A STUDY INTO THE EFFECTS OF VERTICALLY POLARIZED RADIATION IN FM BROADCASTING

JAMPRO
ANTENNA COMPANY
6939 POWER INN RD.
SACRAMENTO, CALIFORNIA 95828

A STUDY INTO THE EFFECTS OF VERTICALLY POLARIZED RADIATION IN FM BROADCASTING

By Peter Onnigian, Jampro Antenna Company

GENERAL

Dual polarization of FM transmitting antennas in the United States has been permitted by the FCC since 1946. Until recently it found only limited application; perhaps due to lack of technical knowledge about its usefulness. Dual polarized radiation requires more transmitter power for a given amount of horizontally polarized radiation. The horizontally polarized radiation, or effective radiated power (ERP), is the value which the FCC licenses FM stations to use. The vertically polarized ERP must not exceed the horizontally polarized value under present FCC rules.

All AM broadcasting transmissions in this country are vertically polarized. Television radiation in this country is required to be horizontally polarized. In England TV broadcasting is vertically polarized. The FCC, in 1946, saw certain advantages to be gained by FM broadcasters using both horizontally and vertically polarized signal components, and authorized its use at that time. It is hoped that this paper will shed some light on this subject of FM antenna polarization by setting forth certain numbers indicating various parameters which may be useful. We present herewith certain facts indicating that additional radiation in the form of vertically polarized power will give the FM broadcaster better penetration into his service area.

This entire subject matter is a rather complex one. It can be explained very well mathematically. However, this paper will concern itself only as to what happens with and without vertically polarized radiation instead of the "why's" and "wherefor's". Some references will be made as to how certain conditions come about. Mathematics will be omitted for simplification.

In the interests of keeping repetition of words in describing various polarizations to a minimum, we will refer to vertical polarization and horizontal polarization, as vertical and horizontal. It should be kept in mind that this does not refer to horizontal patterns and vertical patterns, but to the plane of polarization. This liberty is taken in order to avoid repetition of the word "polarized" or "polarization" throughout the text.

FORWARD

The FCC authorized FM broadcasters in November of 1946 to use vertically polarized radiation in addition to horizontally polarized radiation. It was conditional, in that the vertical components must never exceed the horizontal. It further provided that radiation be circular or elliptically polarized. These terms will be explained later.

Some early FM broadcasters did, in fact, install circularly polarized transmitting antennas, but these were complicated and costly.[1] Some time in the early 1960's broadcasters learned that the Commission would, in fact, authorize linear horizontally and vertically polarized radiation as contrasted to circular or elliptical. This type of polarization is much easier to secure with relatively simple antennas.

POLARIZATION

An electromagnetic wave has four important characteristics. These are frequency, intensity, direction of travel, and direction of voltage action. This last characteristic is more correctly described as polarization. Polarization is referenced to the earth as the reference plane.

The electromagnetic wave is electric energy traveling in space. This is the so-called RF radiation. It has direction and velocity. The velocity is fixed at 186,000 miles per second. The direction can be controlled with various types of antennas. The electromagnetic wave has two components, the electric component of the field and the magnetic component of the field. The electric field is identified as the "E" or voltage field. The magnetic field is assigned the letter "H" for current. The two components are interlocked, having a fixed ratio so that in free space the ratio of voltage to the current always equals 377 ohms.

LINEAR POLARIZATION

When the polarization of an antenna is indicated, the relationship of the "E" plane, which is the voltage field, is referenced to the earth. Thus, a dipole whose "E" plane is parallel to the ground, is said to be horizontally polarized. If this same dipole were physically rotated 90 degrees, so that the "E" plane was right angles to the earth, the radiation would be vertically polarized. Now, if the dipole were 45 degrees to the earth, that is, half way between vertical and horizontal, it would be elliptically polarized. These two types of polarizations are commonly referred to as linear polarization, because the electric fields are always along one particular plane.

CIRCULAR POLARIZATION

If two electric fields of equal magnitude are radiated from an antenna system, one being horizontally polarized and the other vertically polarized, a single constant magnitude vector rotating in the wave front once every RF cycle will result, if either the vertical or horizontal wave voltage is exactly 90 degrees delayed or advanced, with respect to the other. This is called circular polarization. Such polarization can rotate either clockwise or counterclockwise,with reference to the electric fields, depending on which electric field was started first. Circular polarization requires that the magnitudes of the two fields be equal.

ELLIPTICAL POLARIZATION

Elliptical polarization results when there is an equal amount of horizontally polarized energy and vertically polarized energy taking place from a common antenna. The technical conditions are that the horizontally polarized radiation be of equal amplitude and phase with the vertically polarized radiation. This latter condition is nearly fulfilled with several types of FM antennas currently available to FM broadcasters. (Reference: See Section 17-2 (Antenna Engineering Handbook) JASIK, McGraw Hill, 1961.)(2)

DUAL POLARIZATION

For want of a better term, linear horizontally and linear vertically polarized radiation in unequal amplitudes and phase from the same antenna array we shall call dual polarization. This is the most common type of polarization used by FM broadcasters in the United States. It is due to the fact that in many cases unequal ERP ratios are used between the vertical and horizontal, and where the ERP values are equal the phase centers of the two antennas are not identical. Therefore, they do not meet the technical requirements for elliptical polarization. However, dual polarization more closely approaches elliptical polarization

