THE MAGIC TEE AMPLIFIER AND DISTRIBUTION SYSTEM PERFORMANCE

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ABSTRACT

Various Hybrid Amplifier Circuit Configurations are being used in CATV Distribution equipment to improve output capability and provide better reliability.

The MAGIC TEE AMPLIFIER Configuration, which is the utilization of two Hybrid Integrated Circuits in parallel, will be treated in depth in this paper. An analysis of the circuitry and the performance characteristics that can be expected in the normal operating mode and various failure modes will be discussed.

Gain variation, Distortion and Noise Figure performance characteristics are compared to those of the conventional single hybrid circuit. Specific System Performance Degradation Analysis and Measurement data will be presented for MAGIC TEE AMPLIFIERS operating in "soft" failure modes. Also, the performance of MAGIC TEE and conventional single hybrid trunk amplifier cascades is compared.

INTRODUCTION

In response to the demand for cable television signal distribution equipment which has the capability of providing acceptable distortion performance with an ever increasing television signal load, equipment manufacturers are constantly looking for new technology and novel ways to use existing technology. Hybrid integrated circuit technology is continually being advanced as equipment manufacturers constantly convey the need for better distortion performance to the vendors of these circuits. However, the responsibility for improving equipment performance does not rest on the shoulders of the hybrid amplifier manufacturers alone. The equipment manufacturers must also be creative in approaching this problem and do whatever they can to improve the distortion performance of the equipment they supply.

While it is true that the basic distortion performance of cable television signal distribution equipment is controlled by the individual hybrid amplifier performance, the overall performance of this equipment can be improved by using these hybrid amplifiers in various circuit configurations. The MAGIC TEE amplifier is one of the circuit options available to equipment manufacturers which, when used as the output stage amplifier in distribution equipment, provides several advantages over the traditional single hybrid amplifier output stage.

THE MAGIC TEE AMPLIFIER

The basic form of this amplifier has been known to engineers for many years. However, as so often happens, the advantages of this circuit were not necessitated in cable television system distribution equipment until recently. Significantly better distortion performance, relative to the traditional single hybrid amplifier circuit, is the main reason for implementation at this time. However, there are other advantages provided by this circuit which will be detailed as the operation is explained. Figure 1 contains a block diagram which shows the major components of the Magic Tee amplifier.

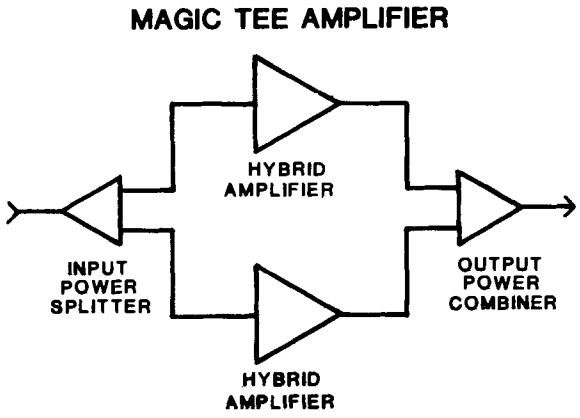


FIGURE 1

The components at issue in this circuit are the input power splitter and the output power combiner. Both of these circuits are constructed exactly the same and are of the circuit configuration known as the Magic Tee. The generally accepted schematic diagram for this circuit is contained in Figure 2.

MAGIC TEE CIRCUIT

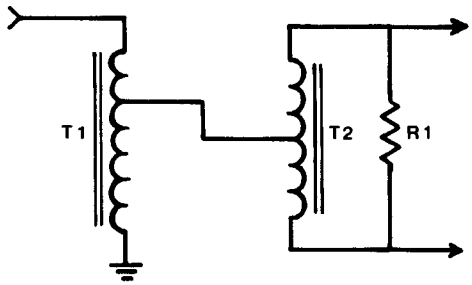


FIGURE 2

The importance of this circuit lies in the fact that it can be used to split a signal or combine two signals with a theoretical loss of 3 decibels. It also provides good isolation between the two output ports when used as a signal splitter and good isolation between the two input ports when used as a signal combiner. The significance of this port to port isolation will be explained later in this paper. The other two major components of the Magic Tee amplifier are the hybrid integrated circuit amplifiers. Let us assume that these are standard units available from several manufacturers.

