius should be the same as the signal at any other point on the radius except for time of arrival and amplitude. The modulation envelope waveforms and audio frequency response curves at all points should therefore be identical. Measurements were made at several points at various distances from the array to see that consistent results were obtained. Square wave modulation envelope photographs and audio frequency response curves from four points on the radius are shown in Figures 11 and 12, respectively. The transmitter was modulated 50% for both tests.

The only significant difference between the square wave photographs at different distances is in the sharpness of the edges of the

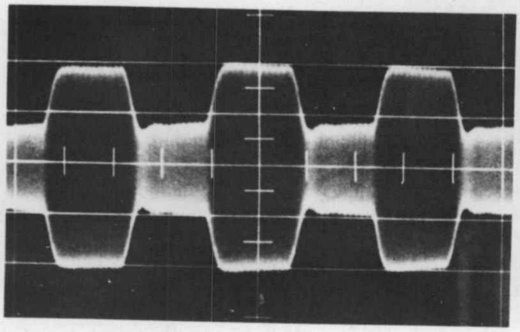
Figure 11



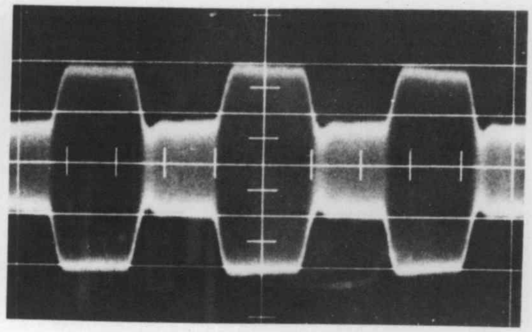
0.8 MILE FROM ANTENNA



3.7 MILES FROM ANTENNA



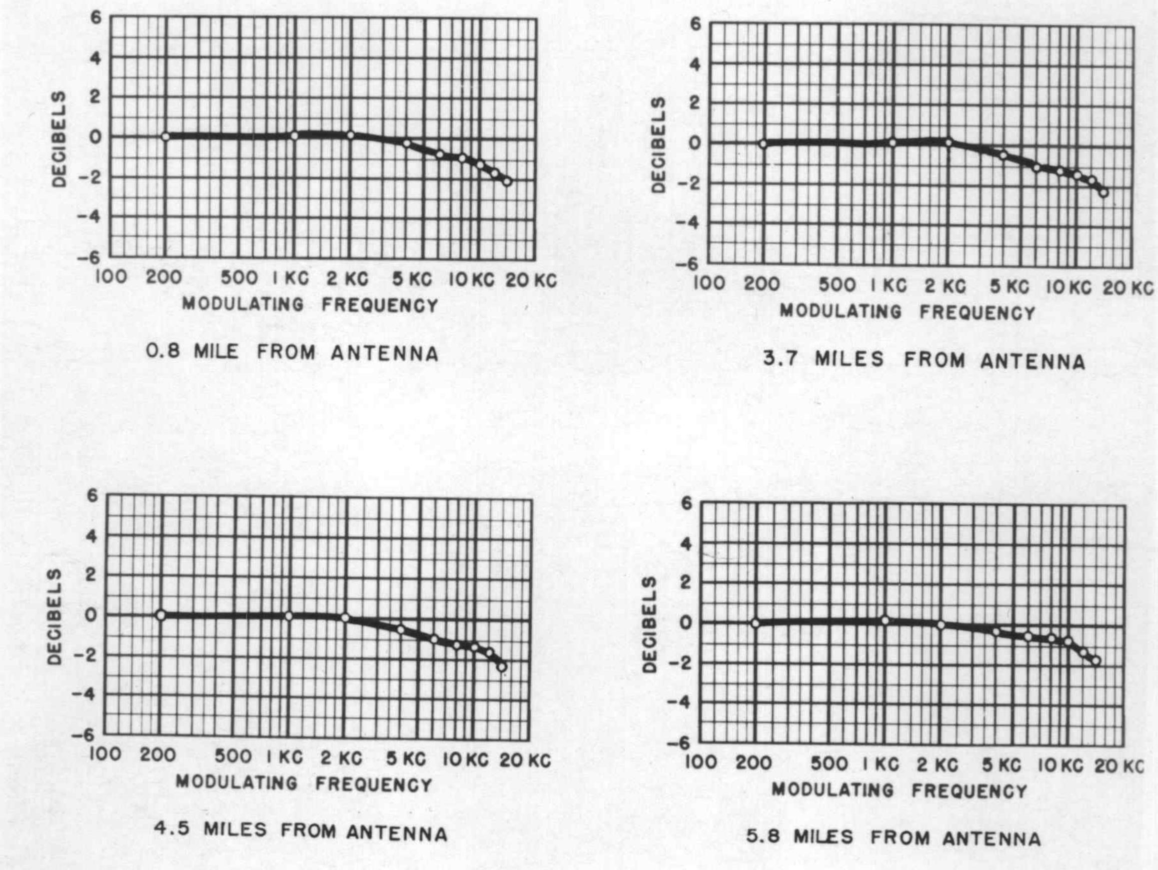
4.5 MILES FROM ANTENNA



5.8 MILES FROM ANTENNA

Station A square wave modulation envelope photographs at an azimuth angle of 240°. The transmitter was modulated 50% with a 2 kilocycle square wave.

Figure 12



Station A audio frequency response curves at an azimuth angle of 240°. The transmitter was modulated 50%.

waveforms. The decreased definition at the edges of the modulation envelope at the most distant point compared to the closest point is due to a higher interference ratio when the received signal was weak. The amplifiers, broad-band to prevent distortion of the received signal waveform, were sensitive to interference from other stations in the frequency range for which they were made responsive. In the waveforms which follow the photographs made at large distances from the arrays and in the null directions have indistinct edges due to interference.

It was found that distortion could not be measured accurately in some locations because of noise. This is because the Hewlett-Packard Noise and Distortion Meter which was employed measured distortion by cancellation of the fundamental frequency component and measurement of the remaining signal, which contained a large amount of noise in addition to distortion components. Whenever the noise level measured without modulation became significant in comparison to the distortion components, distortion measurements were not attempted.

STATION A

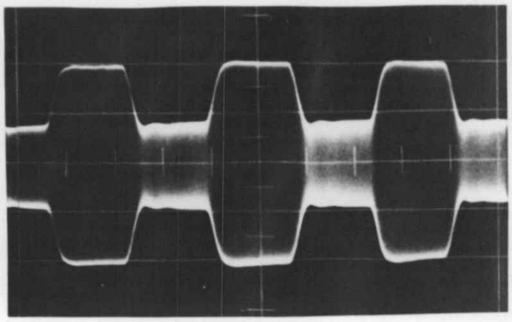
The general nature of the signal distortion due to the antenna system of Station A was surveyed by selecting one good monitoring point on each of 24 radials spaced at 15 degree intervals and comparing the signals received in each direction. Square wave photographs and audio response curves were obtained at all but one point. The square wave photograph was lost for this point due to faulty photography but the audio frequency response data for the point were obtained. Measurements at 30 degree intervals would have been sufficiently close in the region where the photograph was lost, so measurements were not repeated at that point. Distortion was measured only at every third point in order to reduce the time required for taking data.

The null region of Station A is from 145° to 165° on the arbitrary azimuth scale. The null of Station A actually consists of a double null with only a small angle between the nulls. It is important to study the trend of the experimental data with respect to this null region. Square wave photographs for the entire general survey are shown in Figures 13 a, 13 b, 13 c, and 13 d. Audio response curves for the array are shown in Figures 14 a, 14 b, 14 c, and 14 d. Curves of audio distortion as a function of audio modulating frequency with the transmitter modulated 50% are given in Figures 15 a and 15 b. Data for the tests of Station A are contained in Appendix IV.

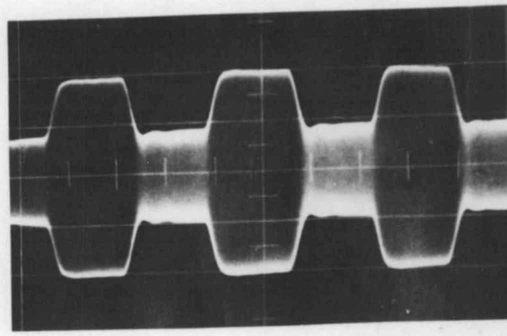
Analysis of the square wave photographs shows that definite changes occur in the frequency distortion and transient response characteristics of the array with changes in azimuth angle. Modulation envelope overshoots are found in the null direction and delayed rises are found in the maximum directions. These correspond to gains and losses in high audio frequency response, respectively.

The positive and negative overshoots of each waveform are seen to match except in the null region waveforms, where the negative overshoot is seen to fill out entirely differently than the positive

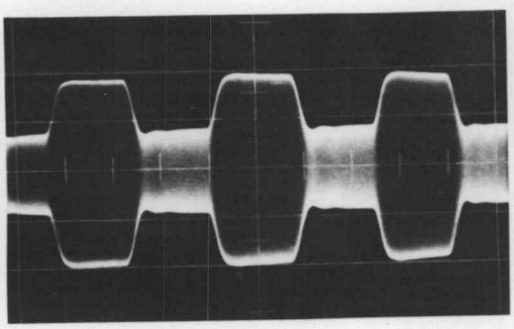
Figure 13 a



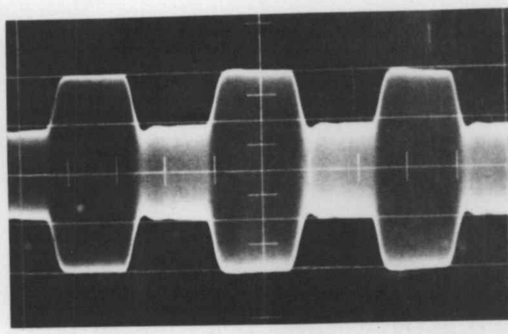
15° AZIMUTH ANGLE



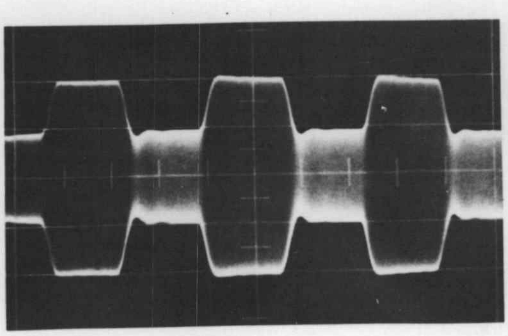
30° AZIMUTH ANGLE



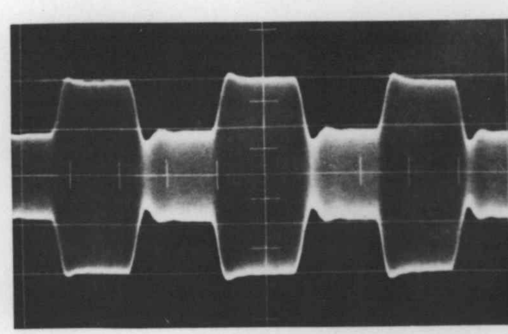
45° AZIMUTH ANGLE



60° AZIMUTH ANGLE



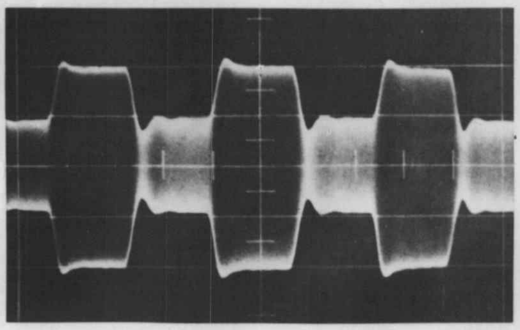
75° AZIMUTH ANGLE



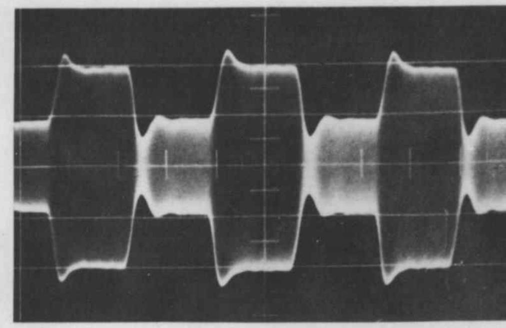
90° AZIMUTH ANGLE

Station A square wave modulation envelope photographs for various azimuth angles. The transmitter was modulated 50% with a 2 kilocycle square wave.