FIELD STRENGTH MEASURING EQUIPMENT

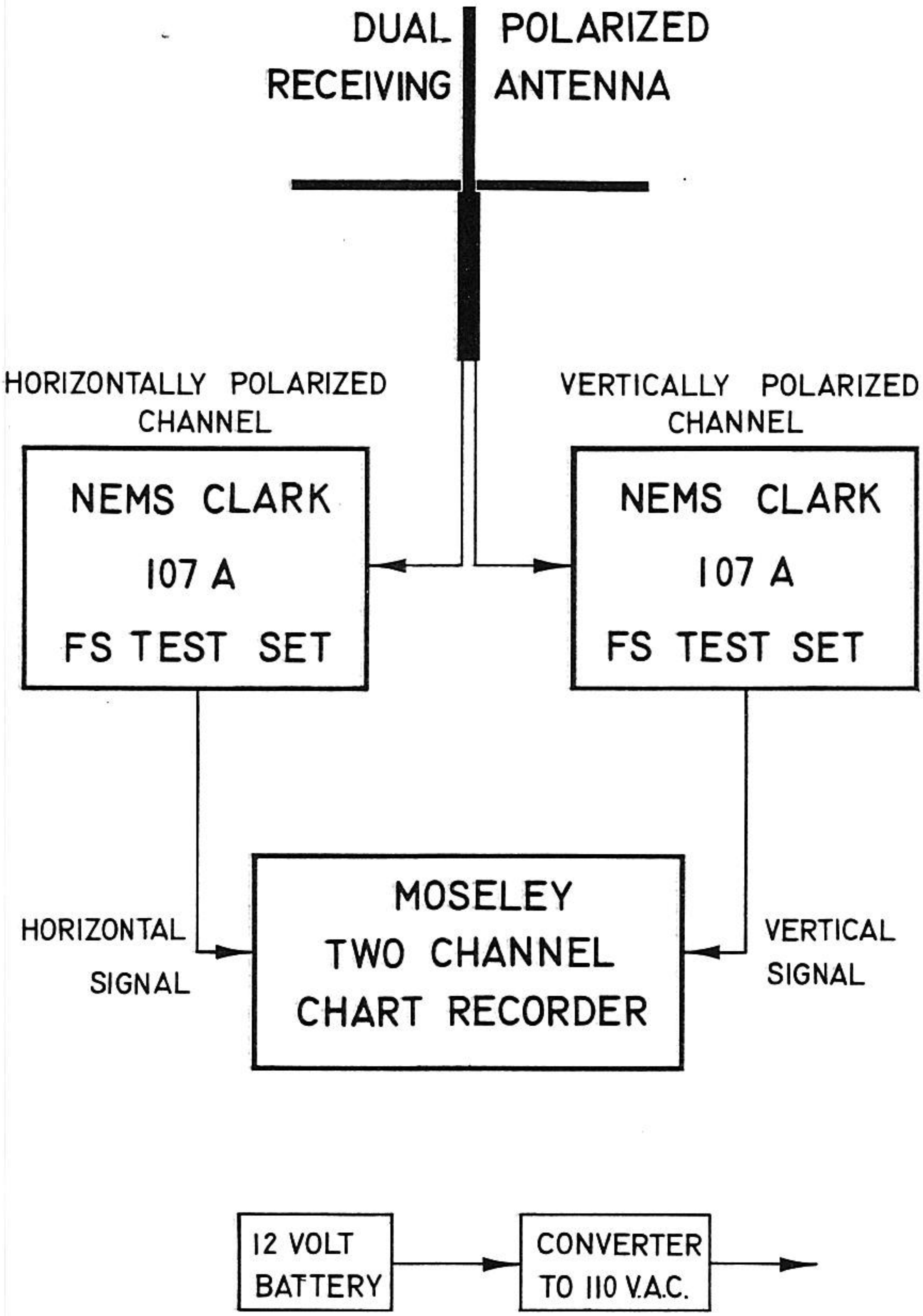


FIG 1

in theory.

For a more detailed and complete discussion on different types of polarization, the reader is referred to the published literature and specifically to J. D. Kraus, ELECTRO MAGNETICS, McGraw Hill Book Company, New York, pages 379 to 386.[3] This reference contains a mathematical discussion using Maxwell's curl equations, to explain the various factors of elliptical and linear polarization.

REFLECTORS

Nature does not treat vertical and horizontally polarized waves in exactly the same manner. This difference is significant and its effects are useful in FM broadcasting. In the discussion to follow, it is assumed that the electromagnetic wave is uniform over a flat wavefront, and the energy is linearly polarized.

When radiation travels through space, which is a transparent material, its various characteristics are not changed. When it travels through non-transparent material, reflections take place. The amplitude and phase of such reflections are quite complicated and depend on many factors.

We shall consider the reflection of dual polarized radiation. That is, two electromagnetic waves, one having its electric, the other its magnetic vector parallel to the reflecting surface. Reflection can be from ground terrain, building, trees, etc.

At low grazing angles of incidence and reflection, the two types of polarization act similarly. If the reflecting surface were a good reflector, such as sheet metal, the two rays would go through a complete reversal of their vectors. For example, the horizontally polarized wave front would emerge as vertically polarized.

BREWSTER ANGLE

Above the grazing incidence, there is a critical angle of incidence, where the reflecting qualities of the surface (still assuming a perfect reflector) do not treat the vertically polarized waves in the same manner as those horizontally polarized. This is called the Brewster angle (from optics).At these angles the amplitude of the reflections is reduced, and phase of 90 degrees lag is introduced. As the vertically polarized energy is reflected, it has 90° lag and is weaker, than when it entered the reflection point. Above the Brewster angle, the vertically polarized energy is not reversed as at lower incidence angles. The horizontally polarized wave, however, is not affected by the angle of incidence, and acts the same, regardless of the angles of incidence and reflection. For more detailed information, the reader is directed to read page 207 of Antennas, Theory and Practice, by Schelkunoff and Friis,John Wiley and Sons,1952.[4]

The amplitude and phase of reversal from ground reflection is dependent on several factors including frequency, the reflection co-efficient of the reflecting object, the angle of incident, the polarization of the wave front,and other factors. Another excellent reference containing numerous pages on polarization and propagation is Reed and Russell's new book, UHF Propagation, 1964, Boston Technical Publishers Inc. (5)

TEST STATION FACILITIES

Figure 2 shows the arrangement of the antenna, transmission line, and switching facilities used for these tests. A 5 KW transmitter of Sacramento station KHIQ-FM, 105.1 mcs was used. The output of the transmitter was fed into a power splitter which provided unequal power distribution of 49%/51%. Forty-nine percent of the transmitter power went to the five bay horizontal antenna,while fifty-one percent was fed to the vertical antenna. This ratio of power with the transmission line losses was used in order that the radiated power for the horizontal and vertical antenna would be identical. The ERP was 12.1 KW for each antenna. The power divider which was installed in the transmitter room was connected on one end to a single pole, double throw coaxial vacuum switch. The switch permitted switching the 51 percent power between the vertical antenna and a dummy load. The coaxial switch was electrically operated and controlled from the audio console position in the station's studio. The transmitter is operated by remote control from the studio which is located about 500 feet away.

The coaxial switching feature permitted instantaneous changes in the antenna system. With a single switch, the control room operator

DUAL POLARIZED FM ANTENNA TESTS

1. HORIZONTAL ANTENNA ERP 12.1 KW
2. VERTICAL ANTENNA ERP 12.1 KW
3. CO-AX SWITCH PERMITS DROPPING V-ERP TO ZERO, WHILE H-ERP REMAINS AT 12.1 KW