In order to explain the operation of the Magic Tee amplifier, a signal flow diagram with signal level magnitudes at various key circuit locations will be used. For comparison purposes, a single hybrid integrated circuit amplifier is also provided. Both diagrams are contained in Figure 3.

Part "A" of this figure illustrates the performance that can be expected from a single hybrid. The amplifier output level and noise figure formulas are as follows:

$$OL = IL + HG$$

where: OL = Amplifier output level

IL = Input level

HG = Hybrid amplifier gain

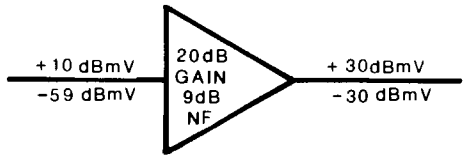
$$NF = ONL - INL - HG$$

where: NF = Noise figure

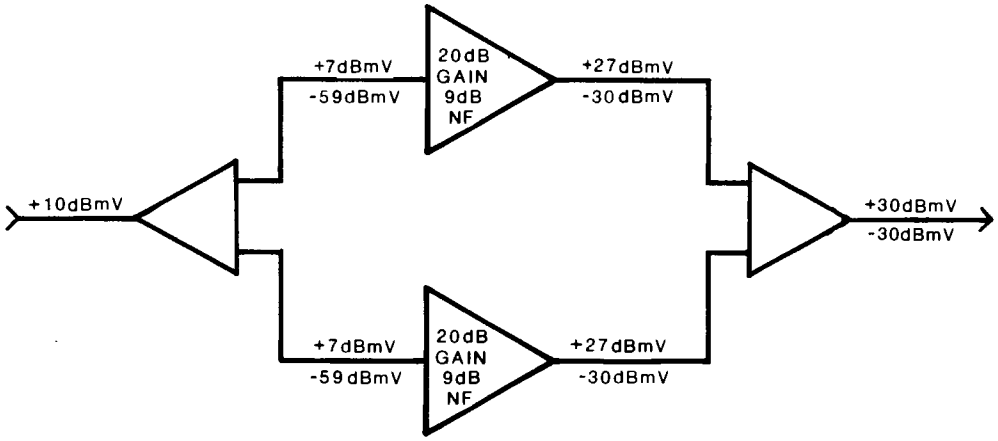
ONL = Output noise level

INL = Input noise level

HG = Hybrid amplifier gain



PART A



PART B

FIGURE 3

Part "B" of Figure 3 illustrates the theoretical performance that can be expected from a Magic Tee amplifier. The amplifier output level and noise figure formulas are as follows:

$$OL = IL + SHG$$

where: OL = Amplifier output level

IL = Amplifier input level

SHG = Single hybrid amplifier gain

$$NF = ONL - INL - SHG$$

where: NF = Noise figure

ONL = Output noise level

INL = Input noise level

SHG = Single hybrid gain

The operation of the single hybrid amplifier is straightforward. However, the operation of the Magic Tee amplifier is not as obvious. Therefore, a detailed explanation will be offered.

The key to correctly analyzing the operation of this amplifier is to view it as two hybrid amplifiers operating in parallel because this is exactly the case. The input splitter provides a signal to the input of each hybrid which is 3 dB lower than the signal level at the splitter common terminal. The output of each of the hybrids is attenuated 3 dB by the output signal combiner. Therefore, at the combiner common port there are two in phase signals which are 3 dB lower in level relative to each of the hybrid amplifier output levels. If both of these signals are of equal level then they will combine on a voltage basis producing one signal which is 3 dB higher in level relative to each of the hybrid amplifier output levels. If the output levels of the individual hybrid amplifiers are not equal then the two signals will combine on a voltage basis to produce one signal which will be less than 3 dB higher in level relative to the higher of the two hybrid amplifier output levels.

