# Modal Analysis of an Antenna Feed System for a Multimode Monopulse Radar

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**Abstract-**A modal analysis for a practical multimode monopulse feed system is presented. Simulations for the complete system are performed. Measurements for different target positions in the 9-10 GHz frequency range are carried out to verify the modal analysis and the simulation results. Measurements showed excellent agreement with the analytical and simulation results

## 1. INTRODUCTION

Monopulse technique is commonly used in modern radars and communication systems for tracking targets or communicating partners because of its high angular accuracy [1]. Monopulse refers to the ability to obtain complete angle error information on a single pulse. The aim of monopulse radar is to generate the signals required for E and H plane error channels (azimuth, and elevation) [2].

The main techniques are to use either multiple antennas or multi-mode waveguide propagation feed systems [2]-[4]. The last technique is found to be better in terms of size, complexity, and accuracy. A proposed structure assembly based on this technique is designed, simulated, implemented, and measured in the 9-10 GHz frequency range.

## 2. Multi-Mode Feed System

A dielectric loaded E-plane rectangular waveguide horn is used. The horn is dielectric loaded in order to allow the propagation of the desired higher order modes [$TE_{01}$, $TE_{10}$, $TE_{20}$, $TM_{11}$, and $TE_{11}$]. The horn is extended by a non standard waveguide allowing the propagation of the previously mentioned modes.

The dimensions of the waveguide and the dielectric constant of the partially filling dielectric material are chosen such that no other higher order modes are allowed to propagate. Figure 1 shows the E-field distribution for the different propagating modes. Modes $TM_{11}$ and $TE_{11}$ are generated together due to offset in the incident waveform. These 2 modes are super imposed forming the field distribution shown in figure 1 (f).

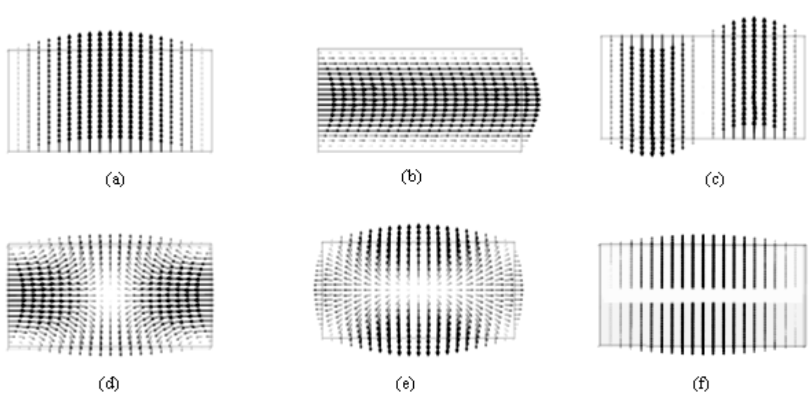


Figure 1. Different propagating waveguide modes; (a) TE01 (b) TE10 (c) TE20 (d) TM11 (e) TE11 (f) TM11 + TE11

### 3. Modal Analysis

When the incident wave-front is on the antenna axis, the source is symmetrically excited, or more exactly, the distribution of the field on the horn aperture is even. In this case, only $TE_{10}$ mode is transmitted by the horn.

If the incident wave-front is offset in plane H of the horn, the diffraction pattern moves along X-axis of the horn aperture (Azimuth). The excitation becomes asymmetrical, such that higher order modes will propagate. The filtering action of the horn propagates only modes $TE_{10}$ and $TE_{20}$.

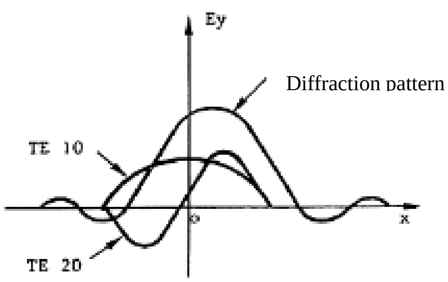


Figure 2. Diffraction pattern in X-plane (azimuth)

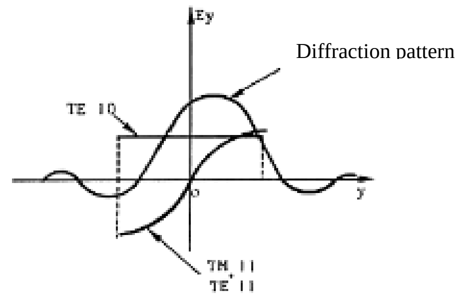


Figure 3. Diffraction pattern in Y-plane (elevation).

Finally, if the incident wave-front is offset in plane E of the horn aperture, the diffraction pattern moves along the Y-axis of the horn aperture (Elevation). This asymmetric excitation produces modes $TE_{10}$, $TM_{11}$, and $TE_{11}$.

As a result of the diffraction patterns given in figure 2 and 3, $TE_{10}$ mode is used for the sum channel. For any small movement of the diffraction pattern in front of the horn aperture, a corresponding variation occurs in the amplitude of the $TE_{10}$ mode.

On the other hand, for a certain movement of the diffraction pattern in front of the horn aperture, not all the amplitudes of the other higher order modes [$TE_{20}$, $TM_{11}$, and $TE_{11}$] vary considerably. The main feature of the field distribution of the higher order modes is being odd (pass through zero at the center of the horn aperture and change sign). Therefore, these modes are able to provide angular discrimination information concerning the wave-front, i.e. generation of error signals.

### 4. System Simulations

A 3D model for the proposed monopulse feed system is built up in order to be used in the performed simulations.