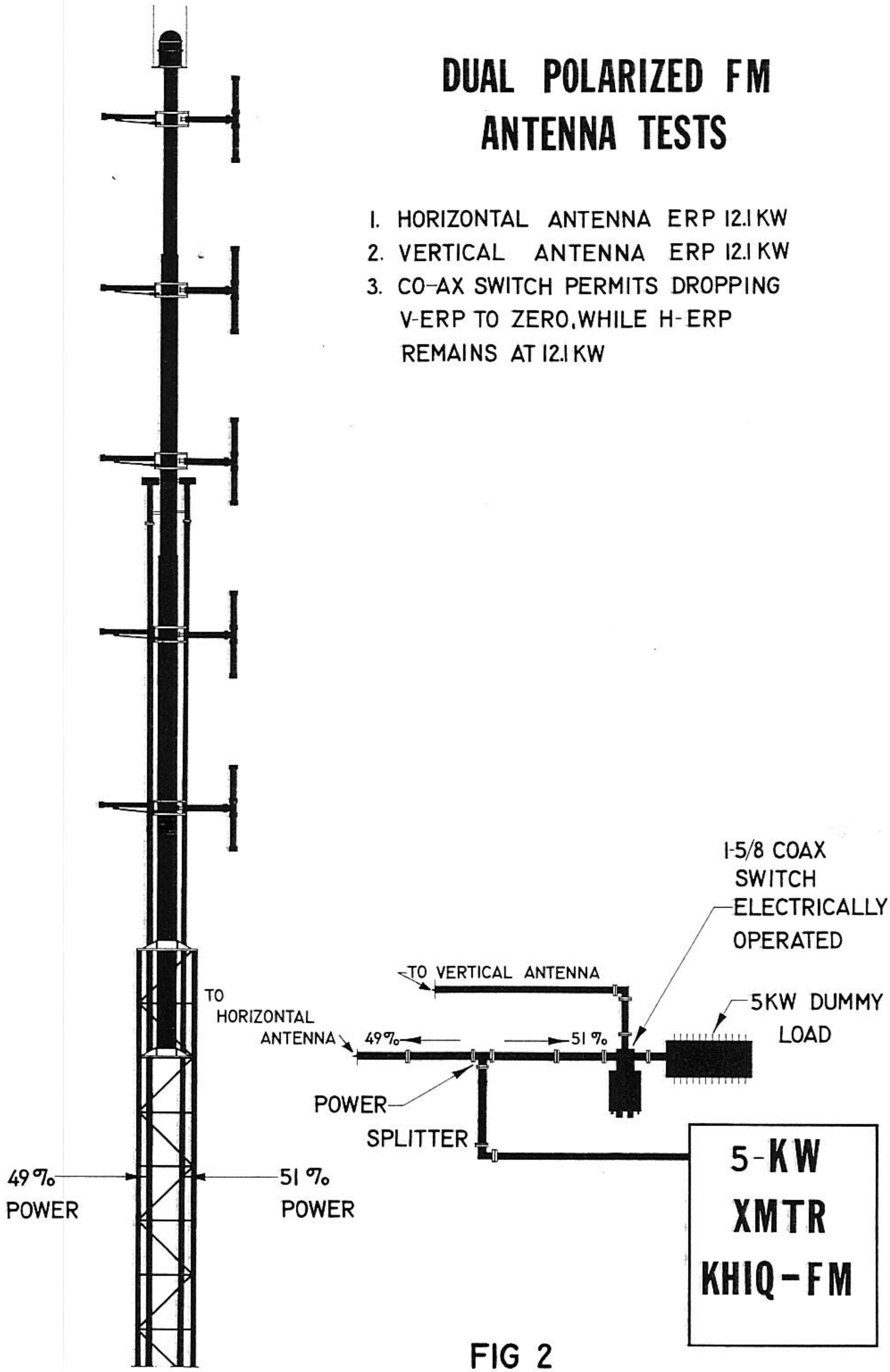


FIG 2

was able to add 12.1 KW vertically polarized power to the station's horizontally polarized power, and by the same token, to eliminate the vertical power. In many of these tests, this was done on an alternate minute basis. That is, on the even minutes of the hour both horizontal and vertical power were radiated, and on the odd minutes the vertical power was not transmitted. This set-up permitted normal broadcasting to take place without program interruptions. It also gave an instantaneous indication of the affects of vertically polarized radiation. The electrically operated coaxial switch being sealed in a vacuum,switched power from the vertical antenna to the dummy load in approximately 25 milliseconds. Switching transients were not present insofar as the transmitter was concerned, and audio clicks, or disturbances, were not noted in the station's stereo operation.

The only complaint noted during these tests from listeners was that their stereo indication lights were going off for approximately 60 seconds every other minute. By correlating this information with actual observation, it was noted that some stereo receivers were changing to the monoaural operation mode when the vertical power was turned off, indicating that either there was insufficient signal or improper phasing for stereo operation. No reports were received or found by our observations to indicate that stereo operation was lost when vertical radiation was being used. In fact, the opposite was true in several cases. No attempt was made to determine the type of receiving antenna used on these stereo receivers so affected.

The pattern of the JAMPRO Type J5B/5V antenna was measured on the JAMPRO antenna range prior to installation. The pattern of the horizontally polarized antenna and the vertically polarized antenna were not identical; and, therefore, precaution was used to insure that the results would not reflect ERP differences. The tests were conducted in azimuth directions, known to have approximately equal horizontal and vertical gains.

MOBILE POLARIZATION TESTS

Approximately 110 miles of radials were measured. This measuring technique consisted of driving the mobile receiving and recording equipment along streets and highways, in residential areas, light industrial areas, and the downtown, built-up areas of Sacramento. A long radial of 35 miles was made between the transmitter and the foothills to the east of Sacramento, California. This latter radial was started at the transmitter, and went out to 35 miles. The end of the radial was in the 2000 foot elevation of the Sierra-Nevada mountains. The transmitting antenna is about 200 feet above sea level.

The technique consisted of the transmitter transmitting 12.1 KW of horizontally polarized power at all times, to which during every even minute of the hour, 12.1 KW of vertically polarized radiation was added. The effects of adding the 12.1 KW of vertical power, in most of the recordings, could be easily seen.

Various chart speeds were used on the dual channel paper recorder, in order to accurately determine the affect of the addition of vertical polarization. Automobile travel speeds varied from 5 mph to 60 mph and recording speeds varied from 0.1 to 0.5 inches per second.

The receiving and recording equipment is shown in Figure 1. This particular sketch shows a dual polarized receiving antenna connected to 2 Nems-Clark, Model 107A, field intensity meters. The outputs of both meters are, in turn, connected to the Moseley two-channel paper recorder.

The channel gains were checked many times during the recording periods to insure tracking between the two channels with a given signal level under various receiver attenuator settings.

The receiving antenna was mounted on the back end of a station wagon. See Figure 3 for details of this test antenna. The height was 10 feet above the ground road level for the horizontal dipole. It was checked for polarization purity and found to be 30 DB for the horizontal, and 32 DB for the vertical, when so mounted. The VSWR was better than 1.06/1 on the 105.1 mcs KHIQ-FM operation frequency for both antennas. The directional qualities of the horizontal dipole were checked with a standard dipole and found to be in close agreement. The Balun skirt on the vertical dipole also serves as a de-coupling skirt for the horizontal dipole feed and was found to be very effective. The coaxial cables from the antenna centers to the receiver inputs were identical lengths to insure equal phase signals. This receiving antenna could technically