When analyzing the noise performance of the Magic Tee amplifier, the standard -59 dBmV must be used directly at the input to the individual hybrid amplifiers, not at the common terminal of the input splitter. The noise level at the output of each of the hybrids is attenuated 3 dB by the output combiner and these two signals arrive at the combiner common terminal. If the noise levels are equal then the resulting noise level will be 3 dB higher and will be equal to the noise output level of each of the hybrid amplifiers. It is important to note that at the output combiner of the Magic Tee amplifier the two signal voltages are coherent and therefore will add on a voltage basis. The two noise voltages will add on a power basis because they are incoherent as a result of being generated independently in each of the hybrid integrated circuit amplifiers.

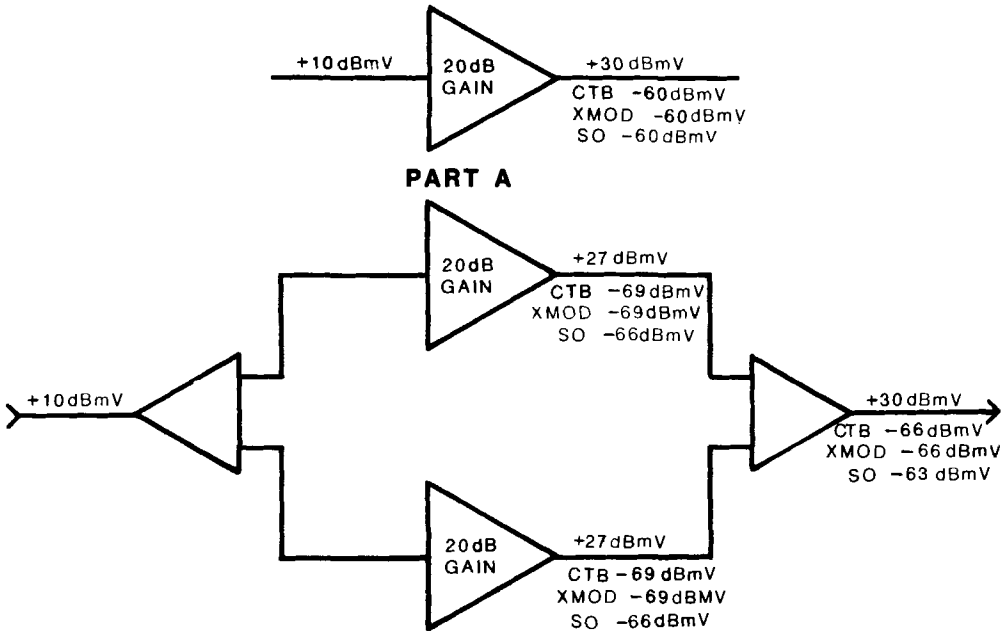


FIGURE 4

The distortion performance of the single hybrid amplifier and the Magic Tee amplifier are illustrated in Figure 4. The gain and signal levels are the same as those used for the previous exolanation. The arbitrary output capability chosen is maintained for both types of amplifiers.

The distortion performance improvement of the Magic Tee amplifier over the single hybrid amplifier can be directly attributed to the lower output level of the Magic Tee amplifier hybrids while still achieving the same total amplifier output signal level. As can be seen in Figure 4B, the theoretical output level of the hybrids will be 3 dB lower than the output level of the single hybrid amplifier which equates to an output capability improvement of 3.0 dB. Therefore, the relative distortion improvement for second order distortion products will be 3 dB and the relative distortion improvement for third order distortion products will be 6 dB. This distortion performance improvement holds true as long as the distortion contribution from each of the hybrids is the same. If the distortion contribution from the hybrids is not the same in terms of magnitude, then the Magic Tee amplifier averages the two distortion levels. The relationship between the distortion level difference between the hybrids used in a Magic Tee amplifier and the total distortion from the Magic Tee amplifier can be seen in Figure 5.

Refering to Figure 5, if the third order distortion contribution from each of the hybrids is the same, then the Magic Tee amplifier will provide a 6 dB distortion advantage relative to one of the hybrids providing the same output level. However, if the distortion contribution from each of the hybrids is not the same, then the Magic Tee amplifier tends to average the contributions from each of the hybrids. For example, if there is a 4 dB difference between the distortion contribution from each of the hybrids, then the total distortion level from the Magic Tee amplifier will be 3.75 dB better than the best hybrid in the circuit and 7.75 dB better than the worst hybrid in the circuit. It is significant to note that this inherent distortion performance averaging provides more consistent overall distortion performance and tends to minimize the normal performance distribution of the hybrid integrated circuits.