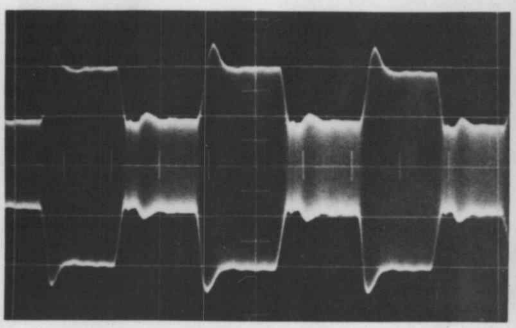
Figure 13 b



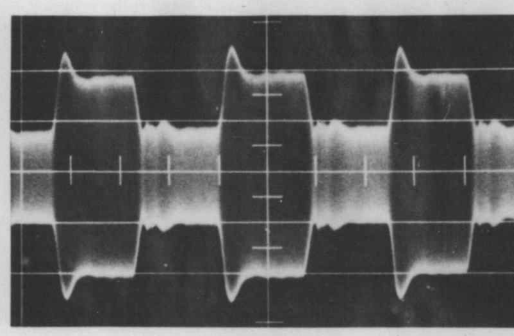
105° AZIMUTH ANGLE



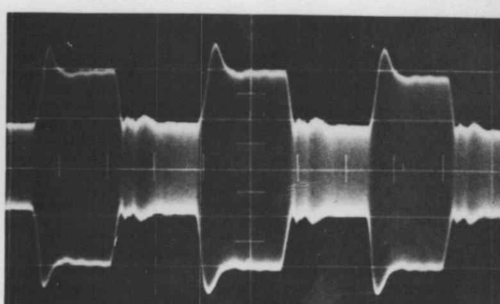
120° AZIMUTH ANGLE



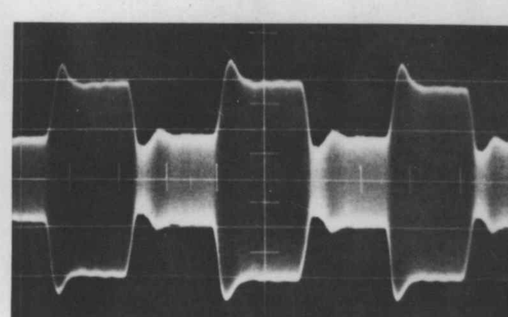
135° AZIMUTH ANGLE



150° AZIMUTH ANGLE



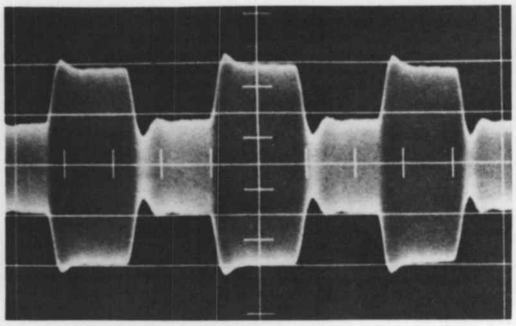
165° AZIMUTH ANGLE



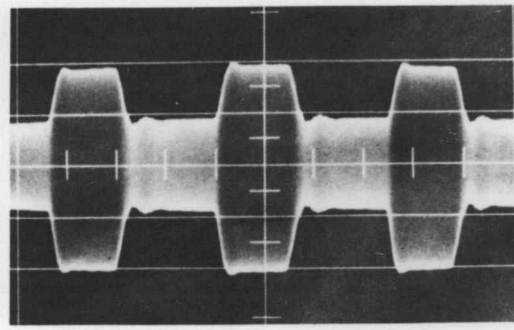
180° AZIMUTH ANGLE

Station A square wave modulation envelope photographs for various azimuth angles. The transmitter was modulated 50% with a 2 kilocycle square wave.

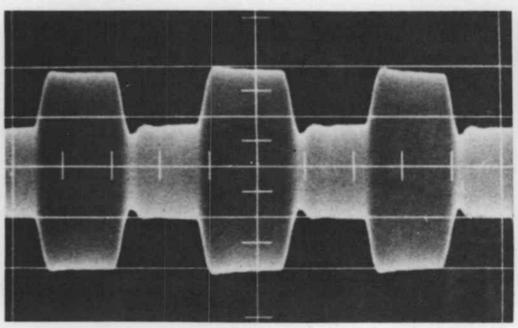
Figure 13 c



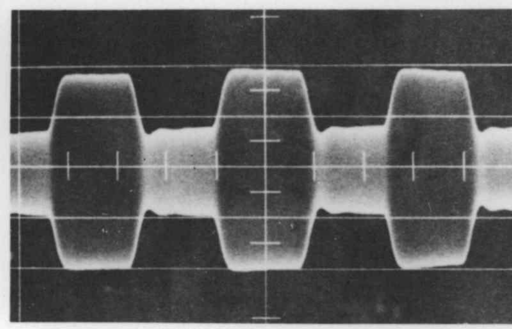
195° AZIMUTH ANGLE



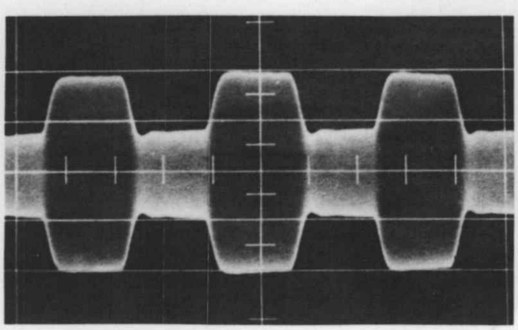
210° AZIMUTH ANGLE



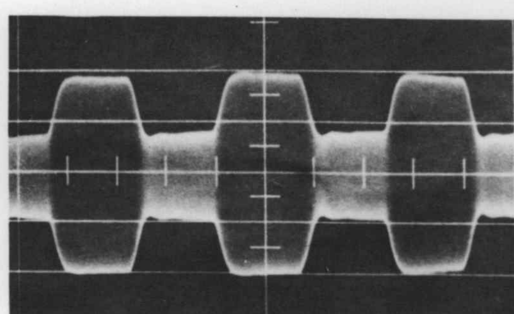
225° AZIMUTH ANGLE



240° AZIMUTH ANGLE



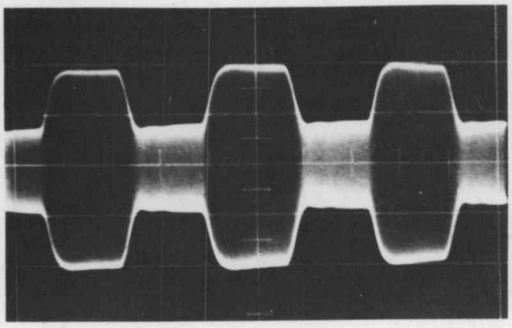
255° AZIMUTH ANGLE



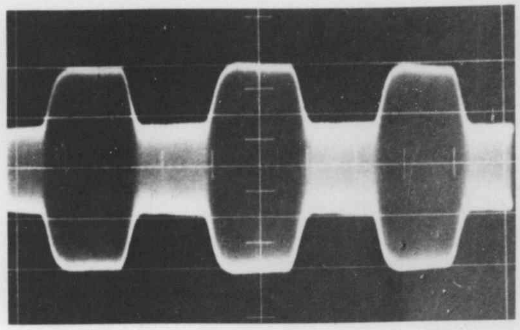
270° AZIMUTH ANGLE

Station A square wave modulation envelope photographs for various azimuth angles. The transmitter was modulated 50% with a 2 kilocycle square wave.