DUAL POLARIZED RECEIVING ANTENNA

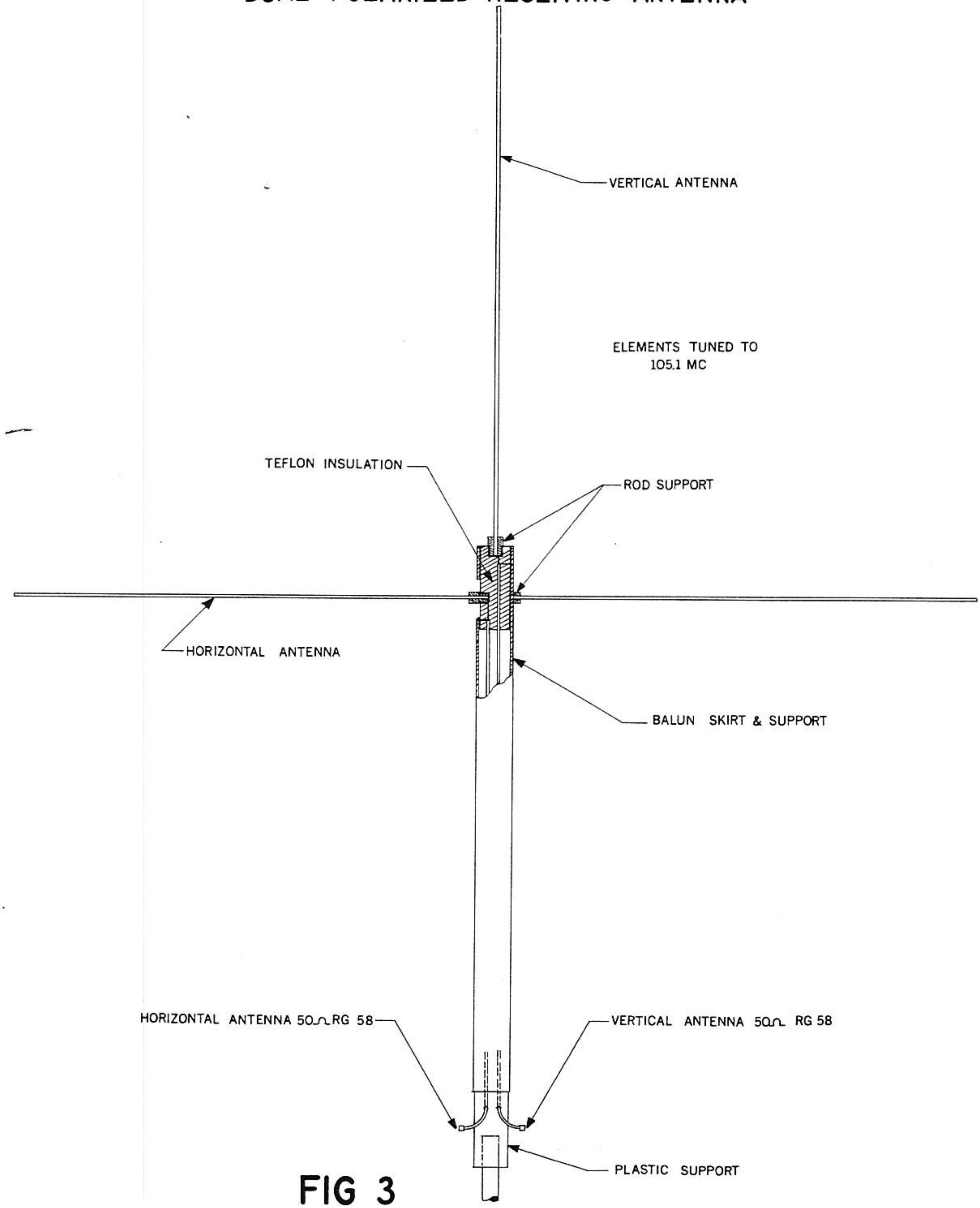


FIG 3

be called an elliptical polarized antenna since its amplitude response and phase responses are equal. The horizontal dipole was rotated in its socket in order that it was broadside to the station during all of the measurement runs.

The radial measurements indicated, amoung other things, that the signal arriving at the receiving antenna was not pure in its polarization. This is to say that a considerable portion of the received horizontal signal had changed polarization during propagation. This is shown on the recordings by the fact that the vertical antenna picked up, at times, signals which were stronger than those picked up by the horizontal antenna under conditions of horizontal ERP transmission only. The opposite condition is also true. That is, part of the vertically polarized ERP changes polarization, and arrives in the horizontal antenna. This is due to the fact that upon reflection the signal changes polarization. The percentage of change is a function of the several factors discussed previously. This fact is borne out very clearly in some of the radial measurements. See Figure 5.

It can be seen by looking at this strip of chart that the vertical channel was receiving considerable signal when the vertical power was off. Also, note the fact that when the vertical power was turned on, the horizontal signal amplitude generally averaged higher. This would indicate that the vertical power was contributing some signal into the horizontal receiving antenna. In other words, the propagation conditions

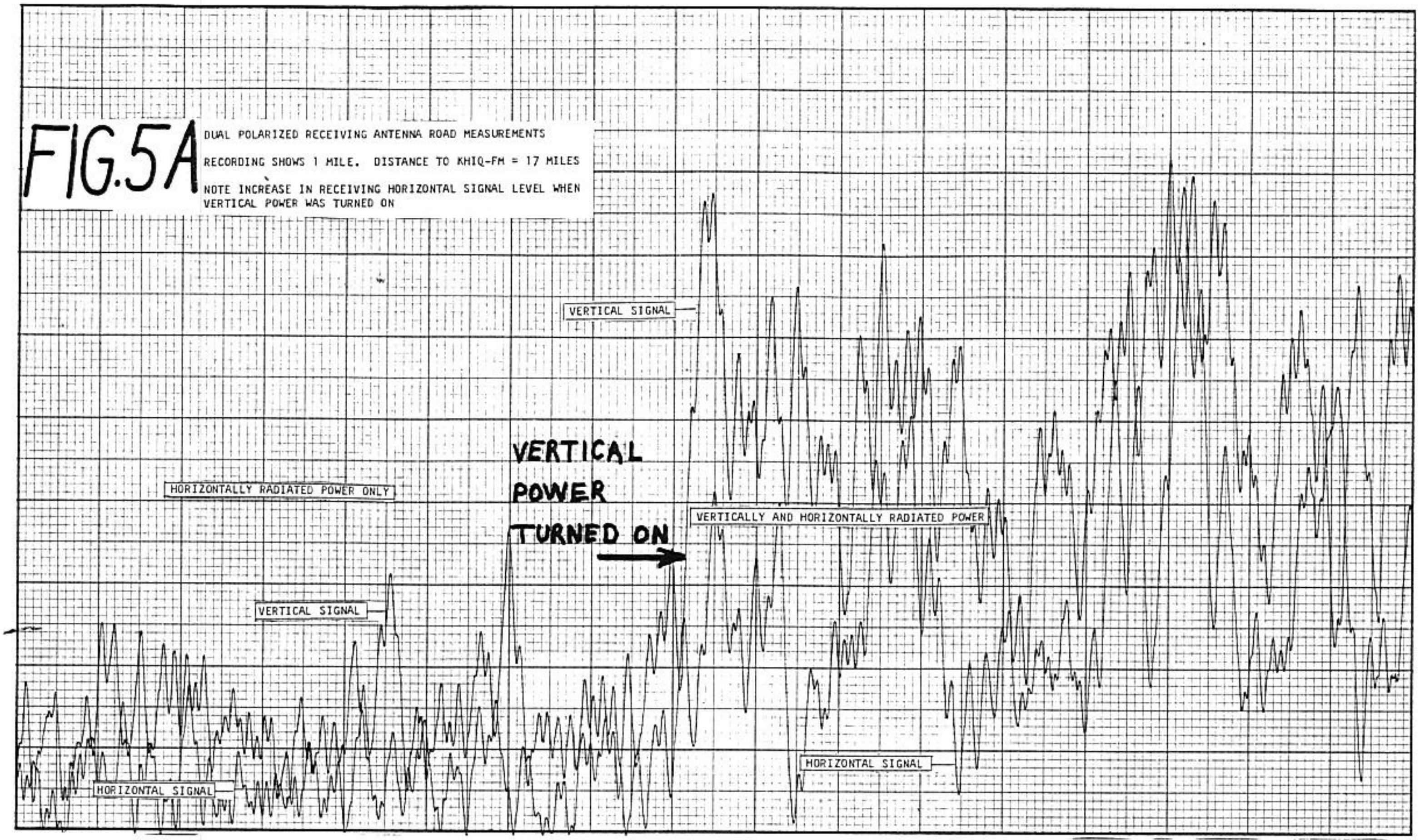


FIG.5A
DUAL POLARIZED RECEIVING ANTENNA ROAD MEASUREMENTS
RECORDING SHOWS 1 MILE. DISTANCE TO KHIQ-FM = 17 MILES
NOTE INCREASE IN RECEIVING HORIZONTAL SIGNAL LEVEL WHEN VERTICAL POWER WAS TURNED ON
VERTICAL SIGNAL
VERTICAL POWER TURNED ON
HORIZONTALLY RADIATED POWER ONLY
VERTICALLY AND HORIZONTALLY RADIATED POWER
VERTICAL SIGNAL
HORIZONTAL SIGNAL
HORIZONTAL SIGNAL