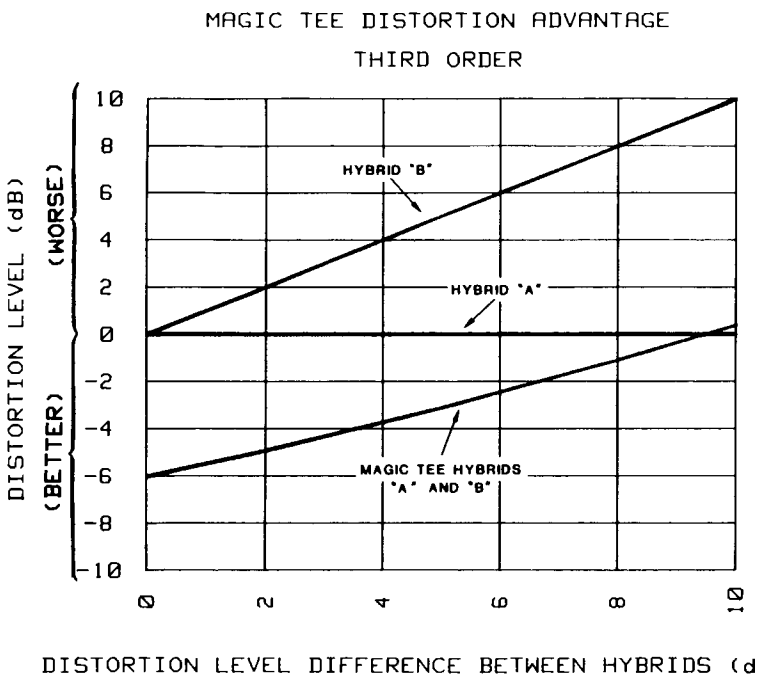


FIGURE 5

Practical Applications

In practice, not all of the theoretical advantages are achieved. This is due primarily to the fact that the loss of the splitter and combiner exceeds the theoretical 3 dB loss by approximately 0.5 dB. This condition causes the signal arriving at the input to the hybrids to be 0.5 dB lower than the single hybrid case. This of course causes an apparent noise figure increase of 0.5 dB. Correspondingly, the signal level out of the hybrids must be approximately 0.5 dB higher than the theoretical signal level in order to produce a total amplifier output level equal to the single hybrid amplifier output level. Therefore, a real world Magic Tee amplifier provides 1 dB less gain, 2.5 dB second order distortion advantage and 5 dB third order distortion advantage relative to the single hybrid amplifier.

Laboratory Test Results

In order to verify the anticipated performance of the Magic Tee amplifier, relative to the single hybrid amplifier, many laboratory experiments have been conducted. The test data obtained from some of these experiments provides valuable insight into the real world performance of the Magic Tee amplifier.

Of primary importance is the gain provided by the Magic Tee amplifier relative to a single hybrid amplifier. The Magic Tee amplifier will provide approximately 1 dB less gain than one of the hybrids that is used in it. This condition results due to the greater than theoretical loss of the input splitter and output combiner. While this is an apparent disadvantage, there are advantages which are offsetting.

One of the advantages relative to the single hybrid amplifier becomes obvious when catastrophic hybrid failures are considered. If a single hybrid amplifier fails catastrophically, then there will be a signal level reduction of approximately 40 dB at the place of occurrence in the system. However, if one of the hybrids in the Magic Tee amplifier fails catastrophically, there will be a signal level reduction at the place of occurrence in the system of approximately 6 dB. This limited gain reduction is made possible by the isolation capabilities of the Magic Tee circuit. If a circuit is used which does not provide isolation from one hybrid to the other, such as a transformer, then signal level reductions of approximately 20 dB can be expected if one of the hybrids fails catastrophically. Supporting test data is provided in Figures 6 and 7.