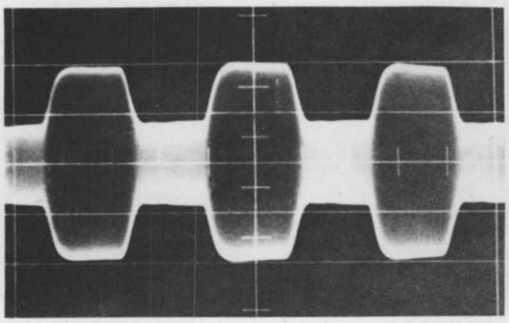
Figure 13 d



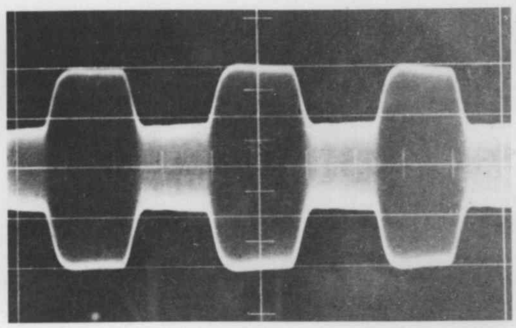
285° AZIMUTH ANGLE



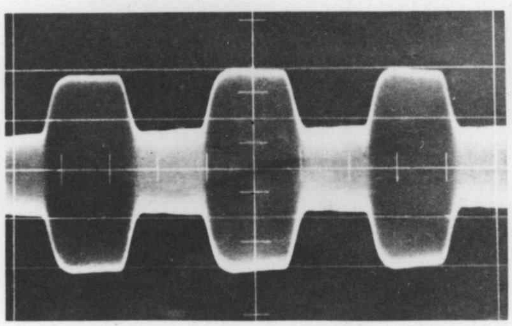
300° AZIMUTH ANGLE



315° AZIMUTH ANGLE



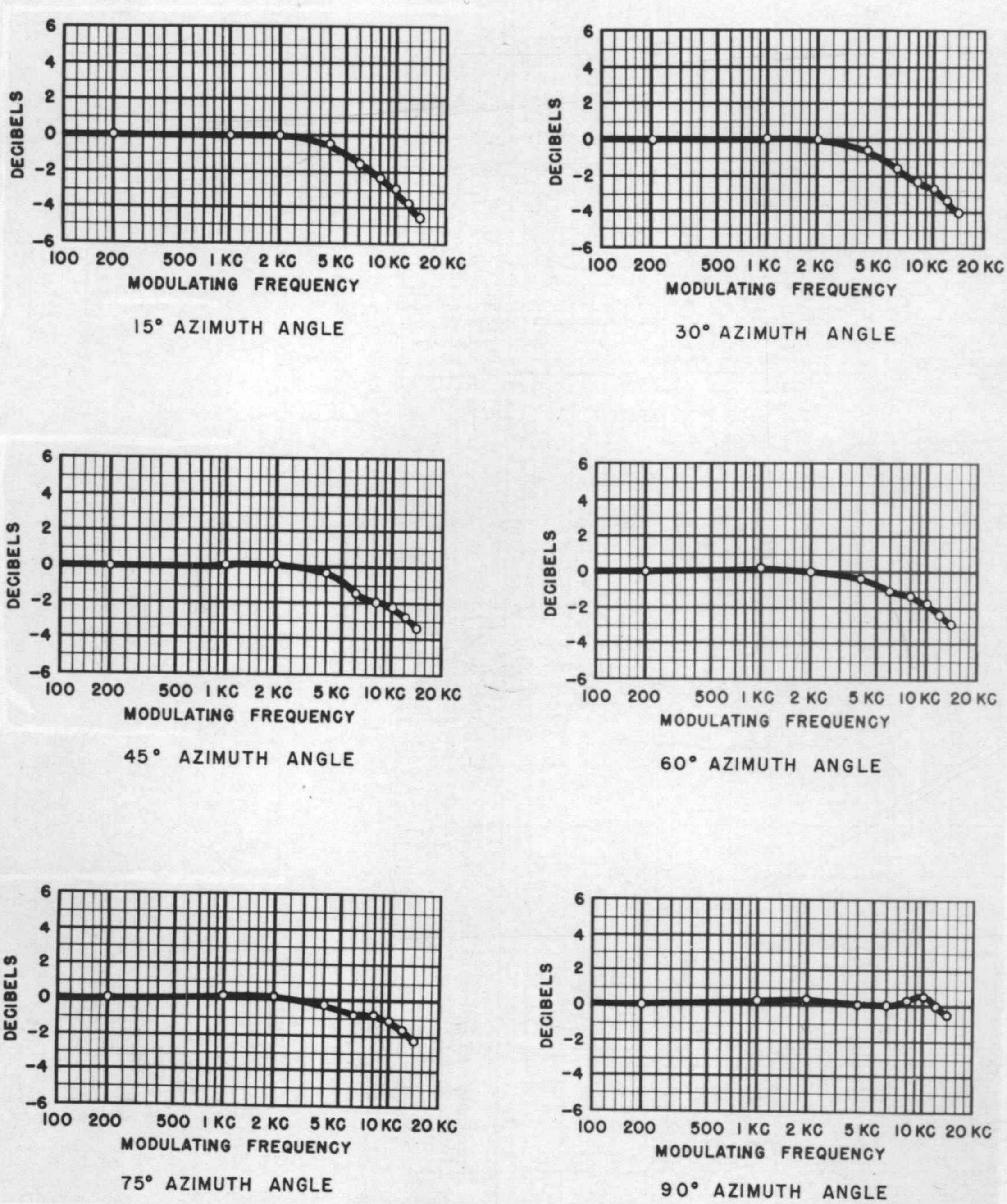
330° AZIMUTH ANGLE



345° AZIMUTH ANGLE

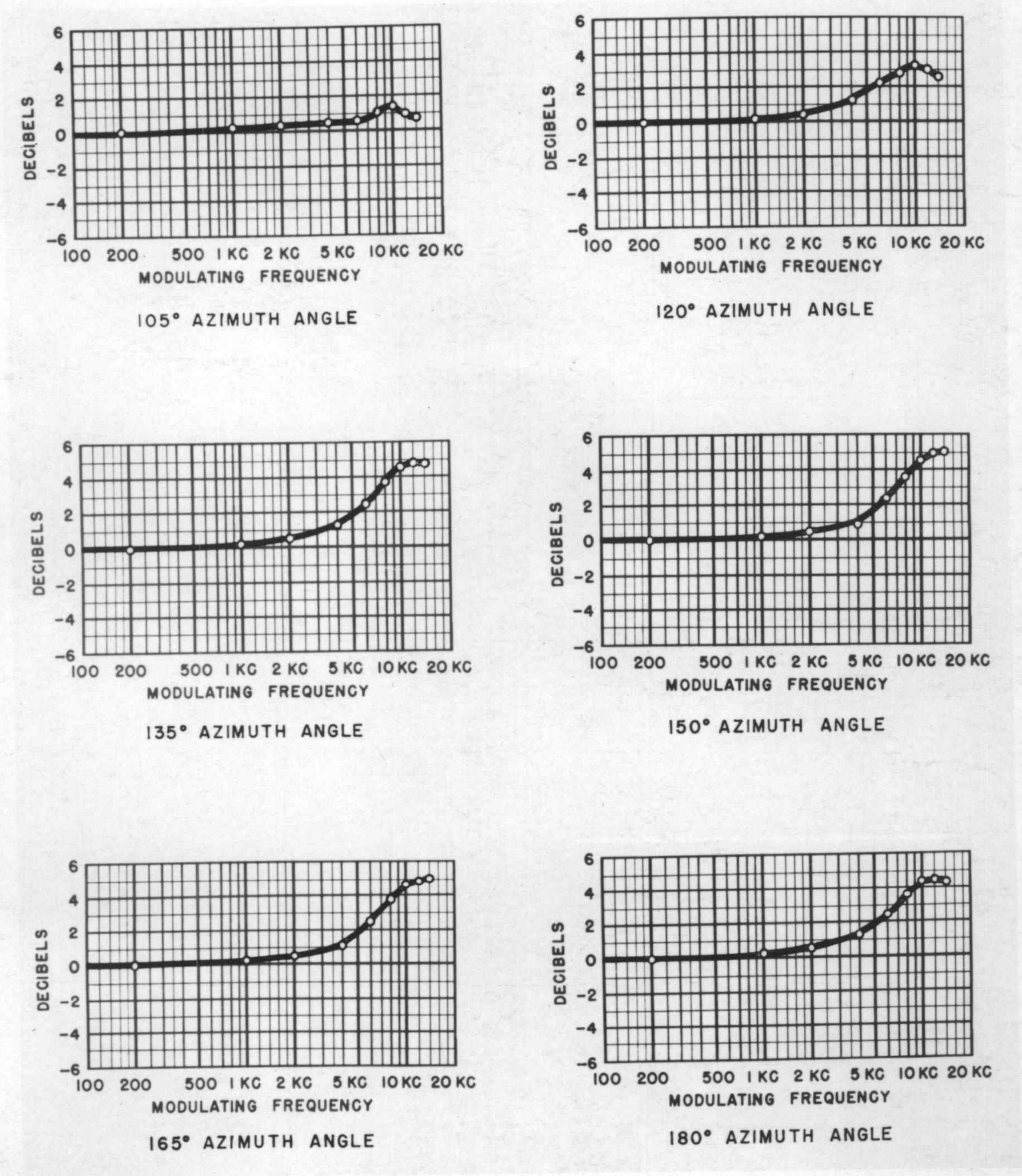
Station A square wave modulation envelope photographs for various azimuth angles. The transmitter was modulated 50% with a 2 kilocycle square wave.

Figure 14 a



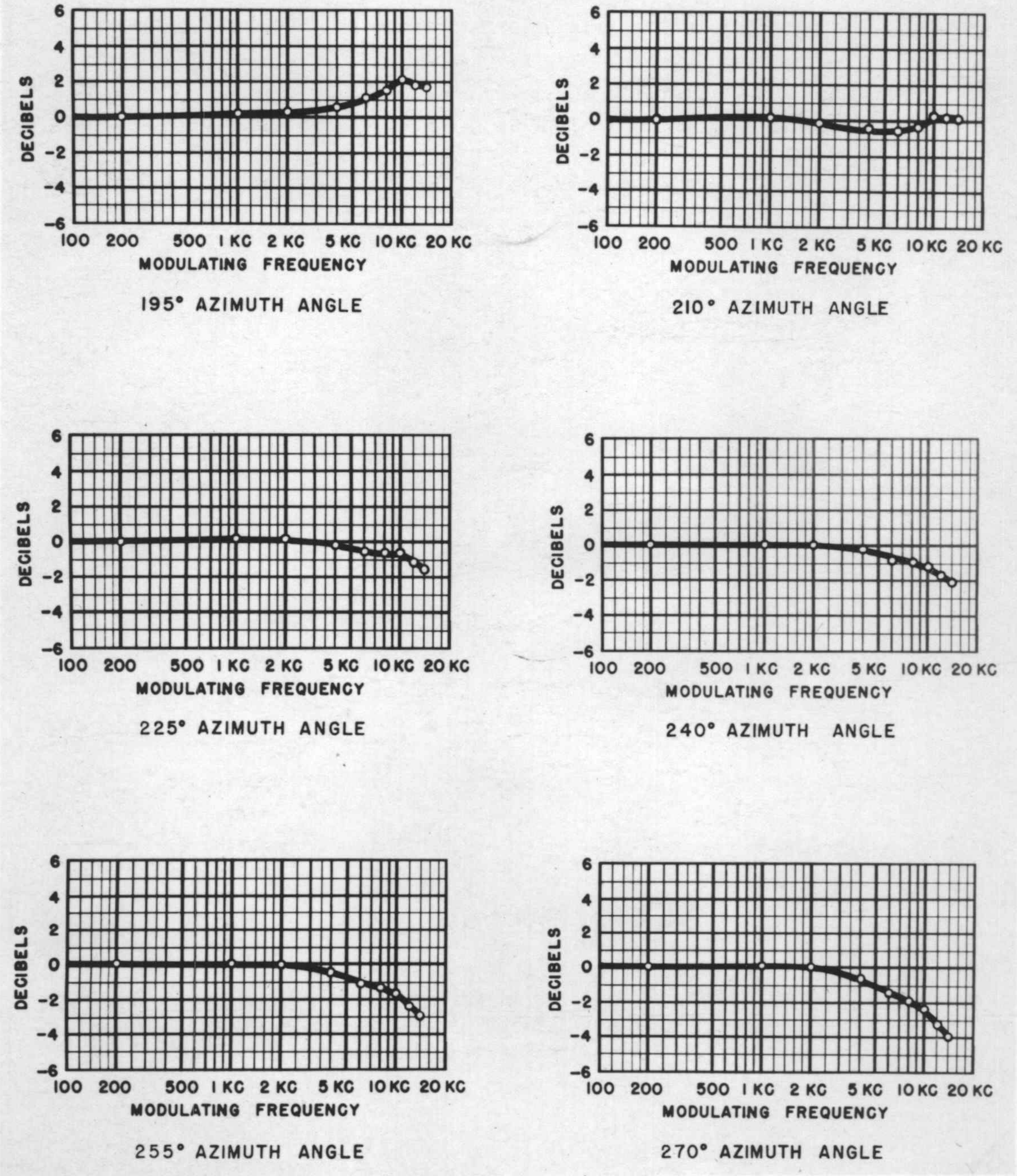
Station A audio frequency response curves at various azimuth angles. The transmitter was modulated 50%.

Figure 14 b



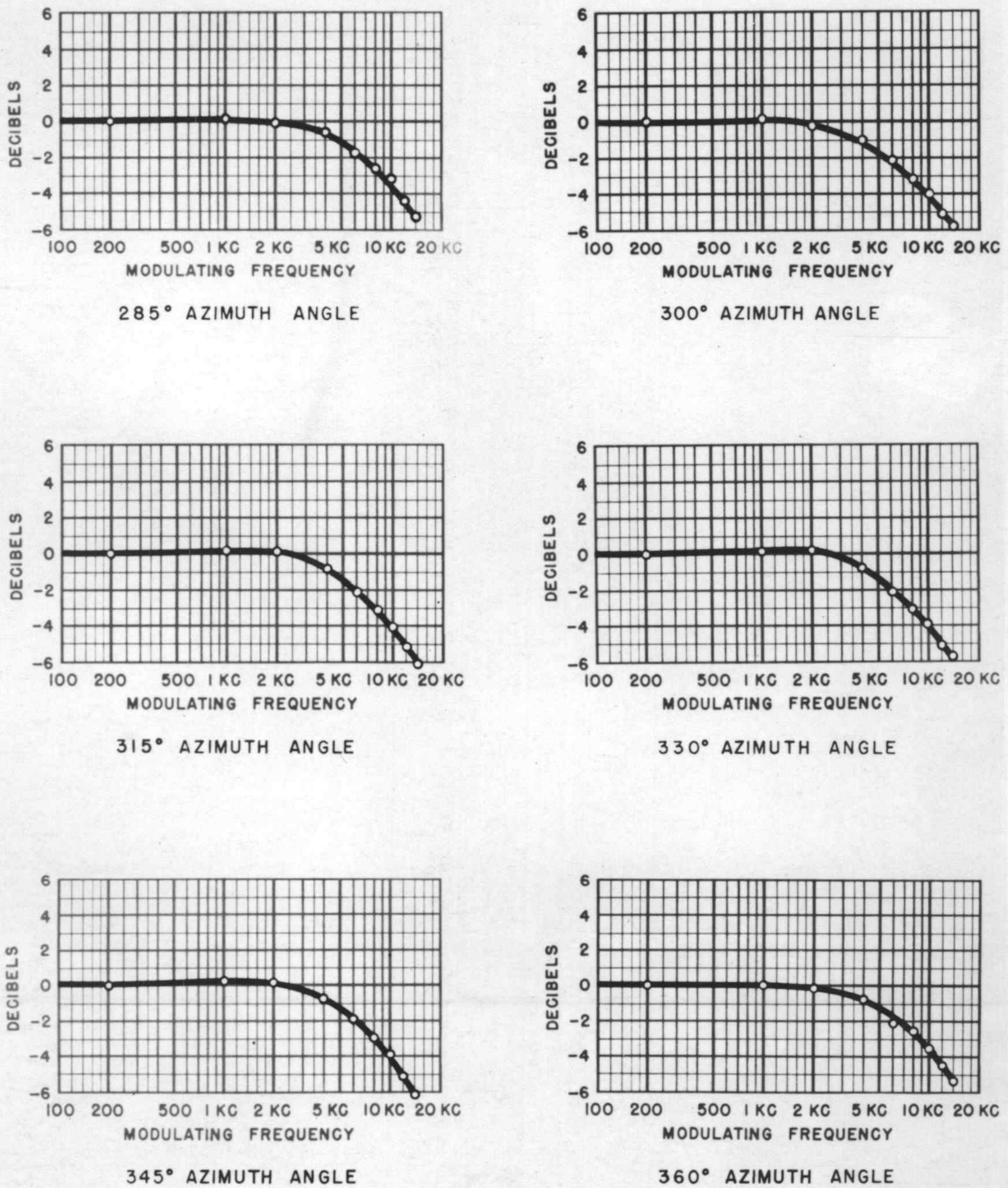
Station A audio frequency response curves at various azimuth angles. The transmitter was modulated 50%.

