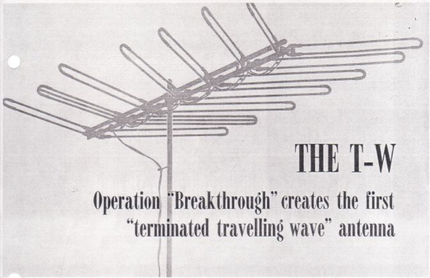

THE T-W

Operation "Breakthrough" creates the first "terminated travelling wave" antenna

Revolutionary New Design Surpasses the Finest Broad Band Yagis

by HAROLD HARRIS
Vice President in Charge of Sales and Engineering
Channel Master Corporation

As commercial television enters its second decade, the self-appointed prophets who predicted the impending disappearance of television antennas have themselves disappeared into the special limbo occupied by those who said, "the wheel, the lever, and the inclined plane can't last."

Not only are TV antennas here to stay, but they are constantly adding to the burdens of the F.C.C. by bringing television reception to areas where the Commission said there could be none. Ever since the first days of TV, antenna engineers have repeatedly introduced new designs which have extended TV's usable range and provided tremendous new markets for advertisers, set manufacturers, servicemen and dealers, and, of course, antenna manufacturers. Indeed, the "doomed-to-disappear" TV antenna has become the vital link in the viewing pleasure of millions of people, as well as the vital link in the creation of hundreds of millions of dollars worth of goods and services which have helped the American economy to grow.

TV antennas, over the past 10 years, represent an unusual study in swift technical progress. They actually evolved and improved more than the TV set itself, as the parade of advancing types passed by: Dipole and Reflector, Conical, Fan, Yagi, Dipole and Screen, and on up to the latest series of Broad Band VHF Yagis. This latter class has been the most powerful type of multi-channel antenna created to date, and practically every antenna manufacturer makes a version of this basic type.

Jerome Schwartz
project engineer

The development of the terminated travelling wave antenna, the T-W, was a joint effort. Mr. Schwartz carried out the initial research independently. He was joined in the later stages by Dr. Lo. The two men completed the investigation and perfected the antenna together.

Mr. Schwartz, a graduate engineer of City College of New York, has played a major role in the development of many of Channel Master's most outstanding UHF antennas. Dr. Lo is well known as the designer of the Champion and the Rainbow.

Dr. Yuen T. Lo
project engineer

Channel Master Antenna Development Laboratories

LIMITATIONS OF YAGI DESIGN

The great acceptance of this antenna by TV installation and servicemen, however, should not conceal the fact that the broad band yagi still has significant shortcomings. Although the complete range of this antenna's possibilities has now virtually been explored to the limit, certain basic limitations still remain:

1. Gain

Although the broad band yagi is the highest gain all-channel antenna developed to date, there is still a great need for additional gain in fringe areas. Because of basic limitations, broad band yagis are not — as many believe — the "ultimate" in high gain antenna design. One of the basic theoretical conditions for maximum antenna performance in a multi-element antenna is that EVERY ELEMENT MUST RECEIVE AN EQUAL AMOUNT OF CURRENT in the proper phase relationship. The broad band yagi cannot fulfill this vital condition on more than one or two channels because the current and phase relationships do not hold constant across the entire band. Therefore, by not making full use of the transmitted energy, this antenna type cannot realize maximum gain on every channel.

2. Front-To-Back-Ratio

Over the years, the increasing number of stations, plus increasing power, have lead to tremendous co-channel and adjacent channel problems. Every serviceman in such areas knows that even the best of the broad band yagis cannot successfully cope with these problems. This is true because of the inherent limitations of the yagi's parasitic system. The self-impedance of each parasite, and the physical spacing between them, determine both the phase and the amplitude of the current flowing in them. As stated above, these should be variable with frequency. But in a yagi they are fixed. Therefore, the front-to-back ratio of a broad band yagi is necessarily limited. This problem will be analyzed in detail further on.

3. Mechanical Structure

Yagi design calls for a series of single tubular elements which extend from the crossboom. They are held straight out, supported on one end much like a diving board. Under conditions of wind or ice this mechanically undesirable "spring board" action directly leads to element breakage and costly antenna failure.

With the above considerations in mind, Channel Master's Chief Engineer, Harry Greenberg, assigned two separate fringe area "Breakthrough" projects to engineers Jerome Schwartz, and Dr. Yuen T. Lo. The objective of this program was to break through the existing concepts of conventional antenna design. Both pursued separate approaches, and after about a year, it became apparent that the direction assigned to Mr. Schwartz would be more fruitful. At this point Chief Engineer Greenberg combined the two projects so that Mr. Schwartz and Dr. Lo worked on the same approach. Dr. Lo made many important contributions to Mr. Schwartz's basic array, particularly in improving front-to-back ratios. The patent application is in both their names.