MAGIC TEE CIRCUIT WITH ISOLATION
GAIN REDUCTION UNDER VARIOUS CONDITIONS

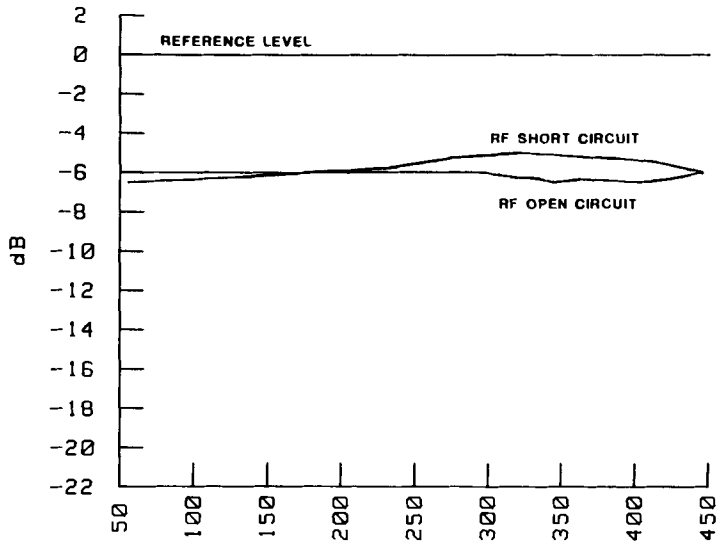


FIGURE 6

Figure 6 shows the gain reduction which resulted when catastrophic failure of one of the hybrids was simulated in a Magic Tee amplifier. Notice that for both the RF open circuit condition and the RF short circuit condition the gain reduction was close to 6 dB. When various "soft" failures of one of the hybrids was simulated, the resultant gain reductions fell between the reference and the open circuit plots. However, when this experiment was repeated using input and output circuits which provided very little isolation between the hybrids, the results were significantly different. This is illustrated in Figure 7. A low frequency gain reduction of approximately 20 dB was observed when a RF open circuit was simulated in one of the hybrid amplifiers.

TRANSFORMER CIRCUIT WITHOUT ISOLATION
GAIN REDUCTION UNDER VARIOUS CONDITIONS

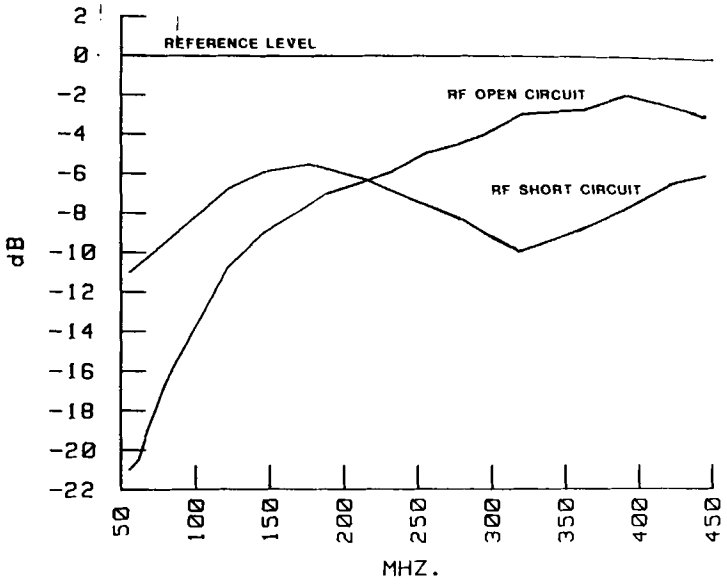


FIGURE 7

Therefore, in order to have as much control as possible over the resultant amplifier gain when a hybrid fails catastrophically, the input power splitter and the output power combiner must provide good isolation between the hybrids.

Distortion Performance

In order to establish a reference against which the performance of the Magic Tee amplifier could be compared, two hybrid integrated circuit amplifiers were characterized for distortion and noise figure performance. The two hybrids were then used in a Magic Tee amplifier and the same characterizations were performed.