Figure 14 c



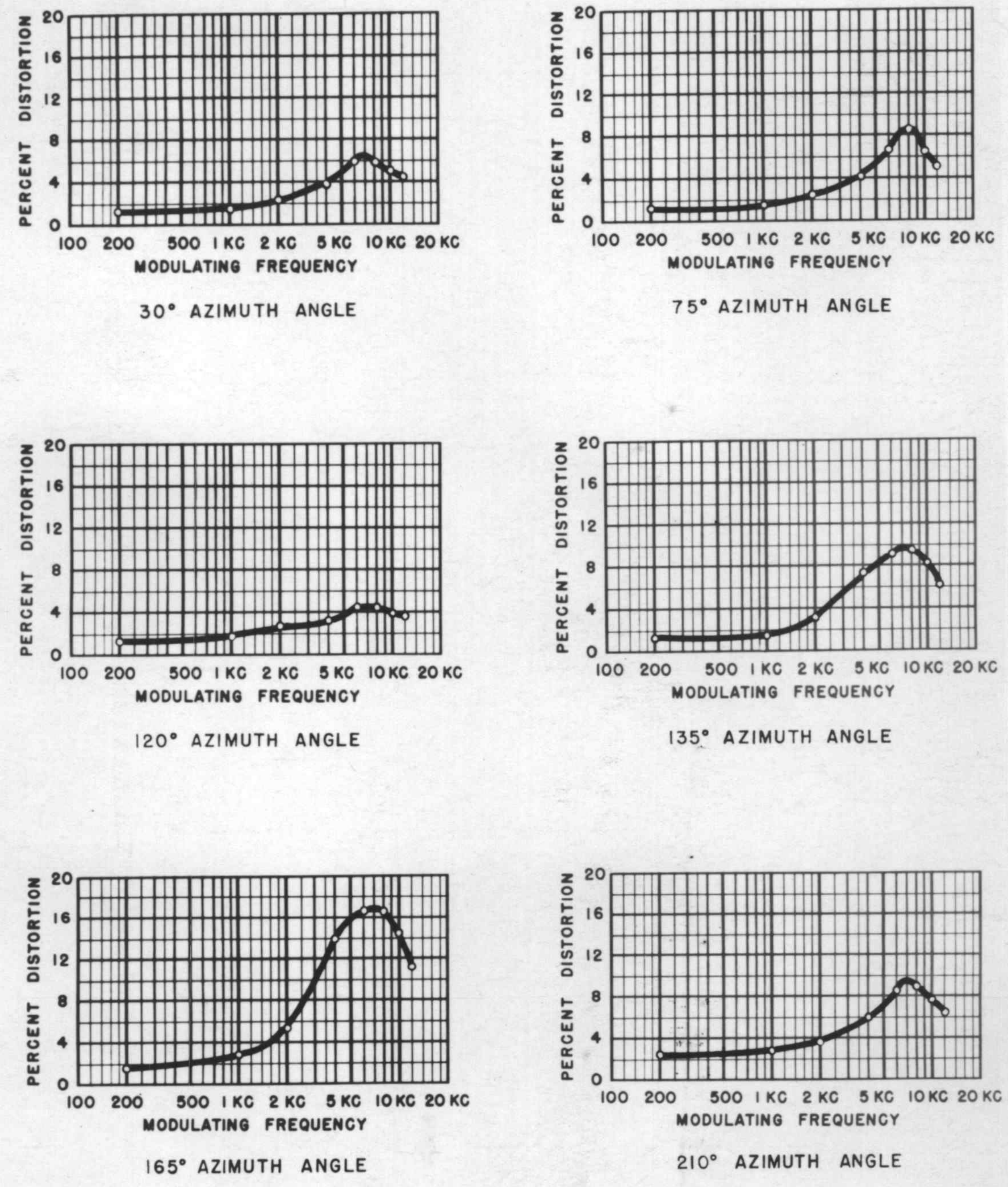
Station A audio frequency response curves at various azimuth angles. The transmitter was modulated 50%.

Figure 14 d



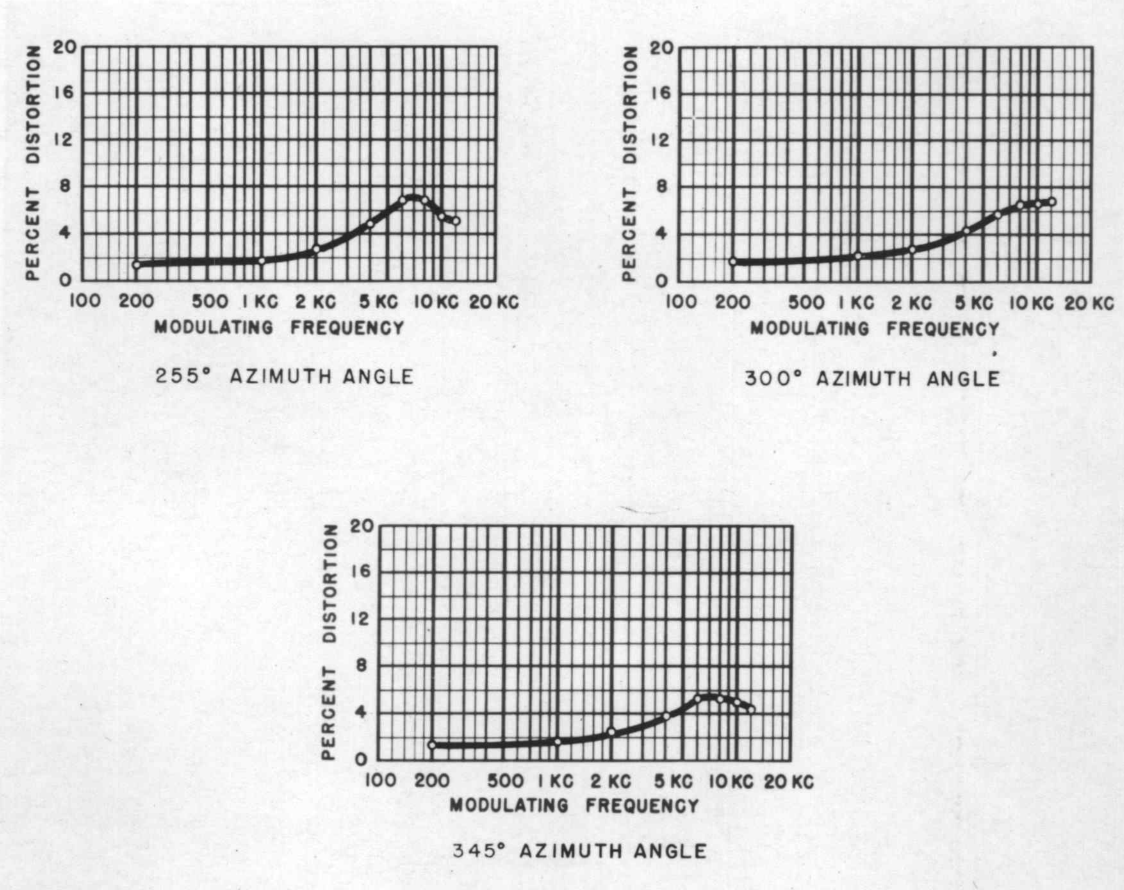
Station A audio frequency response curves at various azimuth angles. The transmitter was modulated 50%.

Figure 15 a



Station A audio distortion at various azimuth angles. The transmitter was modulated 50%.

Figure 15 b



Station A audio distortion at various azimuth angles.
The transmitter was modulated 50%.

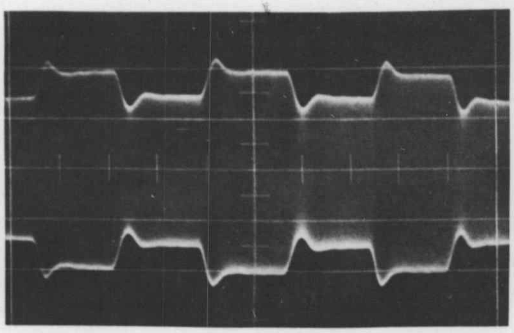
overshoot. This is due to the presence of phase modulation components as well as amplitude modulation components in the null direction signal. This phase modulation condition was explored further with sinusoidal modulation and will be discussed under a later test.

The outstanding fact supported by these data is that the audio output of similar receivers located in directions of different response from a directional a-m station would be dissimilar. One receiver might show increased high frequency audio response while the other has decreased high frequency response; one might sound distorted while the other sounds normal.

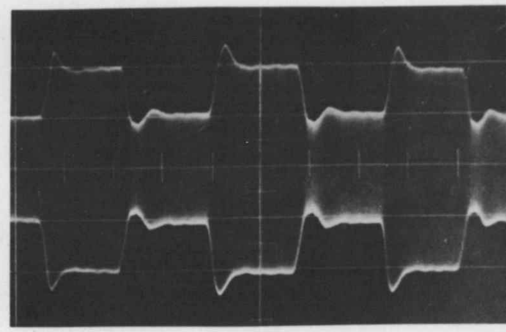
The envelope distortion in the null direction of Station A reaches 14% for 50% modulation of the transmitter at 4 kilocycles. Higher distortion percentages should follow increases in the modulation percentage. High distortion percentages and large audio response changes exist only at high audio frequencies, as would be expected.

A test was made to further show the difference in reception in different directions. A set of square wave photographs was taken at various modulation percentages for a location in the null region and again at a location in the maximum direction. These waveforms appear in Figures 16 a and 16 b. There is a marked difference between the waveforms at these two receiving locations. Severe envelope distortion occurs at high modulation percentages in the null region as would be expected. The square wave response in the maximum

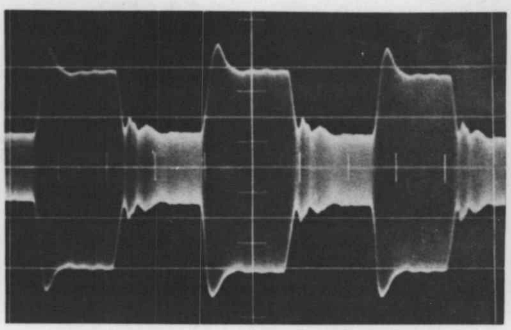
Figure 16 a



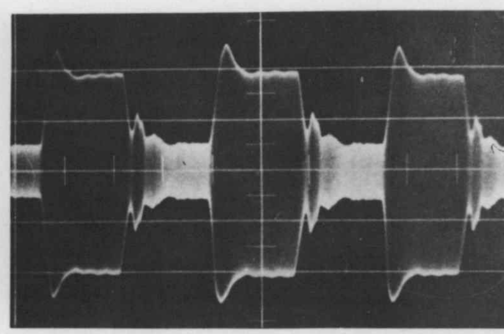
20% MODULATION AT TRANSMITTER



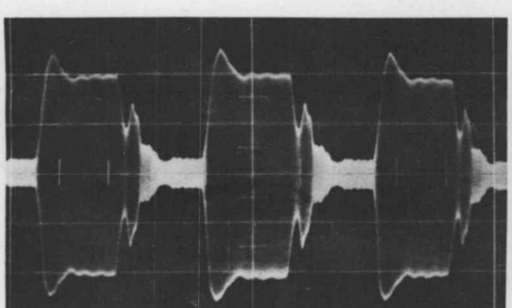
40% MODULATION AT TRANSMITTER



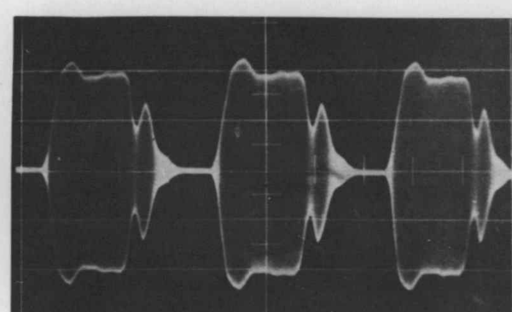
60% MODULATION AT TRANSMITTER



70% MODULATION AT TRANSMITTER



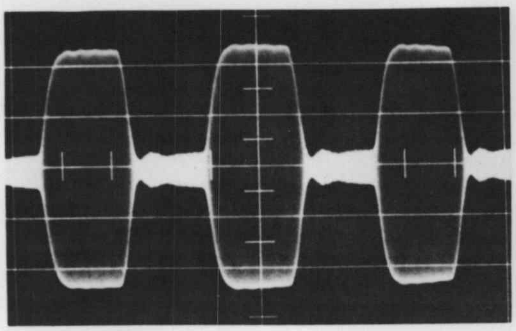
85% MODULATION AT TRANSMITTER



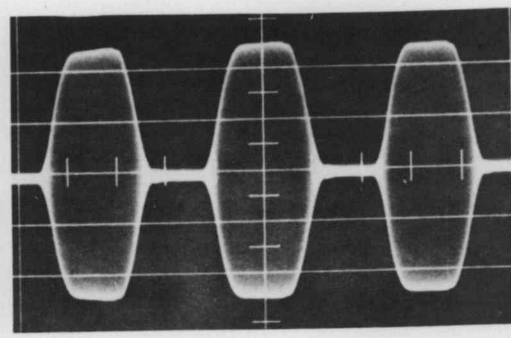
88% MODULATION AT TRANSMITTER

Station A square wave response in the null direction for 2 kilocycle square wave modulation at various modulation percentages.

Figure 16 b



85% MODULATION AT TRANSMITTER



90% MODULATION AT TRANSMITTER

Station A square wave response in the direction opposite the null for 2 kilocycle square wave modulation.

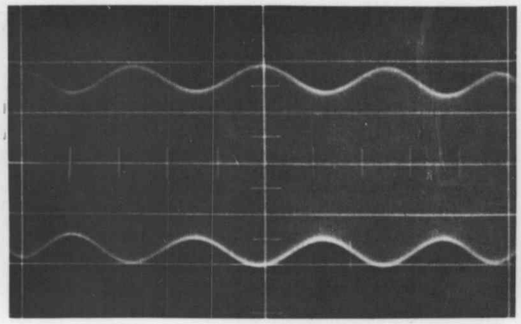
direction is quite excellent, except for slightly slow rise and decay times, which may be attributed to the audio frequency response of the transmitter as well as to the array.

Tests were made in the null direction with sinusoidal modulation and variable modulation percentage to determine the types of envelope distortion present. The resulting modulation envelope photographs are shown in Figures 17 a and 17 b. These waveforms should be compared to the theoretical waveforms of Figures 3, 5 a, 5 b, and 6. From these comparisons it is seen that p-m components as well as a-m components are present in the received signal in the null direction. It is again seen that severe distortion only occurs at high modulation percentages.