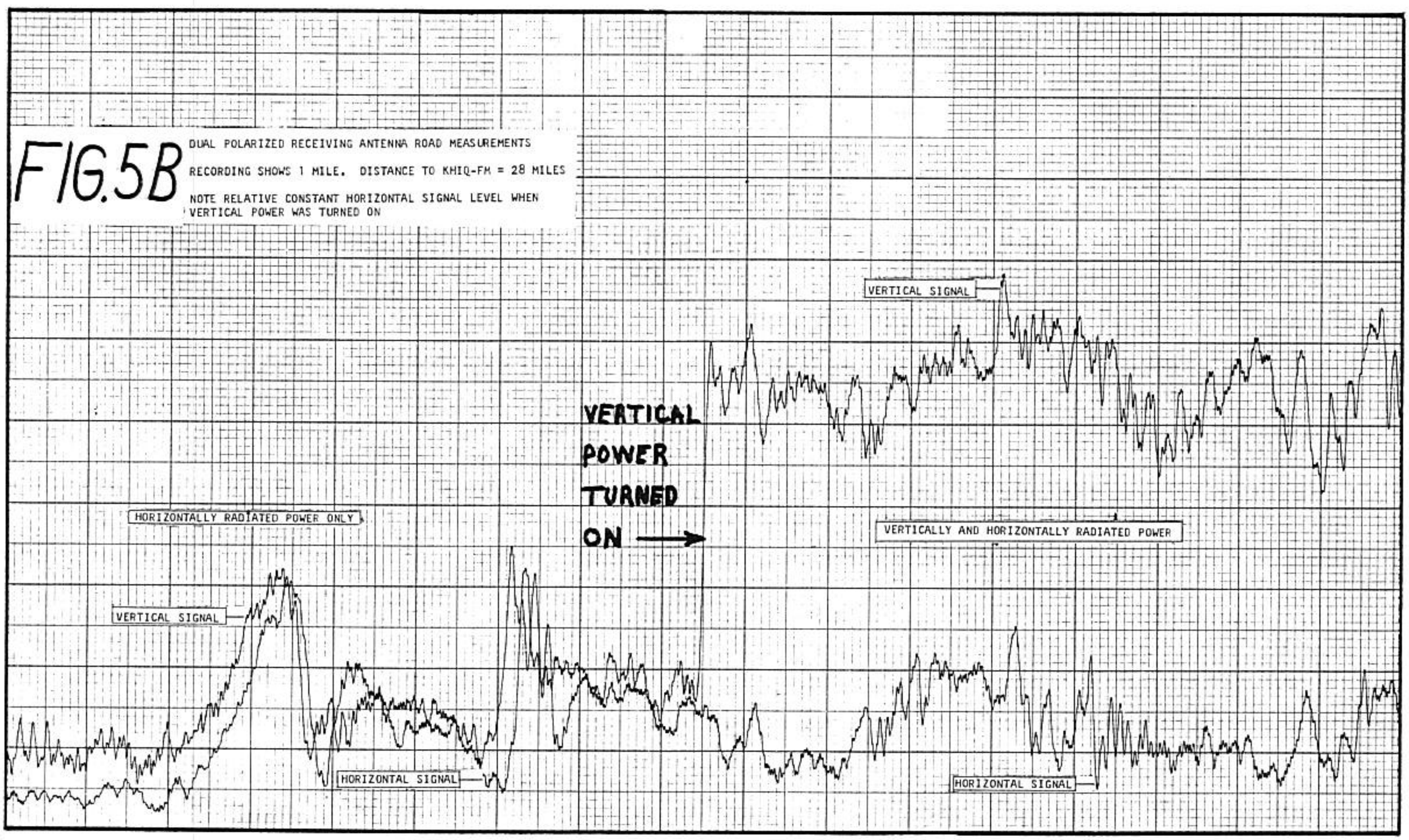


FIG.5B
DUAL POLARIZED RECEIVING ANTENNA ROAD MEASUREMENTS
RECORDING SHOWS 1 MILE. DISTANCE TO KHIQ-FM = 28 MILES
NOTE RELATIVE CONSTANT HORIZONTAL SIGNAL LEVEL WHEN VERTICAL POWER WAS TURNED ON
VERTICAL SIGNAL
VERTICAL POWER TURNED ON
HORIZONTALLY RADIATED POWER ONLY
VERTICALLY AND HORIZONTALLY RADIATED POWER
VERTICAL SIGNAL
HORIZONTAL SIGNAL
HORIZONTAL SIGNAL

were such that the polarizations of the two transmitted signals changed. This contributes energy into the opposite polarization receiving antenna.

No attempt was made during these measurements to measure the absolute field strength of either the vertical or horizontal antennas. Our only concern here was to measure the ratios between the two types of signals, with equal amounts being transmitted. Since identical field intensity meters were used and checked for both calibration and tracking together with antennas with equal field strength response, it can be safely assumed that the variations in signal strength as recorded are due only to propagation factors.