60 CHANNEL COMPOSITE TRIPLE BEAT PERFORMANCE
OUTPUT @ +32dBMV W/6dB TILT.

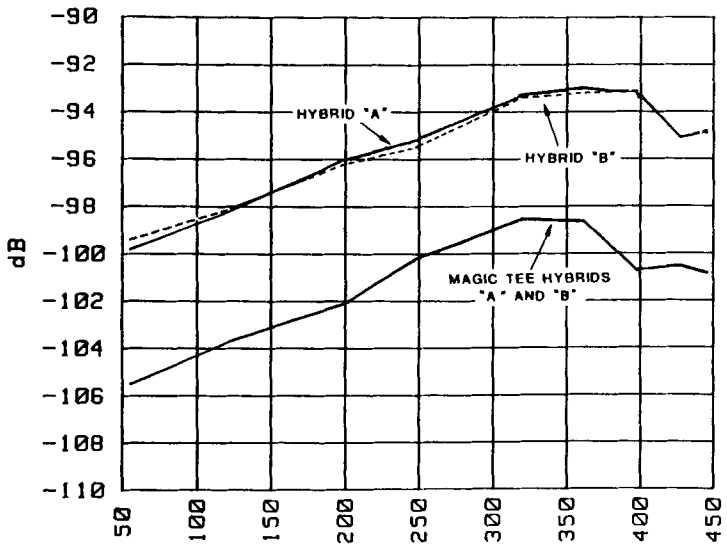


FIGURE 8

The composite triple beat performance obtained from each of the hybrids and the Magic Tee amplifier are contained in Figure 8. This comparison process was repeated for cross modulation and noise figure. The cross modulation data is presented in Figure 9 and the noise figure data is presented in Figure 10. In all cases the modified theoretical performance as detailed earlier was obtained. Note: In all cases, the distortion performance, at the typical trunk operating

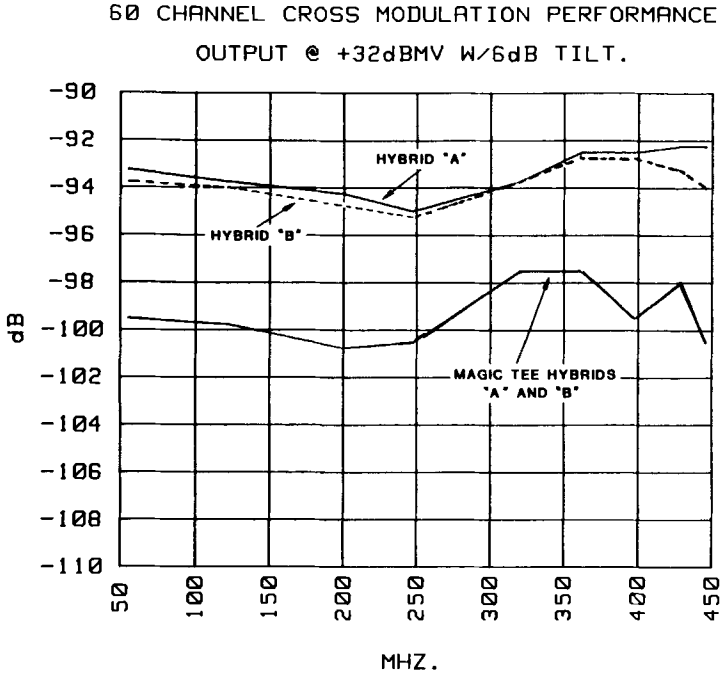


FIGURE 9

level of + 32 dBmV, has been projected from data obtained at higher output levels.