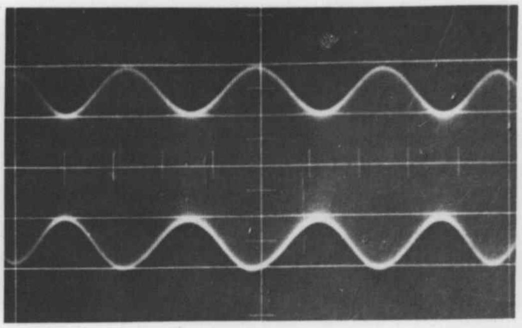
A single waveform was photographed at a test point in the null for 70% modulation at 4 kilocycles because it clearly portrayed another tendency in the distortion waveforms. This waveform, shown in Figure 18, does not appear balanced and symmetrical as do the theoretical waveforms just cited. This is evidently due to audio distortion components produced in the transmitter which add to the fundamental signal components. While the first notch of the double minimum appears to be filled up in the waveform this is not always true. In the waveforms of Figures 17 a and 17 b the second notch in the minimum is filled up more than the first. Both conditions may be found in Figures 19 a and 19 b, which contain other sinusoidal waveforms in the null region.

Figures 19 a and 19 b show the effect of modulating frequency

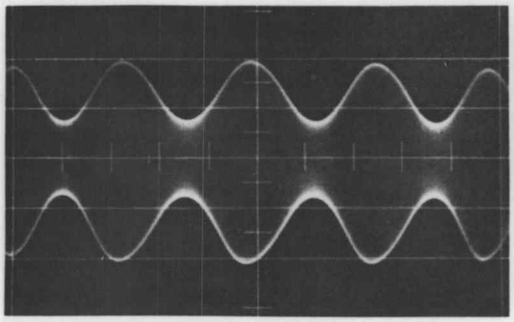
Figure 17 a



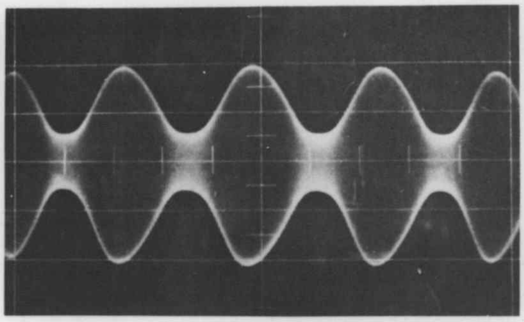
10% MODULATION AT TRANSMITTER



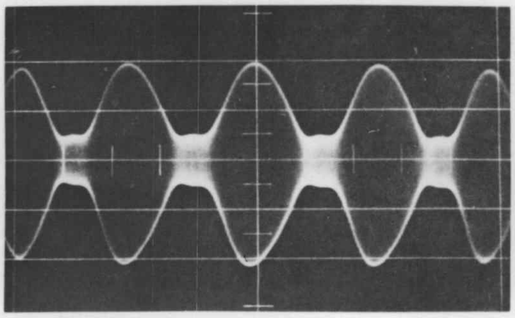
20% MODULATION AT TRANSMITTER



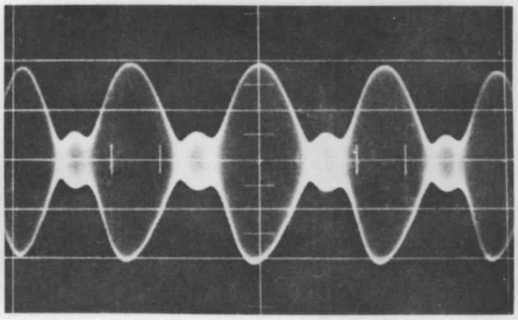
30% MODULATION AT TRANSMITTER



40% MODULATION AT TRANSMITTER



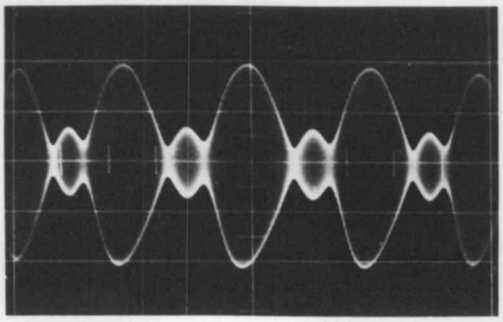
50% MODULATION AT TRANSMITTER



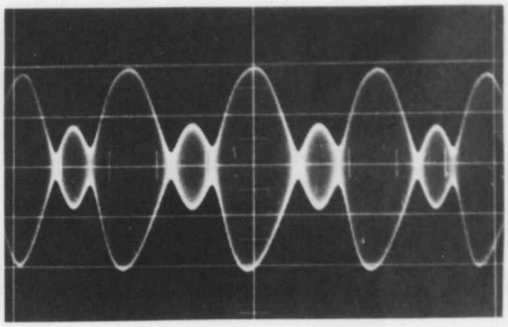
60% MODULATION AT TRANSMITTER

Station A modulation envelope photographs for 10 kilocycle sinusoidal modulation at various modulation percentages. The receiving location azimuth angle was 135°.

Figure 17 b



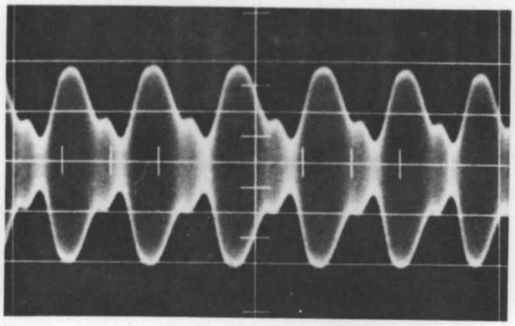
70% MODULATION AT TRANSMITTER



80% MODULATION AT TRANSMITTER

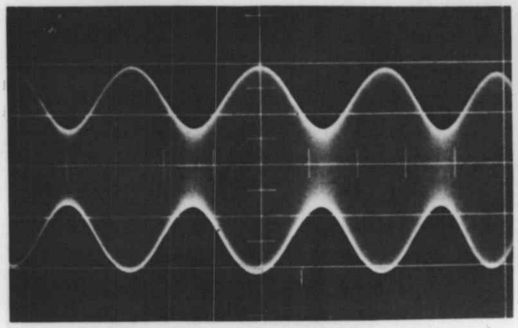
Station A modulation envelope photographs for 10 kilocycle sinusoidal modulation at various modulation percentages. The receiving azimuth angle was 135°.

Figure 18

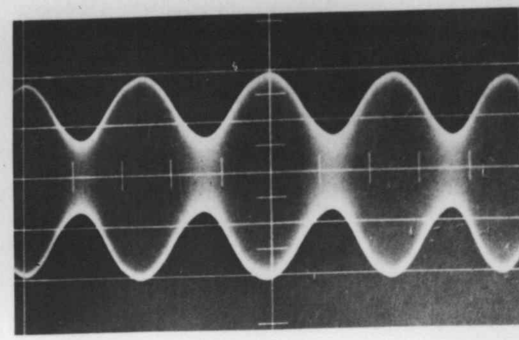


Modulation envelope waveform at Station A for 70% modulation at 4 kilocycles at an azimuth angle of 165°.

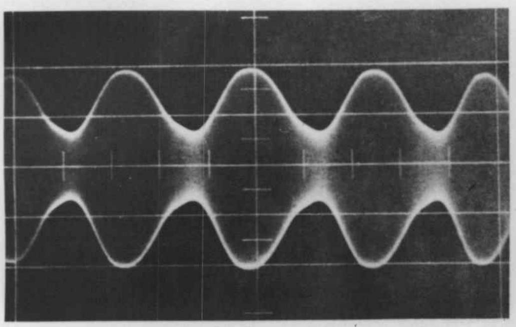
Figure 19 a



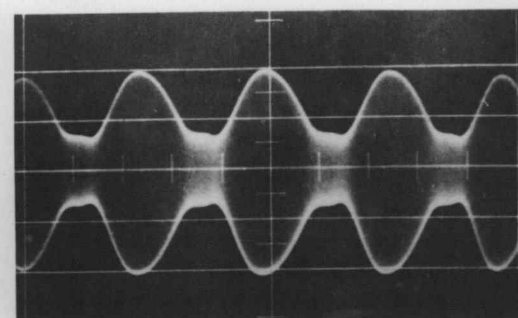
TRANSMITTER 50% MODULATED AT 1 KC



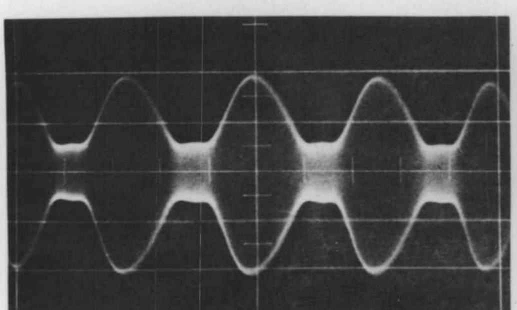
TRANSMITTER 50% MODULATED AT 2 KC



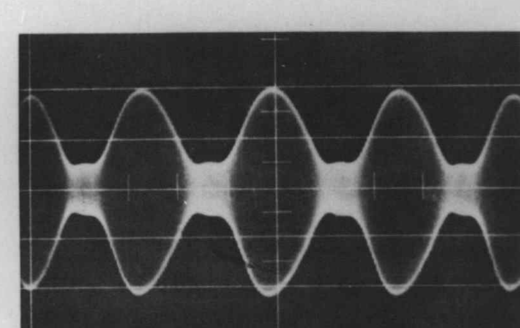
TRANSMITTER 50% MODULATED AT 4 KC



TRANSMITTER 50% MODULATED AT 6 KC



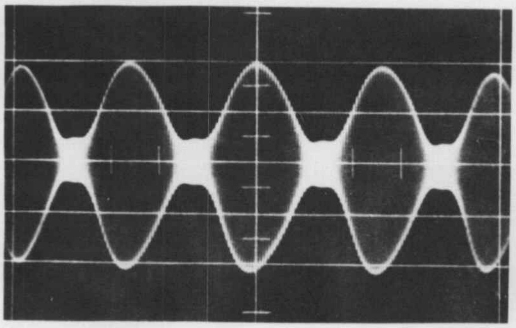
TRANSMITTER 50% MODULATED AT 8 KC



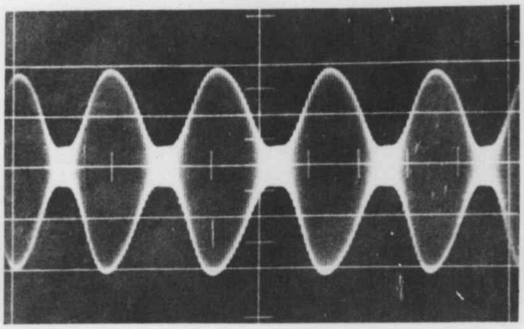
TRANSMITTER 50% MODULATED AT 10 KC

Modulation envelope waveforms for Station A for various modulating frequencies at an azimuth angle of 135°. The transmitter was modulated 50%.

Figure 19 b



TRANSMITTER 50% MODULATED AT 12 KC



TRANSMITTER 50% MODULATED AT 14 KC

Modulation envelope waveforms for Station A for various modulating frequencies at an azimuth angle of 135°. The transmitter was modulated 50%.

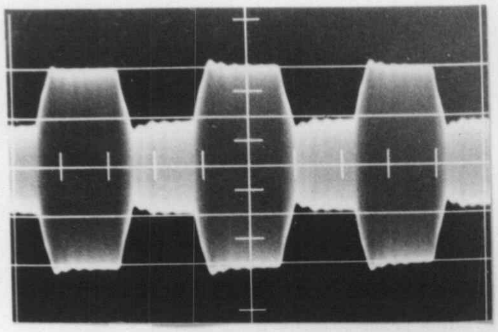
on the received signal waveform with the transmitter 50% modulated. One observation from these photographs is that the apparent modulation percentage increases with frequency, as previously shown. Another important observation is that distortion is not apparent for 1 kilocycle modulation but becomes serious at higher frequencies. Had a larger modulation percentage been held at the transmitter the distortion would have been more severe.

STATION B

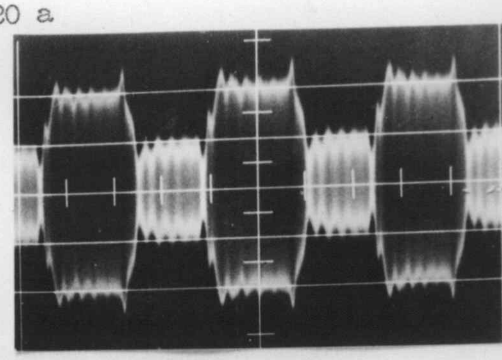
Since the theory of the signal distortion was borne out by the tests of Station A it was not felt necessary to attempt another extensive survey at Station B. Rather, only sufficient data were taken to show definite agreement with the theory and to provide numerical results for fidelity and distortion curves. A serious impairment to the execution of this program was the incapability of the transmitter at Station B to produce high modulation percentages above about 3 kilocycles. It was found, however, that a 2 kilocycle modulating square wave could be used satisfactorily with an indication of 50% modulation on the station modulation monitor. A set of eight square wave photographs, eight audio response curves extending to 8 kilocycles, and five distortion runs were obtained. Three important distortion measurements in the major null region were discarded due to noise.