The purpose of this article is to introduce and describe this entirely new basic antenna type, which by its nature and design represents a tremendous advance beyond all broad band yagis — in gain, front-to-back ratio, and mechanical strength.

The new antenna (Fig. 1) is a TERMINATED TRAVELLING WAVE ANTENNA. It embodies a number of essential features which have never before been incorporated in one antenna. Many of these features are not apparent to the casual observer. For example:

1. Six of the seven elements are "driven."
2. The phasing harness is in two sections, each with a different impedance (Z).
3. Despite its appearance, the antenna has no conventional folded dipoles:
   a) Five dipoles are "hairpin" or "fat" dipoles, (Fig. 1A)
   b) One is a 3-conductor high Z dipole.
   c) One is a folded reflector.
4. All dipoles have a different length.
5. Two different "Vee-ing" angles are used.
6. A terminating resistor is employed.

The configuration of this new antenna is a series of "Vee'd" dipoles. To understand the theory of its operation, it is necessary to review the basic

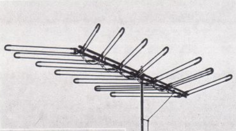

Fig. 1—Seven element terminated travelling wave antenna.

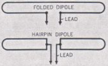

Fig. 1A—Difference between a conventional folded dipole and a "hairpin" or "fat" dipole.

Vee dipole. When this dipole is approximately ½ wave on the low band, it is about 3 half waves on the high band (Fig. 2). Anti-phase high band operation is overcome by the fact that the center section is located 180 degrees in space behind the two outer sections. In effect, the high band dipole operates as shown in Fig. 3. The phase of the current changes 180 degrees as it travels to the point in space where it is abreast of the two outer dipole sections. Therefore, the current of all three sections is in phase.

The basic directivity patterns (and consequently, the gain) of an antenna are determined by the phase and amplitude of the current in the dipoles, as well as the position of the dipoles in respect to each other.

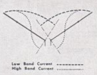

Fig. 2—High and low band current distribution of a basic Vee dipole.

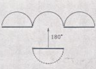

Fig. 3—Phase of the current in high band dipole changes 180 degrees as it travels to the point in space where it is abreast of the two outer dipole sections.

CURRENT PHASE

Keeping the operation of the "Vee'd" dipole in mind, we must now think of these dipoles as impedances. Fig. 4 shows each element of the Terminated Travelling Wave Antenna as an impedance. The lines connecting

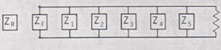

Fig. 4—Dipoles of terminated travelling wave antenna represented as impedances. Connecting lines represent phasing harness.

the dipoles or impedances represent the phasing harness.

The harness length between each dipole is greater than the free space distance. When the total electrical harness length of the driven elements is equal to the physical spacing, plus 180 degrees, the result is termed "Increased Directivity Condition."* This produces narrower lobes and higher gain than would be obtained if the harness length and physical spacing were of equal dimensions. However, the phase relationship which produces increased directivity is not dependent on harness length alone. The phase in each dipole also depends on its impedance. Therefore, the harness must be cut to compensate for the variations in dipole impedances as described below.

CURRENT AMPLITUDE

By controlling the impedance of each dipole, we control the flow of current through that dipole. For maximum performance, the value of the impedances shown in Fig. 4 must be such that each dipole receives an equal amount of current. At first glance the solution would seem to be that since they are all in parallel, the impedances should be equal, and therefore, equal current would flow in each dipole. It must be borne in mind that these impedances occur in a travelling wave antenna and each impedance is separated from its neighbor by a significant portion of a wave length.

THE MAJOR ACHIEVEMENT IN THE DESIGN OF THIS ANTENNA IS THE DEVELOPMENT OF A SERIES OF IMPEDANCES WHICH DECREASE IN MAGNITUDE FROM THE FEED POINT OF THE ANTENNA TO THE FRONT END, MAINTAINING THIS DESCENDING SERIES OF VALUES FOR EVERY INDIVIDUAL VHF CHANNEL.

This is best explained by considering the concept of *reciprocity*. It holds that the gain, directivity, and impedance characteristics of an antenna are the same for both receiving and transmitting. Since this is so, an understanding of this antenna will be simplified by considering it, for the time being, as a transmitting antenna.

Referring again to Fig. 4, it will be seen that the dipole of highest impedance must be at the feed point, with the impedances of the other dipoles in descending order. Since the dipole at the feed point has the highest Z, only a small controlled amount of the total current flows through it (about ⅙ of the total) and most of it continues down the harness. The impedance at the next dipole is the highest of all the remaining dipoles, and again only a small portion of the current is permitted to flow through it. The major portion of the current continues down the harness, which each impedance (dipole) getting a portion of the remaining current. The last impedance, farthest from the feed point, absorbs the remaining current.