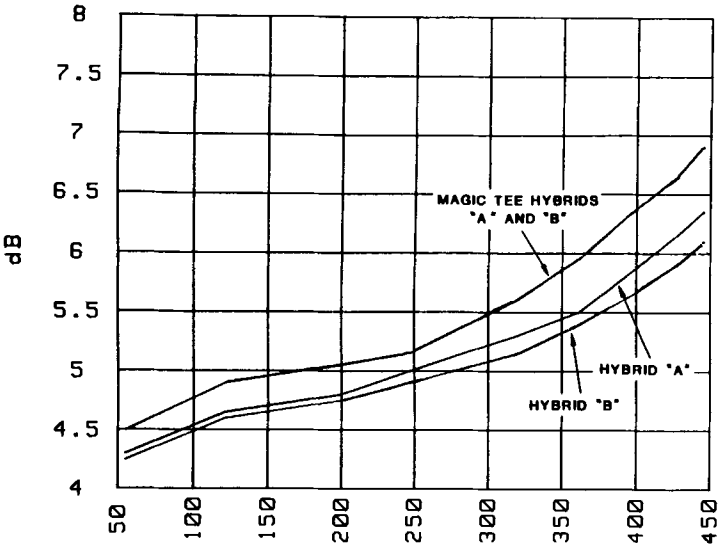


FIGURE 10

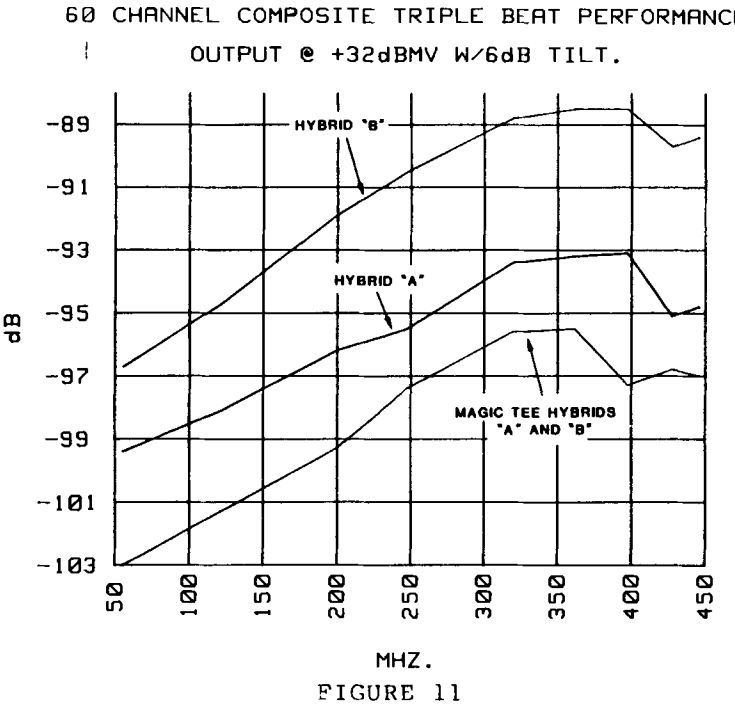


FIGURE 11

Due to the obvious significance of the theoretical distortion averaging capability of the Magic Tee amplifier circuit, an experiment was designed to prove or disprove this advantage. Two hybrids with significantly different composite triple beat performance capabilities were used in a Magic Tee amplifier circuit. The distortion performance obtained from each of the hybrids and the complete amplifier circuit are shown in Figure 11. The data clearly shows that the theoretical analysis presented earlier in this paper is correct when modified to reflect the real world performance in terms of distortion, of the Magic Tee amplifier.

System Performance Data

Eight trunk amplifiers were cascaded in order to verify that the distortion performance improvement observed for a single Magic Tee amplifier would also manifest itself when several amplifiers were cascaded. For comparison purposes, a cascade of traditional single hybrid output stage amplifiers of the same length was also constructed. While all operating conditions for the two cascades were maintained identical, substantially different distortion performance results were obtained from each. The composite triple beat performance of each cascade is contained in Figure 12. The cross modulation performance of each cascade is contained in Figure 13.