The array of Station B operated with a major null at about 35° on the azimuth scale and with a minor null at about 115°. This is important for analysis of the square wave photographs of Figures 20 a and 20 b. The photograph at 90° was taken for a 1

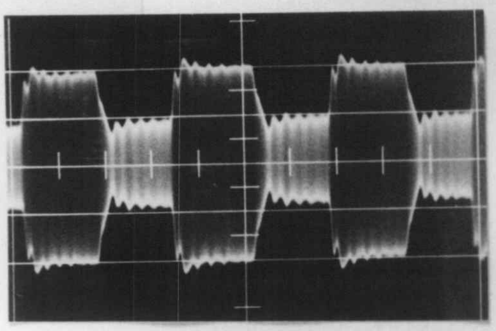
Figure 20 a



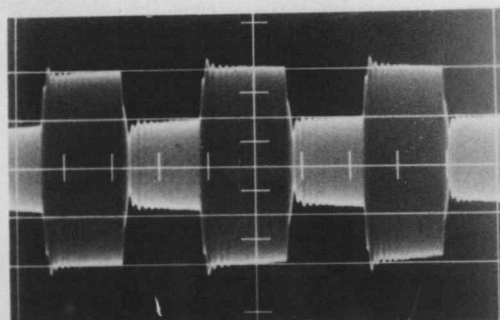
25° AZIMUTH ANGLE



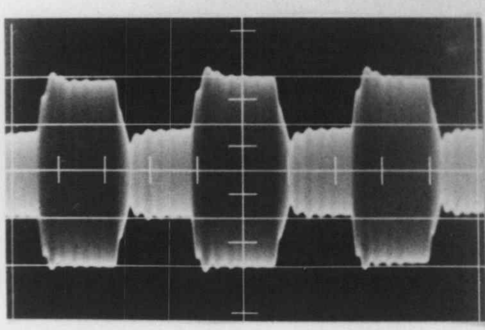
35° AZIMUTH ANGLE



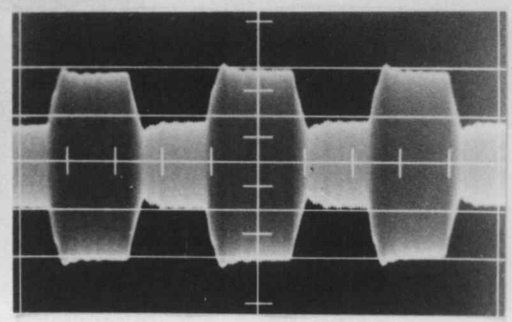
48° AZIMUTH ANGLE



90° AZIMUTH ANGLE



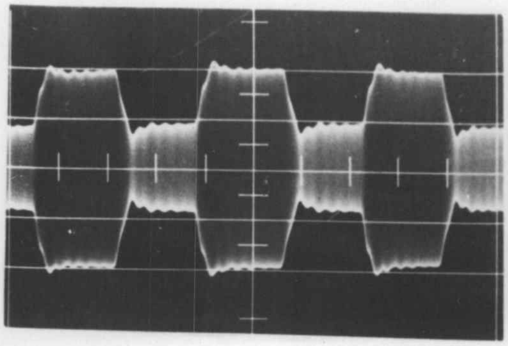
125° AZIMUTH ANGLE



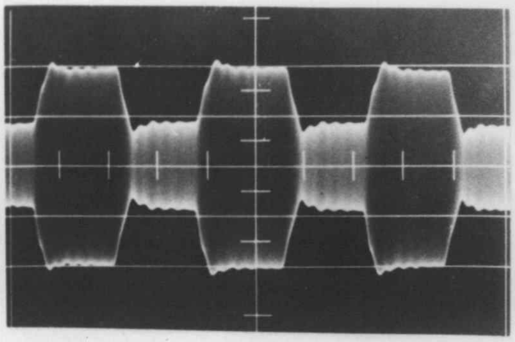
167° AZIMUTH ANGLE

Station B square wave modulation envelope photographs for various azimuth angles. The transmitter was modulated 50% with a 2 kilocycle square wave except at an azimuth angle of 90° where the modulating frequency was 1 kilocycle.

Figure 20 b



270° AZIMUTH ANGLE



327° AZIMUTH ANGLE

Station B square wave modulation envelope photographs for various azimuth angles. The transmitter was modulated 50% with a 2 kilocycle sine wave.

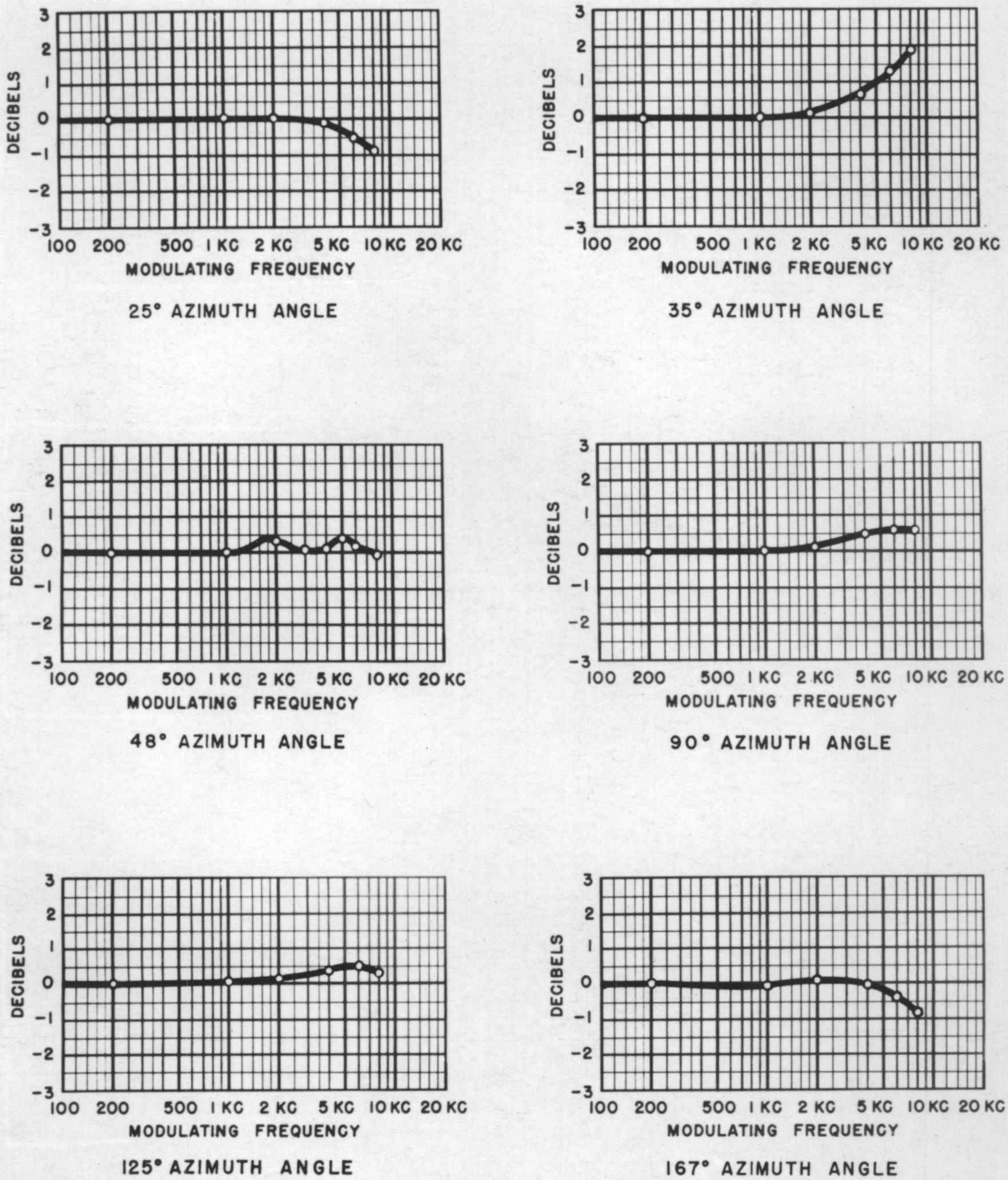
kilocycle modulating square wave by accident instead of a 2 kilocycle square wave. The oscillation appearing on the edges of the waveforms was produced by the transmitter. It was evidently due to an audio tuned circuit resonating at about 26 kilocycles. The amplitude of this audio oscillation changes widely with the azimuth angle indicating a change in the fidelity of the array at 26 kilocycles. Very little fidelity change is shown by the transient portions of the waveforms of Figures 20 a and 20 b, except in the major null region. Here both the leading and trailing edges are peaked, indicating an increase in high frequency components.

Audio frequency response curves for Station B appear in Figures 21 a and 21 b. For 6 kilocycle modulation a spread of 1.7 decibels occurs between the most widely different frequency response curves. For 8 kilocycle modulation the spread is 2.7 decibels.

Very little can be determined from the distortion data of Figure 22 except that the distortion is negligibly small at all times. It is questionable that any conclusions based on these data would be sound, as the numbers are all small and quite subject to errors due to noise. Distortion could not be measured in the major null region due to noise. The noise can be seen in the square wave photographs of Figure 20. The noise level in the null region was high in spite of a tuned circuit used in the mobile amplifier to reduce the bandwidth of the system. No roads were available closer than $1\frac{1}{2}$ miles from the array in the null direction.

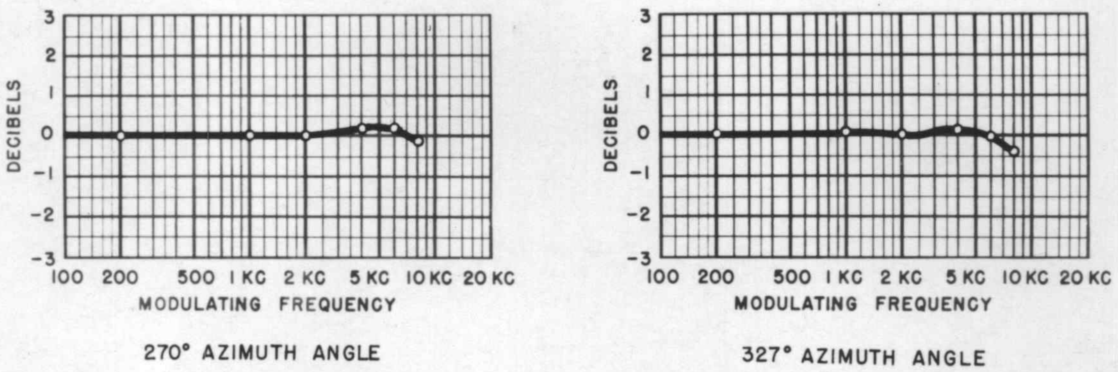
The experimental data for Station B are tabulated in Appendix V.

Figure 21 a



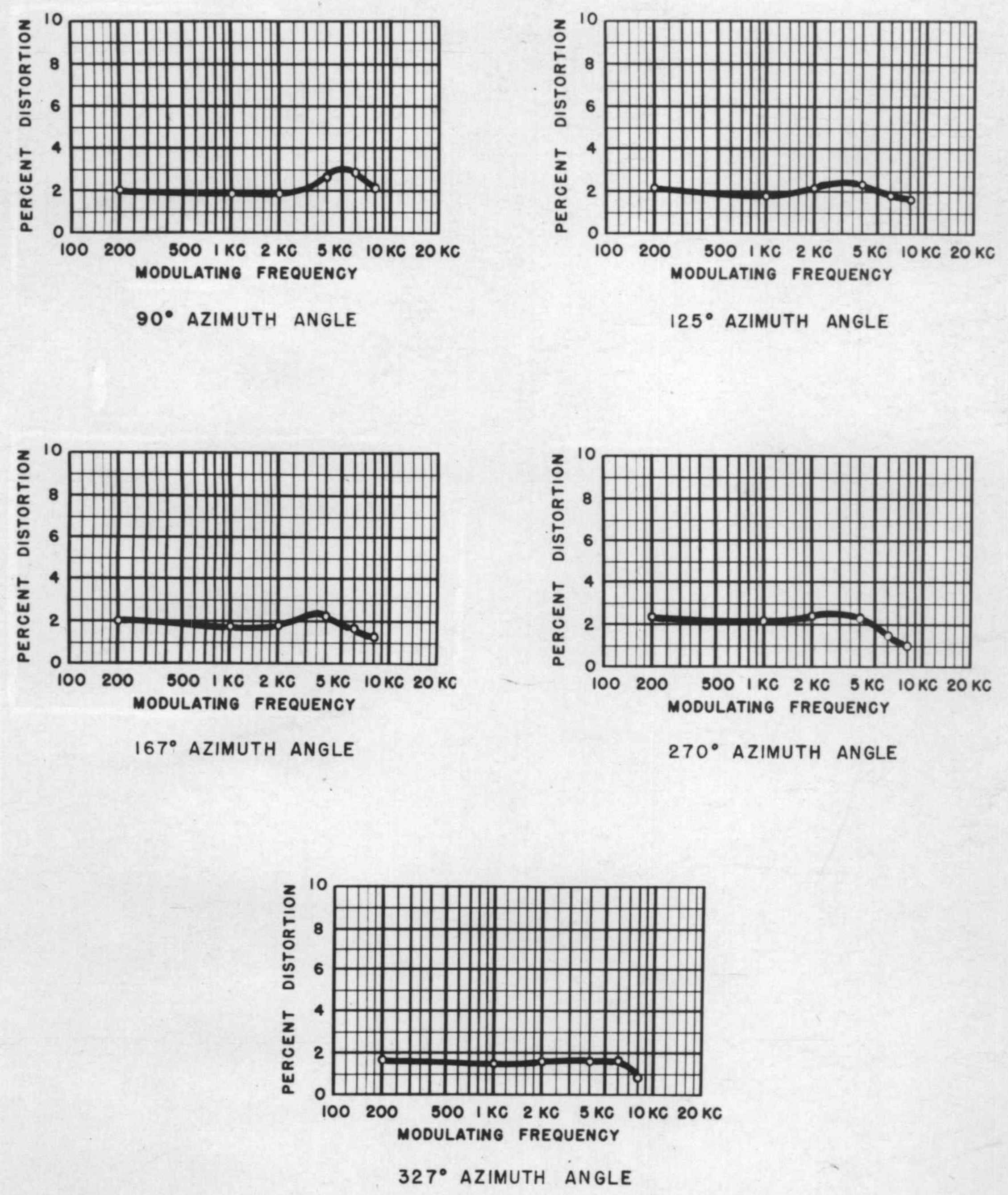
Station B audio frequency response curves at various azimuth angles. The transmitter was modulated 50%.