#### A. Sum Channel

The sum channel signal is the amplitude of the $TE_{10}$ mode which passes through the main non standard rectangular waveguide.

The output port at which the sum signal is received should allow the propagation of $TE_{10}$ mode only and isolate any higher order modes. Thus, the insertion loss between the output and the input of the sum channel for different propagating modes is simulated. The results show that the only propagating mode will be $TE_{10}$, which is the dominant mode, while all other modes will be suppressed.

#### B. Azimuth Channel

The azimuth channel is formed by two slots machined in the wider wall of the main guide. These 2 slots are connected to two guides placed against the source body. These two guides are combined by a folded magic-T.

Considering reception, the incident $TE_{20}$ signal excites the slots in phase-opposition and consequently the two lateral guides which produce the difference signal on the elevation channel.

The insertion loss of all modes at the output of the azimuth channel w.r.t. the input is shown in the following figure. The simulation results show that only $TE_{20}$ mode will propagate, while all other modes will decay.

**C. Elevation Channel**

The elevation channel is formed by a slot machined in the side wall of the main guide. The slot is connected to a guide perpendicular to the main body.

The sum signal, altogether with the difference signal at the input of the main guide create $TE_{11}$ and $TM_{11}$ modes. These 2 modes combine together forming the field distribution given in figure 2(f).

The insertion loss of all modes at the output of the elevation channel w.r.t. the input is shown in the following figure. The simulation results show that only $TE_{11}$ and $TM_{11}$ modes will propagate, while all other modes will decay.

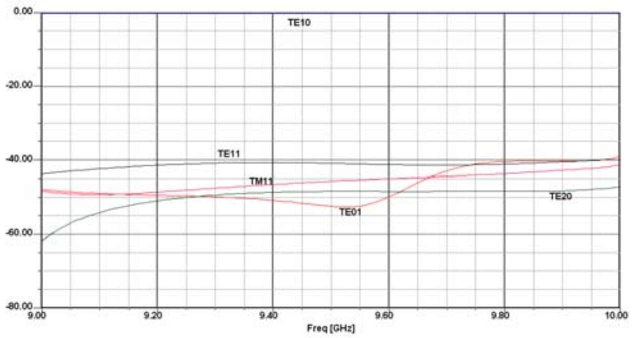


Figure 4. Insertion loss for different modes between input and sum channel

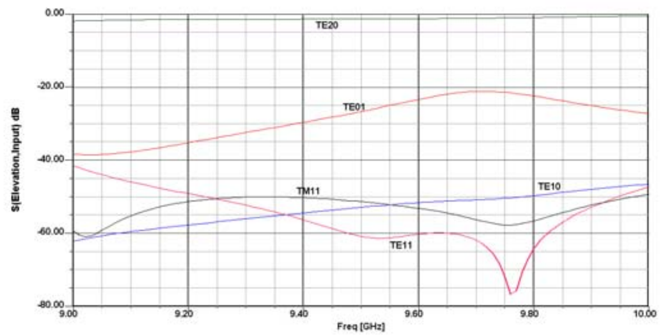


Figure 5. Insertion loss of all modes at the output of the azimuth channel

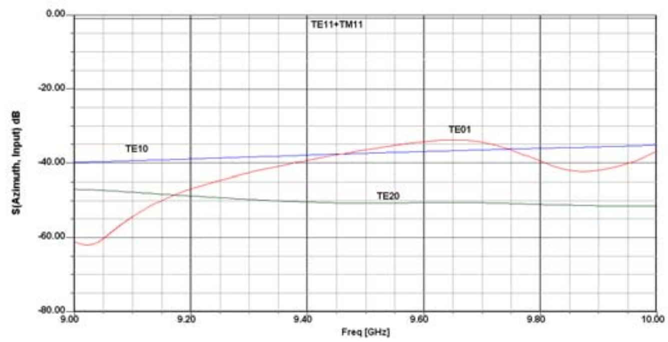


Figure 6. Insertion loss of all modes at the output of the elevation channel

## 5. Measurements

Measurements for the feed system are carried out to verify the modal analysis and the simulation results. To carry out the measurements the monopulse feed system is mounted and a transmitting horn antenna is placed at different positions; bore sight, elevation and azimuth. The horn antenna and the monopulse feed system are connected to the two ports of a network analyzer. The transmitting horn is placed at different positions the output from each channel (sum, elevation, and azimuth) is measured with the other two ports matched.

Measurements are carried out in the 9-10 GHz frequency band [X-band]. The channels output are measured at five positions (bore sight, $+20^{o}$ elevation, $-20^{o}$ elevation, $+20^{o}$ azimuth, and $-20^{o}$ azimuth) in order to verify the multimode monopulse theory.

Table 1 provides the results of the simulated and measured data for all channels at different target positions.

Table 1 Simulated vs. measured S-parameters for different modes [dB]

| | $TE_{10}$ | | $TE_{11} + TM_{11}$ | | $TE_{20}$ | |
|---|---|---|---|---|---|---|
| | ***Simulated*** | ***Measured*** | ***Simulated*** | ***Measured*** | ***Simulated*** | ***Measured*** |
| Sum | -0.2 | -0.8 | -42 | -30 | -50 | -30 |
| Azimuth | -40 | -30 | -2 | -3 | -50 | -30 |
| Elevation | -55 | -30 | -50 | -30 | -2 | -3 |

Its clear that there is an excellent agreement between theoretical, simulated, and measured data showing great understanding for the practical multi-mode monopulse feed system.

## REFERENCES

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