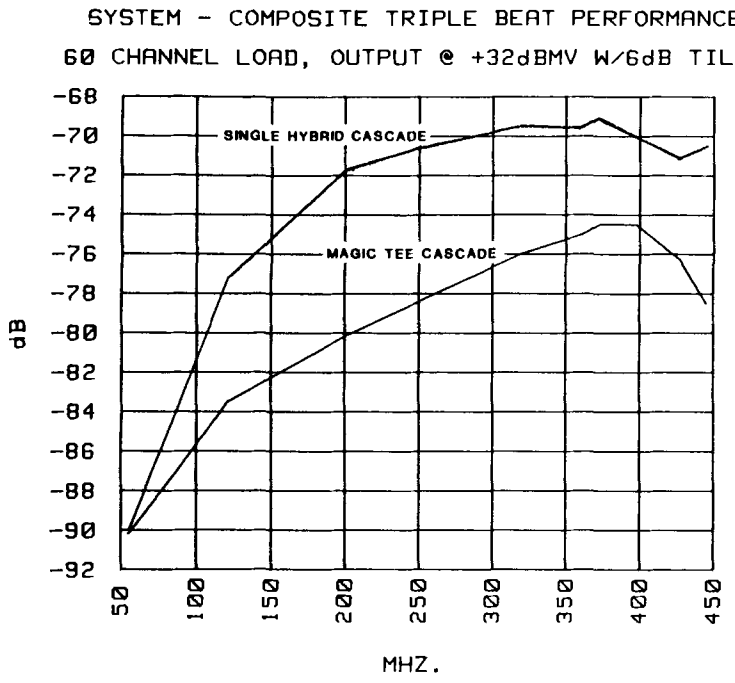


FIGURE 12

Figures 12 and 13 clearly indicate that the composite triple beat and cross modulation distortion performance of a Magic Tee amplifier cascade will provide the anticipated distortion improvement based on individual amplifier performance. It is for this reason that the Magic Tee amplifier is gaining widespread acceptance.

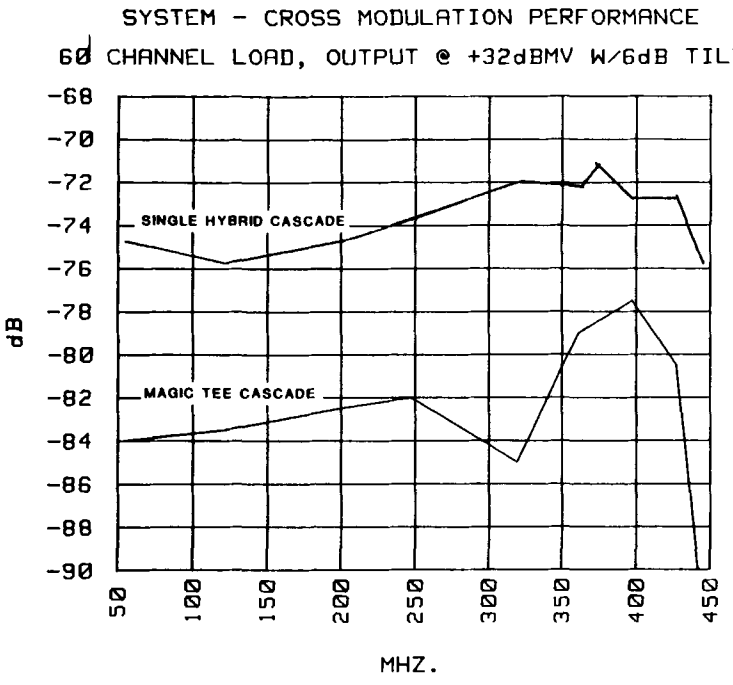


FIGURE 13

The second order performance of trunk amplifier cascades containing Magic Tee amplifiers will be the subject of a future paper. Phase matching and inverting techniques that can be used with this basic circuit configuration provide substantial latitude by which this distortion form can be minimized.

SUMMARY

In response to the demand for cable television system distribution equipment which can provide improved distortion performance, the Magic Tee amplifier has been implemented. This amplifier circuit is composed of a Magic Tee input power splitter, a Magic Tee output power combiner and two hybrid integrated circuit amplifiers. In theory, this amplifier will provide the same gain and noise figure, a 3 dB second order advantage and a 6 dB third order advantage relative to a single hybrid amplifier. In practice, due to the higher than theoretical loss of the input power splitter and the output power combiner, the Magic Tee amplifier provides approximately 1 dB less gain, 0.5 dB worse noise figure, a 2.5 dB second order advantage and a 5 dB third order advantage relative to a single hybrid amplifier. Inherent hybrid amplifier distortion averaging and limited gain reduction when one of the hybrid amplifiers fails catastrophically are other features of the Magic Tee amplifier.