Figure 21 b



Station B audio frequency response curves at various azimuth angles. The transmitter was modulated 50%.

Figure 22



Station B audio distortion at various azimuth angles. The transmitter was modulated 50%.

DISCUSSION OF RESULTS

The antenna tests at Station A showed excellent agreement with the theoretical signal distortion behavior of a directional broadcast array. The maximum spread in audio frequency response for this station was 4.6 decibels for 6 kilocycle modulation and 8.55 decibels for 10 kilocycle modulation. The most bothersome distortion condition measured was 14% distortion for 50% modulation at 4 kilocycles which occurred in the null region. The distortion was much more severe in the null direction than in any other direction. The transient response conditions were analogous to a simple high-pass R-C network producing increased amplitude and accompanying phase shift in the high-frequency audio components of the square wave. Severe transient response distortion was observed in the null region at high modulation percentages.

At first, the results of the tests at Station B do not appear to be as outstanding as at Station A. A spread of only 2.7 decibels for 8 kilocycle modulation was found between the most widely different frequency response conditions at Station B, while a spread of 4.6 decibels occurred for 8 kilocycle modulation at Station A. The transient response photographs indicated much less distortion at Station B than at Station A.

On closer inspection, however, it is found that there is an important difference between the antennas. Station A is a low frequency broadcast station while Station B is a rather high frequency station. The ratio of their frequencies is more than 2 to 1. The bandwidth of the antenna of Station B, expressed as a percentage of the carrier frequency, need not be nearly as great as the percentage bandwidth of the antenna system of Station A for like distortion behaviors. If the two antennas had like bandwidths, the distortion at a given audio frequency should be much more severe at Station A than at Station B.

The most acute bandwidth problems in broadcast antennas occur at the lowest frequency in the band. For this reason it would be most fitting to study only directional stations operating at low frequencies. Since this was not possible in the case of Station B it was necessary to correct the results to a lower frequency for analysis. When the modulating frequencies of Station B are divided by the ratio of the frequency of Station B to Station A, a modulating frequency of 2 kilocycles at Station B is comparable to less than 1 kilocycle at Station A. The tests of Station B extended to a modulating frequency of only 8 kilocycles, which becomes somewhat less than 4 kilocycles when corrected to the lower carrier frequency. This accounts for the relatively low envelope distortion measured at Station B. Actually, when the audio frequency response changes of Station B are converted to the frequency of Station A a greater response spread is observed for Station B than for Station A.

It is interesting that the audio quality of the transmitter of a directional broadcast station should not be measured for the purposes of showing compliance with F.C.C. regulations by a single measurement of the antenna output. The quality so determined may bear little resemblance to the quality of the signal at the antenna input.

FUTURE INVESTIGATIONS

The scope of this paper has been limited to a preliminary survey of the nature and magnitude of the signal distortion produced in directional broadcast antennas. This study suggests a number of other projects in related problems. Some of these projects are listed below:

1. A study of antenna distortion at lower and higher frequencies when bandwidth problems are encountered in directional arrays.

2. A study of engineering methods to reduce the distortion.

3. A study of the effect of local distortion sources on receiving conditions.

4. Theoretical analysis of a directional broadcast antenna to arrive at the received waveforms analytically.

5. A study of the effects of tuning methods, antenna height, number of elements, phasing equipment, type of directive pattern, etc., on the distortion.

6. A study of the effects of the distortion in narrow band f-m transmissions at low frequencies.

7. A study of signal distortion due to antennas employed in high frequency, wide band f-m.

8. A study of selective fading by use of square wave techniques.

CONCLUSIONS

1. Signal distortion is found to exist in directional broadcast antenna systems. The distortion is most severe at high audio modulating frequencies and at high modulation percentages.

2. The signal distortion results from changes in the magnitudes and phases of the transmitted signal components. These changes produce distortion in the modulation envelope which result in audio distortion at the receiver.

3. Changes in frequency distortion are found at various azimuth angles.

4. The attenuation and phase shifts of the signal components are directly related to bandwidth. The signal distortion is therefore most severe at low frequencies.

BIBLIOGRAPHY

1. Terman, Frederick Emmons. Radio engineering. Third edition. New York, McGraw Hill, 1947. 969 p.

APPENDICES

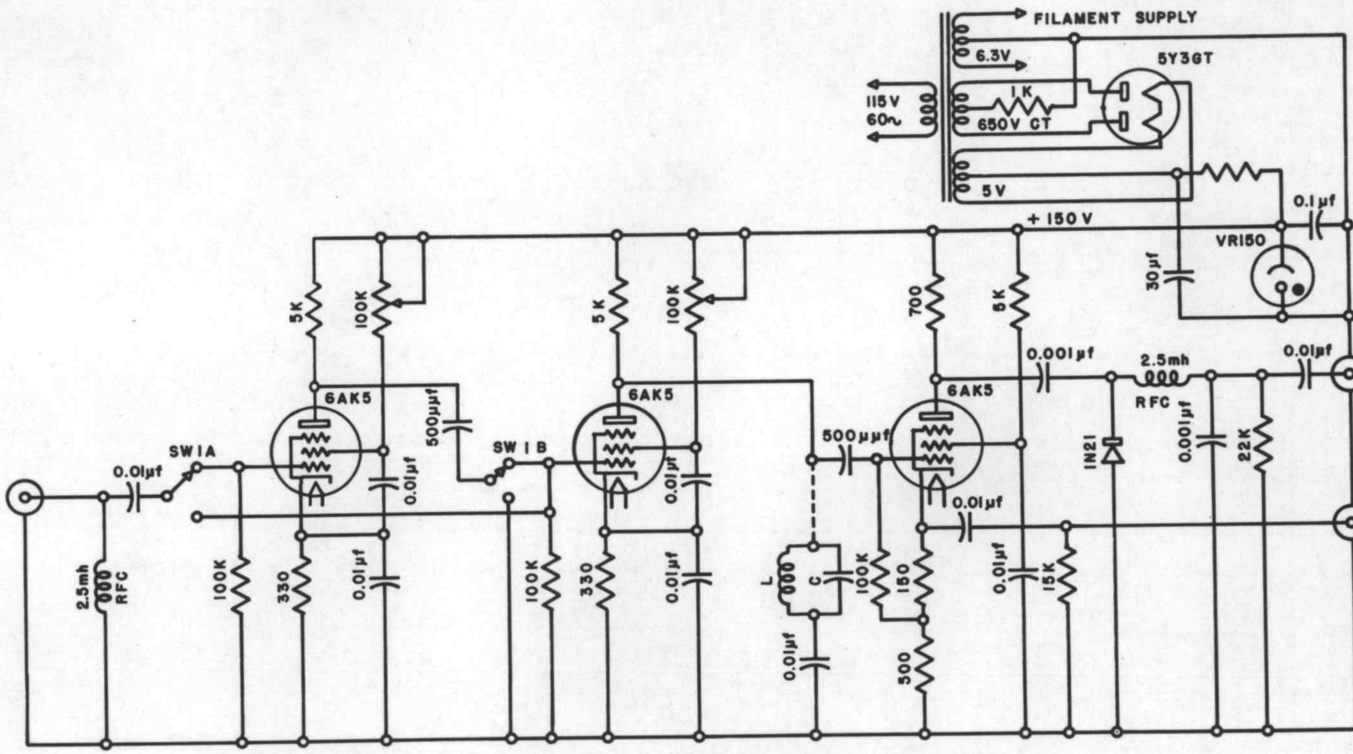
APPENDIX I

MOBILE PREAMPLIFIER

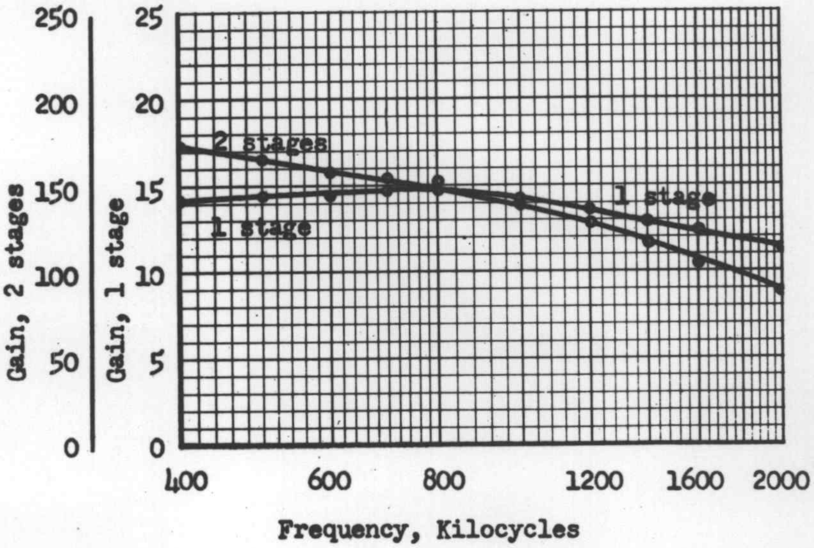
The mobile preamplifier provided gains of approximately 15 or 150 from the input to the output terminals. A frequency response curve for each gain setting is given below. The maximum open circuit signal output amplitude without appreciable distortion was 10 volts peak to peak. A portion of the amplifier signal was detected to provide an audio signal for triggering the Tektronix oscilloscope sweep. The detector for this purpose was a type 1N21 crystal diode. The diode was connected in the plate circuit of the cathode follower as shown in the circuit diagram. The power supply was designed for operation from a 115 volt 60 cycle supply.

It was necessary to install a 52 ohm terminating resistor at the input connector of the mobile amplifier when the coaxial cable from the portable unit was connected. This resistor terminated the cable and prevented reflections. At Station B a tuned circuit was installed in the amplifier to pass the desired frequency band and attenuate noise and interference outside this band. This tuned circuit is shown connected with a dotted line in the circuit diagram. The bandwidth of the tuned circuit was approximately 300 kilocycles.

The signal calibrate circuit of the Tektronix oscilloscope was used to measure the output level of the mobile amplifier and prevent overloading.



Circuit diagram for the mobile amplifier.



MOBILE AMPLIFIER FREQUENCY RESPONSE
Tektronix oscilloscope connected to output

MOBILE AMPLIFIER FREQUENCY RESPONSE

Tektronix oscilloscope connected to output.