AUTOMOBILE ANTENNA MEASUREMENTS

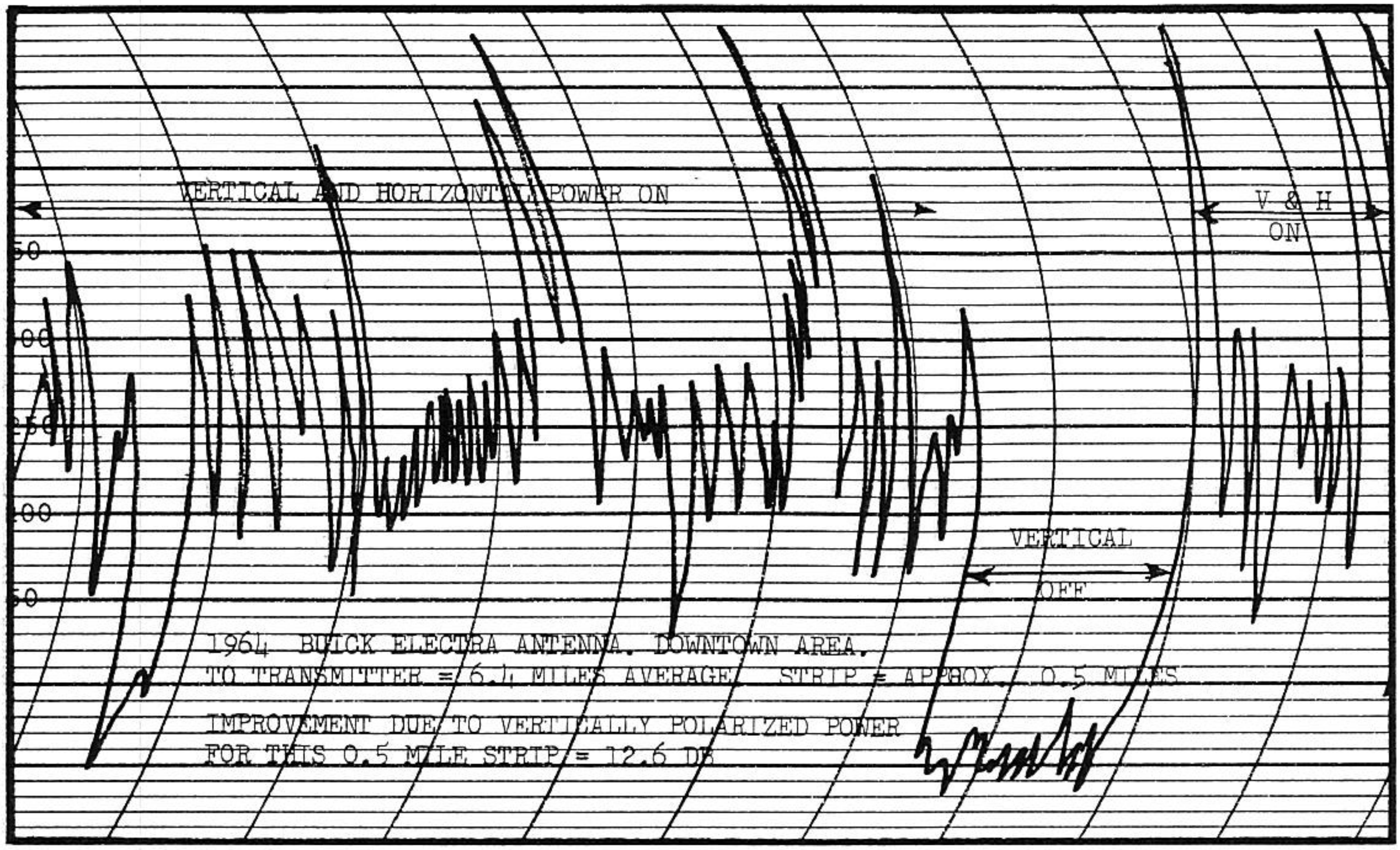
Since FM car radios are becoming more and more popular with the general public, the affect of vertically polarized receiving antennas in automobiles was investigated. Nearly all U.S. automobiles of current production use adjustable whip antennas that are vertically polarized. By proper adjustment these antennas may be made a quarter-wave length long in the FM band, which turns out to be about 30 inches. This length also gives quite satisfactory reception for AM service in metropolitan areas.

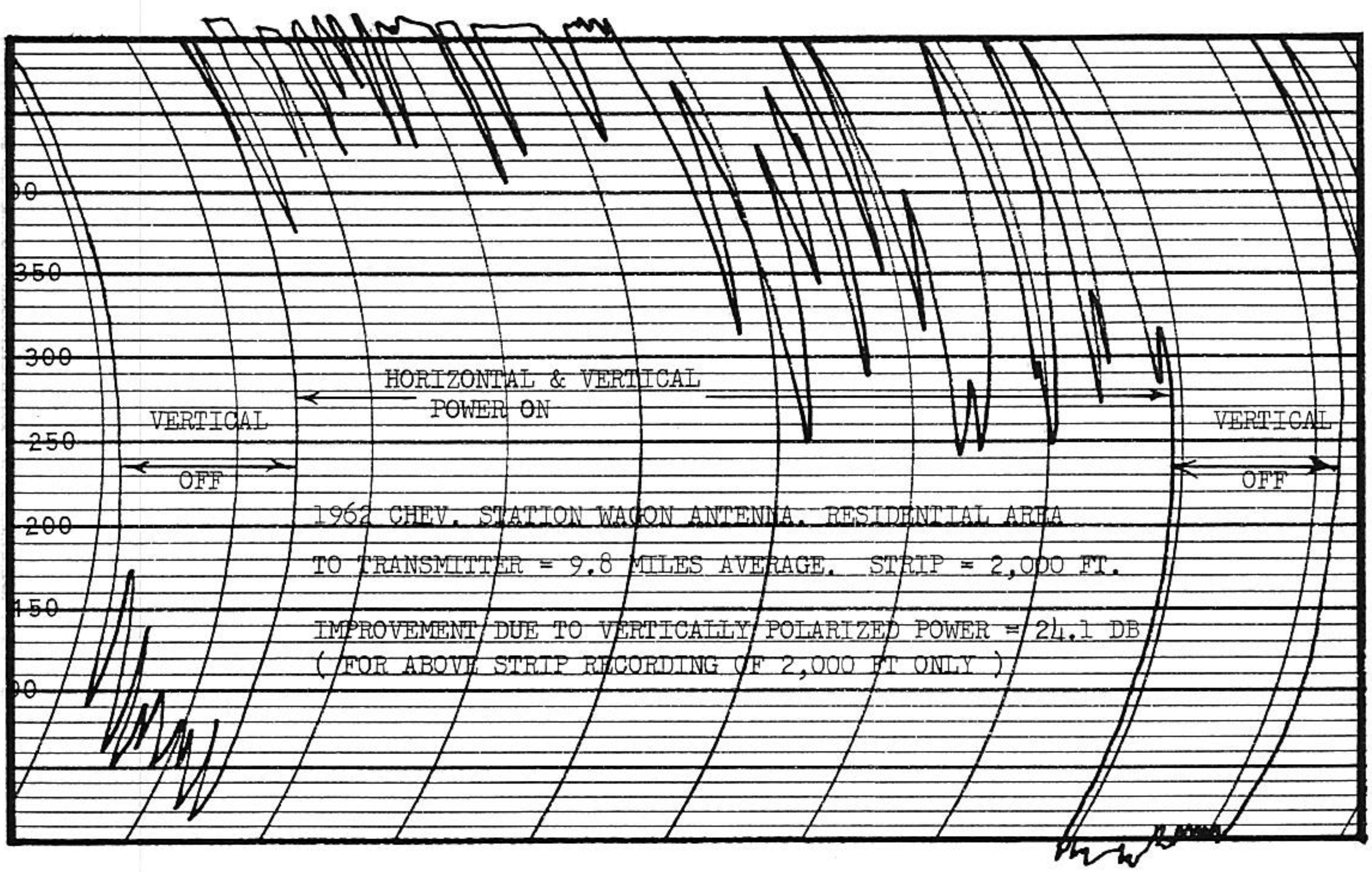
The placement of the vertical antenna on automobiles makes it somewhat directional. This directional property varies according to model and make. In our measurements every effort was made to average these directional receiving characteristics by driving the car in a square block configuration, so that all four quadrants of the directional pattern would be equally exposed to the incoming signal.

The test consisted of disconnecting the automobile antenna from its receiver and plugging it into an adaptor that went into a Nems-Clark field intensity meter. This meter in turn fed a single channel Esterline-Angus mechanically driven strip recorder. The field intensity meter was powered by a storage battery. This was done in order to avoid d-c voltage fluctuations normally associated with automobile system stop-and-go driving. Fifty-five miles of measurements were made, including residential areas, light commercial areas, freeways, and downtown multi-story areas of Sacramento. Two portions of typical measured data charts are shown in Figure 4.

Again, no attempt was made to determine absolute signal levels, but instead it was only desired to determine the ratio of change or improvement when an equal amount of vertically polarized power was added to the station's horizontal power.