In a travelling wave antenna any current which is not absorbed is reflected back up the harness, and this in turn, produces rear lobes. A terminating resistor, such as used on long wire rhombics, absorbs whatever power the dipole impedances do not. This resistor, together with the folded parasitic reflector *provides front-to-back ratios higher than 10:1 (relative voltage) on all low band channels.*

METHODS OF MAINTAINING DESCENDING IMPEDANCES

A point of major importance concerns the method of controlling the descending impedance values over the entire frequency range. The solution to this problem lies in "tapering" the lengths of the dipoles so that each dipole gets progressively shorter as you go from the feed point to the terminating resistor. The theory behind this involves the basic charac-

**W. W. Hansen, J. R. Woodyard — "A New Principle In Directive Antenna Design," Proceedings of the Institute of Radio Engineers, 26 March 1938.*

teristics of any dipole. Fig. 5 shows the typical spiral curve of the impedance of a dipole. The horizontal line indicates resistance of 0 to infinity. Inductive reactance is indicated by the area above the line, and capacitive reactance by the area below. Wherever the spiral crosses the horizontal line the dipole impedance is purely resistive, and the dipole is resonant. Points A, B, C, and D represent the 1st, 2nd, 3rd and 4th harmonics — or in effect, what happens when a dipole is ½, 1, 1½, and 2 wave lengths long. It is important to note that the dipole's characteristics are about the same between points A and B and between points C and D. The arc AB represents the impedance on the low band; arc CD, the high band.

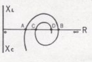

Fig. 5—Typical spiral curve of the impedance of a dipole.

Looking at the actual antenna it will be seen that the problem of having a very high impedance at the feed point was solved by using specially designed new type of 3-conductor dipole.

The next dipole is a hairpin type, which has better impedance characteristics than either a folded or straight type. It is cut so that it is a full wave on channel 6. Its characteristics, Fig. 6A, show that this dipole has its greatest low band impedance on channel 6, with the impedance decreasing with frequency. The same is true of the high band. The second dipole from the feed point is shown in Fig. 6B and the third in Fig. 6C. Since the remaining dipoles are progressively shorter, the frequency points of channels 2, 6, 7, and 13 would be farther to the left. In other words, the shorter the dipole, the lower the impedance on each of the VHF channels. By comparing Fig. 6A, 6B and 6C, which represent dipoles A, B, and C in Fig. 7, it will be

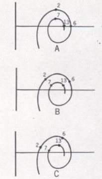

Fig. 6—(a) Impedance characteristics of the dipole nearest the feed point. (b) Impedance characteristics of the second dipole from the feed point. (c) Impedance characteristics of the third dipole from the feed point.

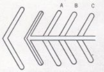

Fig. 7—Relative positions of dipoles described in Fig. 6. Impedances decrease from feed point to shortest dipole on all channels.

seen that no matter what channel we compare, the impedances of the dipoles decrease as we move from the feed point to the shortest dipole. This in turn creates the condition which guarantees that the current will be divided *equally* between all of the dipoles.

This is the most basic of the limitations which cannot be overcome by the parasitic elements of a yagi. As stated earlier, both the phase and the amplitude of the current flowing in each parasite is determined by the self-impedance of the parasites and the physical spacing between them. Since there is no way to make them variable with frequency as was accomplished with the travelling wave antenna, the broad band yagi has severe front-to-back limitations as well as major problems in broad band gain.

SMALLER MODELS DEVELOPED

Since there is an apparent reawakened interest on the part of TV servicemen in the mechanical strength of antennas, this new antenna design, which Channel Master calls the T-W, should attract added attention. The antenna utilizes *folded* elements exclusively. This provides tremendous physical advantages. Each fold is, in effect, a truss and actually 25 times stronger than a straight dipole of the same tubing under normal operating conditions.

The structure of the antenna is strengthened still further by an unusual type of "boom bracing." This too employs the truss principle. The "boom" actually amounts to a second full-length crossarm, joined to the basic crossarm by aluminum truss members. The entire "twin boom" unit is completely and permanently assembled in the factory by riveting.

The durability of this antenna — its exceptional resistance to excessive wind and ice loading — will appeal both to profit-conscious dealers and service-conscious consumers.

The original design project called for the development of an antenna for deep fringe use —very high gain and very high front-to-back ratios. This led to the development of the 7-element Travelling Wave Antenna—described and illustrated above. However, this antenna lent itself ideally to modifications for both suburban and near-fringe application. As a result, 3 element and 5 element models have been developed to provide improved reception and durability for these areas as well.

When the first high gain tripole yagi was introduced by Channel Master laboratories, many had the feeling that antenna design, performance-wise, was reaching the end of the trail. They underestimated the power of creative research. It has taken two years of concentrated development work to produce the T-W. Embodying new ideas and an entirely new approach, it is a breakthrough of major proportions in antenna technology. It may be safely predicted that antenna development in the years to come will be largely based on the innovations in the T-W — the very first antenna design to make practical use of the super-efficient "Travelling Wave" principle.