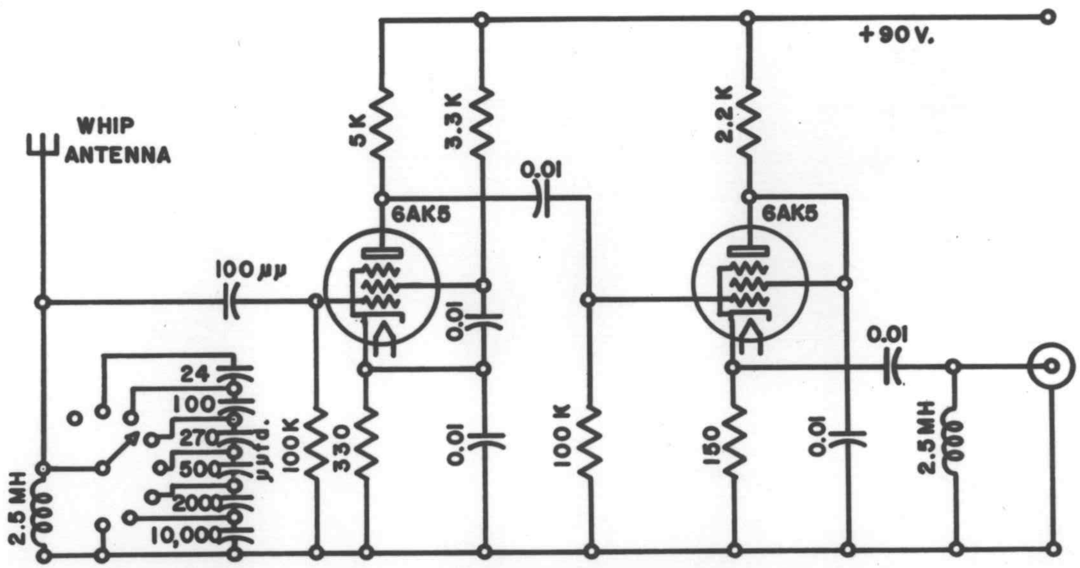
Frequency (kilocycles)	Amplification 1 stage	2 stages
100	10.1	95.5
200	13.3	153.7
300	14.1	172.5
400	14.1	172.5
500	14.4	164.5
600	14.4	157.0
700	14.7	153.6
800	14.7	150.5
1000	14.1	138.7
1200	13.6	128.5
1400	12.9	115.9
1600	12.4	103.9
2000	11.4	87.3

APPENDIX II

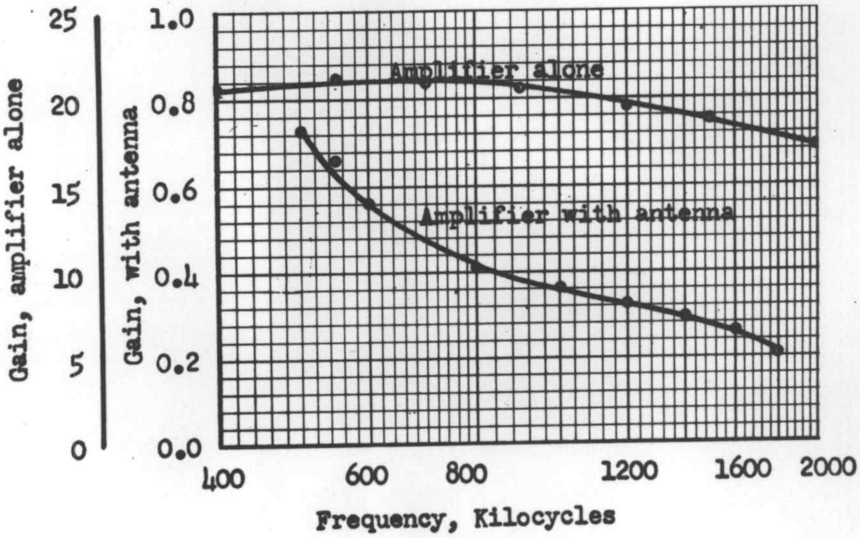
BATTERY POWERED PORTABLE AMPLIFIER

The portable amplifier served as a combined amplifier and impedance matching unit to supply power to the low impedance coaxial cable feeding to the truck. The amplifier consisted of a single broad-band amplifier stage and a cathode follower. Power for the tube heaters was supplied by two Burgess type 2F4 or Eveready #718 heavy duty 6 volt batteries. Plate power was furnished by three Burgess M30 or Eveready #482 portable 45 volt B batteries connected in series. The batteries are not included in the circuit diagram.

The receiving antenna was mounted to the side of the battery amplifier case. The antenna resonated with the input radio frequency choke between 345 kilocycles and 83 kilocycles depending on the gain setting. The frequency response curves of the amplifier alone and of the amplifier and antenna are shown below. In the latter case the antenna was extended to full length and driven by a radio frequency oscillator through a capacity smaller than 1 micro-micro-farad. The gain control was set to maximum gain for this test and the antenna was resonant at about 345 kilocycles.



Circuit diagram for the battery powered preamplifier.



BATTERY POWERED PREAMPLIFIER FREQUENCY RESPONSE
Response with antenna is for 1 micro-micro-farad coupling capacitor from antenna to the signal generator. Maximum gain setting, output terminated in 52 ohms resistance.

BATTERY POWERED PREAMPLIFIER FREQUENCY RESPONSE
Response with antenna is for 1 micro-micro-farad coupling capacitor from antenna to the signal generator. Output terminated in 52 ohms resistance.

Frequency	Amplification	
(Kilocycles)	Amplifier alone	Amplifier with antenna
100	15.95	
200	18.6	
300	20.29	
400	20.6	
500		0.73
550	21.15	0.66
600		0.56
700	20.95	
800		0.415
900	20.6	
1000		0.362
1200	19.5	0.325
1400		0.291
1500	18.9	
1600		0.262
1800		0.205
2000	17.1	

APPENDIX III

CORRECTION OF NOISE AND DISTORTION METER

The Hewlett Packard type 330 B Noise and Distortion Meter contains a tuned circuit in the radio frequency detector circuit. At the lowest broadcast frequencies it is necessary to correct the audio frequency response data for the attenuation of this circuit. An accurately measured modulated signal was fed into the entire test unit to calibrate for this error. The resulting correction data are tabulated below. This correction is valid only for the carrier frequency of Station A. The correction changes with the carrier frequency. The data for Station B were not corrected because the correction amounted to less than 2% at the highest modulating frequency.

CORRECTION DATA FOR STATION A

Frequency	Correction, db.
200	0
1 kc.	+0.10
2 kc.	+0.20
4 kc.	+0.30
6 kc.	+0.45
8 kc.	+0.65
10 kc.	+1.05
12 kc.	+1.30
14 kc.	+1.65

APPENDIX IV

STATION A CORRECTED AUDIO FREQUENCY RESPONSE DATA FOR VARIOUS AZIMUTH ANGLES AT RANDOM DISTANCES FROM THE ANTENNA SYSTEM. TRANSMITTER 50% MODULATED, FREQUENCY RESPONSE MEASURED WITH HEWLETT PACKARD MODEL 330-B NOISE AND DISTORTION METER

(See Appendix III for corrections).

Freq.	200	1 kc	2 kc	4 kc	6 kc	8 kc	10 kc	12 kc	14 kc
Azimuth (Degrees)	Response in decibels at above frequencies:								
15	0	0	0	-0.45	-1.55	-2.35	-2.95	-3.80	-4.55
30	0	+0.05	0	-0.55	-1.55	-2.25	-2.65	-3.30	-4.05
45	0	+0.05	+0.10	-0.35	-1.45	-1.95	-2.15	-2.75	-3.35
60	0	+0.15	0	-0.35	-1.05	-1.35	-1.75	-2.40	-2.95
75	0	+0.1	+0.10	-0.25	-0.85	-0.85	-1.05	-1.70	-2.25
90	0	+0.15	+0.30	+0.05	+0.05	+0.25	+0.55	0	-0.45
105	0	+0.15	+0.25	+0.45	+0.65	+1.05	+1.35	+1.00	+0.75
120	0	+0.10	+0.40	+1.25	+2.15	+2.85	+3.25	+3.00	+2.65
135	0	+0.10	+0.50	+1.25	+2.45	+3.75	+4.55	+4.80	+4.75
150	0	+0.10	+0.40	+0.95	+2.35	+3.65	+4.55	+5.00	+5.05
165	0	+0.10	+0.50	+1.05	+2.45	+3.85	+4.65	+4.90	+5.05
180	0	+0.20	+0.50	+1.25	+2.45	+3.65	+4.35	+4.40	+4.35
195	0	+0.10	+0.25	+0.55	+1.05	+1.55	+2.05	+1.90	+1.75
210	0	+0.10	-0.10	-0.45	-0.60	-0.35	+0.25	+0.10	+0.05
225	0	+0.10	+0.10	-0.15	-0.55	-0.60	-0.65	-1.10	-1.55
240	0	+0.10	+0.10	-0.25	-0.85	-0.95	-1.15	-1.70	-2.05
255	0	+0.10	+0.10	-0.45	-1.05	-1.35	-1.65	-2.40	-2.95
270	0	+0.05	0	-0.65	-1.45	-1.95	-2.35	-3.20	-3.95
285	0	+0.10	-0.10	-0.65	-1.85	-2.55	-3.25	-4.40	-5.25

Freq.	200	1 kc	2 kc	4.kc	6 kc	8 kc	10 kc	12 kc	14 kc
Azimuth (Degrees)	Response in decibels at above frequencies:								
300	0	+0.10	-0.20	-1.00	-2.15	-3.15	-4.00	-5.10	-5.85
315	0	+0.10	+0.10	-0.85	-2.05	-3.15	-4.05	-5.20	-6.15
330	0	0	-0.10	-0.75	-2.05	-3.05	-3.95	-5.10	-5.75
345	0	+0.20	+0.10	-0.75	-1.95	-2.95	-3.95	-5.10	-6.15
360	0	0	-0.10	-0.80	-2.05	-2.55	-3.55	-4.50	-5.35

APPENDIX IV (Cont'd)

STATION A CORRECTED AUDIO FREQUENCY RESPONSE DATA FOR VARIOUS DISTANCES FROM THE ANTENNA SYSTEM AT AN AZIMUTH ANGLE OF 240 DEGREES
(See Appendix III for corrections)

Freq.	200	1 kc	2 kc	4 kc	6 kc	8 kc	10 kc	12 kc	14 kc
Distance (Miles)	Response in decibels at above frequencies:								
0.8	0	+0.10	+0.10	-0.25	-0.85	-0.95	-1.15	-1.70	-2.05
3.7	0	+0.05	+0.10	-0.45	-1.05	-1.25	-1.35	-1.70	-2.35
4.5	0	+0.05	0	-0.45	-0.95	-1.15	-1.25	-1.70	-2.15
5.8	0	+0.10	0	-0.25	-0.55	-0.65	-0.85	-1.30	-1.65

APPENDIX IV (Cont'd)

STATION A AUDIO FREQUENCY DISTORTION FOR VARIOUS AZIMUTH ANGLES AT RANDOM DISTANCES FROM THE ANTENNA SYSTEM. 50% MODULATION AT TRANSMITTER, DISTORTION MEASURED WITH HEWLETT PACKARD MODEL 330-B NOISE AND DISTORTION METER.

Freq.	200	1 kc	2 kc	4 kc	6 kc	8 kc	10 kc	12 kc
Azimuth (Degrees)	Distortion in percent at above frequencies:							
30	1.3	1.5	2.3	3.8	6.0	5.9	5.0	4.3
75	1.4	1.6	2.4	4.1	6.6	6.3	5.2	4.6
120	1.4	1.8	2.6	3.2	4.4	4.4	3.9	3.7
135	1.2	1.5	3.2	7.2	9.1	9.5	8.1	6.1
165	1.6	2.8	5.4	14.0	16.5	16.5	14.0	11.2
210	2.5	2.8	3.7	6.0	8.5	8.8	7.5	6.4
255	1.6	1.8	2.7	4.7	6.8	6.8	5.6	5.2
300	1.8	2.2	2.7	4.2	5.8	5.5	5.5	5.8
345	1.4	1.7	2.5	3.9	5.3	5.2	4.9	4.3

APPENDIX V

STATION B AUDIO FREQUENCY RESPONSE DATA FOR VARIOUS AZIMUTH ANGLES AT RANDOM DISTANCES FROM THE ANTENNA SYSTEM. TRANSMITTER 50% MODULATED, FREQUENCY RESPONSE MEASURED WITH HEWLETT PACKARD MODEL 330-B NOISE AND DISTORTION METER (No corrections necessary).

Freq.	200	1 kc	2 kc	3 kc	4 kc	5 kc	6 kc	8 kc
Azimuth (Degrees)	Response in decibels at above frequencies:							
25	0	0	0		-0.10		-0.50	-0.90
35	0	0	+0.10		+0.70		+1.30	+1.90
48	0	0	+0.30	+0.05	+0.10	+0.40	+0.20	-0.05
90	0	0	+0.10		+0.40		+0.60	+0.60
125	0	+0.05	+0.10		+0.40		+0.50	+0.30
167	0	-0.05	+0.05		-0.05		-0.40	-0.80
270	0	0	0		+0.20		+0.20	-0.10
327	0	+0.05	0		+0.10		-0.05	-0.40

APPENDIX V (Cont'd)

STATION B AUDIO FREQUENCY DISTORTION FOR VARIOUS AZIMUTH ANGLES AT RANDOM DISTANCES FROM THE ANTENNA SYSTEM

Freq.	200	1 kc	2 kc	4 kc	6 kc	8 kc
Azimuth (Degrees)	Distortion in percent at the above frequencies:					
90	2.0	1.9	1.9	2.7	2.9	2.1
125	2.1	1.8	2.1	2.3	1.8	1.7
167	2.0	1.7	1.8	2.2	1.7	1.3
270	2.3	2.2	2.3	2.3	1.5	1.0
327	1.7	1.5	1.6	1.6	1.7	0.8