It was noted that the signal from the car's automobile antenna dropped considerably when the station was transmitting horizontal energy only. When the automobile was on elevated freeways or on higher ground, the drop was even greater and would indicate that the received signal, which was horizontally polarized,was much more pure and had less vertical component than when the signal was being received on flat terrain. This characteristic was also confirmed by the earlier chart recordings made with the dual polarized receiving antenna. In theory, the popular vertically polarized whip automobile antenna would discriminate against


VERTICAL AND HORIZONTAL POWER ON
V & H ON
VERTICAL OFF
50
00
250
200
50
1964 BUICK ELECTRA ANTENNA. DOWNTOWN AREA.
TO TRANSMITTER = 6.4 MILES AVERAGE. STRIP = APPROX. 0.5 MILES
IMPROVEMENT DUE TO VERTICALLY POLARIZED POWER
FOR THIS 0.5 MILE STRIP = 12.6 DB


00
350
300
250
200
150
00
HORIZONTAL & VERTICAL POWER ON
VERTICAL OFF
VERTICAL OFF
1962 CHEV. STATION WAGON ANTENNA. RESIDENTIAL AREA
TO TRANSMITTER = 9.8 MILES AVERAGE. STRIP = 2,000 FT.
IMPROVEMENT DUE TO VERTICALLY POLARIZED POWER = 24.1 DB
(FOR ABOVE STRIP RECORDING OF 2,000 FT ONLY)

a pure horizontally polarized wave so that no signal would be received. However, in practice, the received signal is not pure in polarization and the vertical components, though small, are received by the vertically polarized automobile antenna. Our recordings show that the reflected signal thus received by the whip antenna varies somewhat with distance, the nature of the area in which the automobile is located, and other factors. From our measured data the following breakdown for automobile antennas is valid:

TABLE I

AUTOMOBILE ANTENNAS

LOCATION	MILES OF TESTS	IMPROVEMENT DUE TO VERTICAL POWER
RESIDENTIAL	19.2 miles	17.4 DB
COMMERCIAL	7.7 miles	15.1 DB
INDUSTRIAL	6.2 miles	17.6 DB
DOWNTOWN	4.6 miles	13.7 DB
FREEWAYS	16.3 miles	18.2 DB
TOTAL SAMPLE	54 MILES	
AVERAGE IMPROVEMENT		16.00 DB

It is apparent that for proper penetration into automobiles radios, the FM broadcaster needs vertically polarized radiation. This is especially true if the station is limited to 3 KW ERP. All currently available FM transmitting antennas radiate some vertically polarized power. The JAMPRO Vee antenna has been measured to average roughly 4 percent of its radiation, vertically polarized. This value varies approximately 25 percent based upon the type of supporting structure the antenna is mounted on, that is, pole, or tower leg, face, and so forth. From our tests there was, on the average, 16 DB improvement when an equal amount of vertical power was added to that normally transmitted. This is an improvement in the car radio of 40 times power, or an increase in the received field voltage of 6.3 times.

In our tests, we found the greatest improvement in reception with vertical polarization, in car FM radios.

In automobile radios, there is an indication that a vertical signal can be received at a greater distance than a horizontal signal. This is due to the discrimination against the horizontally polarized signals. This is another argument in favor of vertically polarized ERP for FM broadcasting since FM car radios are making a significant contribution to the total FM receiver market.

INDOOR PIGTAIL ANTENNAS

Many FM radios have a small piece of wire approximately 30 inches long used as an antenna. This short wire is effective in high signal intensity areas. Its use and quality as a receiving antenna was also measured.

The procedure for this test was to use a Nems-Clark field intensity meter into which was plugged either a 28 inch long or 30 inch long wire pigtail. Placed in residences, the ratio of the received signal with and without vertical power was measured and noted. This procedure was followed in ten different locations in each home so visited. Locations where we thought FM radios would be placed were used. They included kitchen drainboards, bathrooms, bedroom dressers, bedroom nightstands, bookshelves, small tables, etc. The pigtails were varied as to direction and placement; sometimes behind the test equipment, sometimes parallel to the a-c cord.

Here again the advantages of vertical power were demonstrated. Pigtail tests in over 50 homes made possible some 500 individual test measurements. With an equal amount of vertical and horizontal power there is an average improvement of 7.75 DB over a condition in these pigtails where only the horizontal power is being transmitted.

TABLE II

PIGTAIL FM RECEIVING ANTENNAS

LOCATION	NO. OF TESTS	IMPROVEMENT DUE TO VERTICAL POWER
RESIDENCES	353	7.35 DB
OFFICES	52	7.64 DB
STORES	116	8.25 DB
TOTAL SAMPLE	521	
AVERAGE IMPROVEMENT		7.75 DB

BUILT-IN FM ANTENNAS

Many modern day AM-FM stereo consoles have built-in antennas. Sometimes these are of insulated wire in the form of a dipole stapled to the masonite back cover, sometimes they are in the form of foil and fan shaped in order to increase the band width, and sometimes they are rectangular loops. There are several other forms of built-in antennas which may be found in FM stereo consoles.

Whenever a test was made in a home where the consoles were present, the built-in antennas were connected to a 300 ohm balanced transformer which, in turn, fed the field intensity meter. The ratio of the received signal strength was compared between horizontal power only, and horizontal plus vertical power transmitting conditions. The console was moved from its usual place in the home to at least two other locations,approximately one-quarter wave length minimum separation,so that an average could be obtained. Consoles on sale in FM shops were also tested in this manner, providing a large number of built-in antenna measurements.

The improvement with vertical polarization in the stereo consoles is due to the fact that the receiving antenna in these units is both vertically and horizontally orientated. Since the incoming signal consists of vertical and horizontal power, the receiving antenna is able to capture more overall signal when both polarizations are present from the transmitter. The results of these tests are shown below:

TABLE III

BUILT-IN CONSOLE FM ANTENNAS

LOCATION	NO. OF TESTS	IMPROVEMENT DUE TO VERTICAL POWER
RESIDENCES	38	5.42 DB
COMMERCIAL	4	5.94 DB
TOTAL SAMPLE	42	
AVERAGE IMPROVEMENT		5.68 DB

OUTDOOR FM ANTENNAS

Homes with outdoor antennas, provided another series of tests. Many were TV antennas while some were FM antennas. When the antennas had rotors, they were rotated for maximum signal pickup from the station. Most of the Sacramento area outdoor antennas are over 40 feet above the street level. They, therefore, tend to be in a level where reflections from ground objects are much less than, say inside a home. These outdoor antennas are all horizontally polarized and, therefore, discriminate against vertically polarized energy. The case is opposite to the automobile antennas. The outdoor antennas, as expected, responded much better to the station's horizontally polarized signal and the addition of the vertically polarized power did not make a large improvement in received signal level. Much of the vertical signal picked up by these antennas is believed to come from the 300 ohm transmission line which is not matched at the FM frequencies, and, therefore, subject to radiation pickup. Several antennas designed for FM reception were also tested in this outdoor antenna group and were found to behave very much like the TV antennas. Therefore, they were not broken up into a separate group.

The outdoor antennas were tested by disconnecting the antenna from its associated receiver, connecting it to a 300 ohm balanced transformer which then went into a field intensity meter. If the antenna had a rotor, it was rotated for maximum signal strength. Then, the difference between vertical and horizontal, and horizontal only was recorded. Some 70 antennas were tested in this manner.

TABLE IV

OUTDOOR ANTENNAS

LOCATION	NO. OF TESTS	IMPROVEMENT DUE TO VERTICAL POWER
RESIDENCES	47	3.80 DB
COMMERCIAL	24	4.60 DB
TOTAL SAMPLE	71	
AVERAGE IMPROVEMENT		4.20 DB

DESIRABLE RATIO OF VERTICALLY & HORIZONTALLY POLARIZED ERP VALUES

In our tests we used a 1/1 ratio of vertical to horizontal power. This is the maximum allowable ratio by the FCC. Under certain cases the maximum allowable vertical power is based upon the present rules of the FCC and may be much less than the authorized horizontal power.

Where stations are "grandfathered" into these situation, the available vertical ERP values should be studied. While any value of additional ERP in the form of vertical polarization will increase the received signal level, in practice the economics of the situation must be considered.

When it is desired to have as much vertical ERP as present horizontal ERP, the horizontal antenna gain must be doubled and corresponding number of vertical bays must be added. For example, a 1 kw transmitter is used to feed an older type of horizontal antenna with an ERP of approximately 3 kw. In order to maintain the 3 kw horizontal power and add 3 kw of vertical power, a 6 bay horizontal antenna and a 6 bay vertical antenna would be required. This is due to the fact that in this example 50 percent of the power goes to the horizontal antenna and the rest to the vertical antenna. This power division reduces the antenna gain by the same ratio, and must be increased through the use of a larger antenna or more transmitter power. In some cases, it is more economical to add antenna gain only; and in others, both a larger antenna and a larger transmitter. It must be remembered, as in all things, something cannot be had for nothing. So it is true with vertical ERP, in order to get this additional radiated power, it must come through concentration in an additional antenna or through an antenna and a transmitter.

At the present time, it appears to be economically justifiable to add a minimum of 20 percent vertically polarized power to the existing horizontal. Values of vertical power less than 20 percent, which is

7 DB down, do not appear to be practical. To be effective and noticable in the average home radio, the vertical power must be least 20 percent of the horizontal power. The only exception to this statement is that values less than 20 percent are definitely noticable in automobile radios, and may be justifiable in some communities with large numbers of automobile FM radios.

The economics of adding vertical polarization concern first the determination of the amount of vertical power necessary or allowable; second, the antenna size and configuration; and, third, the availability of transmitter power. Tower supporting capabilities may also be very important. It is quite possible to tailor the exact amount of vertical to horizontal powers through the use of power splitters, or dividers as they are sometimes called. These devices permit 50/50 power splits, or such finite values as 19½ percent to 80½ percent.

EFFECTS ON STEREO OPERATION

The stereo separation of the transmitted signal was measured in four different receiving locations. The oscilloscope and distortion analyzer methods were used to measure the left and right channel separation. After the equipment had been set up, using high quality FM tuners in all four cases, the vertical power was swtiched on and off, and the difference in separation recorded. A 400 cycle tone was used as the audio test frequency. There was very little improvement in stereo separation, with vertical polarization. The greatest improvement occured in an installation, whose outdoor receiving antenna, also showed a comparatively large improvement with vertical polarization. The stereo improvement in this particular test was 2.5 DB. The other three tests yielded 1 DB, 1½ DB and no measureable improvement. The average separation in these four tests was 21 DB between left and right channels at 400 cycles. While the number of tests were limited, we feel it is indicative that vertical polarization does not in itself significantly improve stereo separation, nor does it degrade it.

There appears to be no correlation between the phases and power ratios of vertical and horizontal radiation, to stereo channel separation, or distortion. Therefore true circular or elliptical polarization would not significantly improve stereo operation.

CONCLUSIONS

Different tests and measurements made under acceptable engineering conditions have indicated the desirability of using both vertically and horizontally polarized power by FM broadcasters. These tests have indicated that vertically polarized energy along with horizontal will put more signal into automobile radios, small FM radios, FM portables, and large FM stereo consoles with built-in antennas. Even with outdoor antennas there appears to be a 4.2 DB advantage when using an equal amount of vertically polarized power. The greatest improvement with vertical polarization is in automobile radios.

TABLE V

COMPARISONS OF
IMPROVEMENT DUE TO EQUAL VERTICALLY POLARIZED POWER

TYPE OF ANTENNA	AVERAGE DB IMPROVEMENT	EQUIVALENT POWER RATIO
OUTDOOR	4.2 DB	2.63
BUILT-IN CONSOLE	5.68 DB	3.69
PIGTAIL	7.75 DB	5.95
AUTOMOBILE	16.00 DB	39.81

Since most of the FM receivers are located within 10 feet of the ground, the FM signal from the broadcasting station at this level consists of many reflections from nearby objects as well as the terrain. This results in changes of polarization as well as phase and amplitude. An arbitrarily polarized receiving antenna or one whose polarization is quite complex will respond better to these reflected signals. The net result is more signal into the FM receiver.

The data obtained from these tests, indicate that all class A stations should strive for an equal amount of vertical and horizontal power. Class B and C stations should use as much vertical power as economics will allow. There is no doubt about the superiority of coverage by a dual polarized FM station, compared to one, using horizontal power only, when the transmitting antenna heights are approximately equal.

There appears to be no advantage in FM broadcasting between circular polarization, elliptical polarization, and dual polarization. Dual polarization is easier and, therefore, less expensive to obtain from currently available transmitting antennas.

In our discussions on the merits of vertical polarization we do not want to say, or lead the reader to believe, that there is anything superior about vertical polarization as compared to horizontal polarization. What we are saying here is that vertical polarization <u>added</u> to the horizontal polarization will penetrate receiving antennas much more than when only one type of polarization is used. The FM broadcaster needs <u>both</u> types of radiation in order to put more signal into the average FM receiving antenna.

There is one exception to this statement,and it concerns vertically polarized automobile antennas. Since the automobile antenna responds very well to vertically polarized radiation and discriminates against horizontal radiation, only vertical power is required for automobiles, for good limiting and the elimination of "picketing".

ACKNOWLEDGEMENTS

Our warmest thanks go to Station KHIQ-FM, Sacramento, California, and to its general manager, Jim Hodges, without whose help and cooperation this project would not have been possible. To Loren Williams, of JAMPRO, who designed the dual polarized receiving antenna, and conducted most of the receiving tests. To Don Ferguson, chief engineer of KXTV, for the use of one Nems-Clark field intensity test set, and to Hewlett-Packard for the use of the dual chart Moseley

recorder. Our thanks also go to those in the broadcast industry, as well as in the FCC, who showed interest and gave us suggestions as well as encouragement.

REFERENCES AND SUGGESTED READING

(1) Circular Polarization in FM Broadcasting, ELECTRONICS, Sept. 1948, Smith & Fouty

(2) Types of Polarization, Section 17-2, ANTENNA ENGINEERING HANDBOOK, Jasik, McGraw Hill, 1961

(3) Types of polarization, pages 379 to 386, ELECTRO MAGNETICS, Kraus, McGraw Hill, 1954.

(4) Brewster angle reflection, page 207, ANTENNAS, THEORY AND PRACTICE, Schelkunoff and Friis, John Wiley and Sons, 1952.

(5) UHF PROPAGATION, Reed and Russell, Boston Technical Publishers, Inc. 1964.