DESIGN TECHNIQUES FOR COMPACT MONOPULSE ANTENNA FEEDS FOR W-BAND RADAR SYSTEMS

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ABSTRACT - Radical differences between system requirements require great flexibility in the design process for the millimeter wave monopulse feed. This paper discusses design approaches used for three feed systems: a three channel multimode monopulse feed, a six channel dual linear polarized monopulse feed, and a four channel dual circular polarized monopulse feed. Each of these feeds was designed for a 94 GHz radar application.

Performance levels achieved for each of these feeds include >35 dB null depth, >30 dB cross polarization, sidelobe levels >25 dB down, comparator insertion loss of <1 dB, axial ratios of 2 dB, pattern symmetry to BW/15 of ≤3 degree, and boresight error of ≤1 milliradian.

The feed assemblies consist of brazed assemblies; package size varies from a volume of 8.0 cu. in. down to 0.32 cu. in., while cross sectional diameter ranges from 2.1 cu. in. down to 0.5 cu. in.

I. INTRODUCTION

Present day radars must be upgraded to detect and track multiple targets having reduced cross sections under the adverse conditions associated with clutter and bad weather. The need for lower development and production costs is a major goal of these upgrades. As a result, many evolving systems make use of existing hardware, requiring repackaging of the subassemblies to fit within system constraints. The resulting retrofit items must not only fit within a significantly reduced volume, but they must also usually improve system performance.

Development of novel packaging techniques and a monolithic approach for integrated assemblies has allowed attainment of these goals for three complex monopulse feed assemblies. These assemblies include a three channel multimode monopulse feed, a six channel dual linear polarized monopulse feed, and a four channel circularly polarized feed. Performance of these feeds is discussed and components unique to each assembly are described.

II. DESIGN CONSIDERATIONS

Each of the monopulse feed assemblies consists of several individual components. Components which are common to all three feed systems include the magic tee hybrids which form the monopulse comparators and the corrugated horns. Components not shared by all assemblies include the moder, the mode launcher, the quad planar OMT and the dual circular polarizer.

The moder couples several incoming waveguide modes into a comparator where the sum and difference channels are separated. In this type of structure, special care must be taken with regard to phase slope and its compensation in order to ensure accurate tracking. The mode launcher couples the desired aperture modes to the moder section. This transducer has a pronounced effect upon null depth, match and cross polarization. The quad planar orthomode transition (OMT) must preserve pre-comparator phase equality and permit the coupling of eight $TE_{1,0}$ waveguide ports to four square waveguide ports, while maintaining a common match and isolation between adjacent input ports. The dual circular polarizer permits dual sense operation of a crossed multiple slot array feeding a common waveguide.

System tracking performance is crucial in monopulse radar applications and, consequently, antenna null depth is important. Cross polarization, beam pointing, and null shift are other important factors to be considered in designing each monopulse feed assembly.

III. THREE CHANNEL MULTIMODE FEED

The three channel multimode feed is used in a multiple reflector antenna system. This comparator/feed assembly is the interface between the existing transceiver and reflector assemblies, and consists of four major components, as noted in Figure 1. These components include the feed, the mode launcher, the moder, and the comparator. The overall dimensions for the final assembly are noted in Figure 2.

THREE CHANNEL MULTIMODE

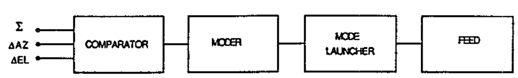

FIGURE 1

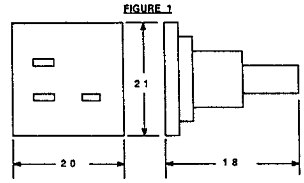

FIGURE 2

Feed

The feed horn for this assembly is a form of wide flare horn where the aperture is much larger than that normally associated with the aperture beamwidth factor; this results in low feed efficiency. In this case, the half power beamwidth is approximated by the flare angle.

The radiation pattern requirements for this system dictated the use of a corrugated horn, exhibiting nearly constant beamwidth over broad bandwidths for both the E and H planes and approximating circular symmetry. The radiated beam represents a Gaussian distribution to about the -15 dB level. At this point the pattern begins to broaden; sidelobe levels of -25 to -30 db can be maintained. The corrugation depth is selected to control the various modes within the flare for very low cross polarization levels. The circular symmetry of the feed radiation indicates the existence of a true phase center. The directivity of the corrugated feed increases to a maximum value with increasing aperture diameter, and then oscillates about a lower value.

Use of the corrugated feed in a reflector system can result in an increase in efficiency due to spillover reduction, and the presence of a true phase center, constant illumination taper, and circular symmetry .

Mode Launcher

The function of the mode launcher is the efficient transfer of energy from the comparator/moder to the feed. The corrugated feed is physically a circularly symmetric device and is fed by a circular waveguide, while the comparator/moder is a rectangular waveguide structure. System physical constraints do not permit the introduction of a long, tapered matching section. In designing the mode launcher, several factors must be taken into consideration; these include junction impedance mismatch, waveguide array factor, field linearity, and mode phasing.

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An impedance mismatch occurs at the junction between the two rectangular waveguides and the circular waveguide in the mode launcher; the mismatch is presented to both the $TE_{1,0}$ and $TE_{2,0}$ modes. This mismatch is corrected to a VSWR of 1.5:1 by using a symmetrical transformer section. Symmetry must be maintained within this section, since it is susceptible to mode excitation.

The impedance at this junction is also affected by the array factor, since in the vertical orientation the two rectangular waveguides act as two slots with an array factor, while in the horizontal orientation we effectively have a single slot and no array factor. The spacing between the two slots controls the radiated fields; by reducing the spacing between phase centers of the two slots as well as reducing the waveguide height we control the radiation such that the two orthogonal planes become symmetrical.

The abrupt step present in the waveguide at the junction creates field distortions which result in a modified phase front at the feed aperture. A section of uniform line could correct the field distortion but the form factor does not permit this. A modification was made to the junction resulting in a compensating field which corrected the distortion. This modification also has the beneficial effect of reducing the junction mismatch.

Finally, the mode launcher must present the proper conditions for controlling the phase velocity of the $TE_{2,0}$ mode; total path length for this mode should be an integral number of half guide wavelengths. This will ensure maximum transfer of $TE_{2,0}$ energy and will result in maximum peak levels for the associated difference pattern.

Moder

The moder section transitions from two rectangular waveguides, each propagating the $TE_{1,0}$ and $TE_{2,0}$ modes, to four waveguides propagating the $TE_{1,0}$ mode. Two waveguides are necessary so that in the vertical orientation the elevation difference function is realized; as noted in the previous section these two waveguides interface with the feed throat circular waveguide as a pair of slots. Thus, these two waveguides are 'stacked' with parallel H planes. The azimuth difference function can be realized by the $TE_{2,0}$ mode in a single waveguide.

The design for the transition between the dual mode waveguide and two single $TE_{1,0}$ mode waveguides is based upon that of a short slot hybrid or, more accurately, one half of a short slot hybrid. As noted earlier, the two stacked dual mode waveguides are reduced in height. This height reduction requires the introduction of transformers at each transition. A variable reactance (tuning screw) is also located in each waveguide section near the bifurcating junction. This screw provides a match for the $TE_{1,0}$ mode, while not affecting the $TE_{2,0}$ mode. Great care must be used in adjusting these elements; if the tuning screws in each junction are not set identically, elevation pattern peak unbalance and squint can result. The bifurcating vane, just behind the tuning screw, is located in the maximum field of the $TE_{1,0}$ mode and the minimum field of the $TE_{2,0}$ mode.

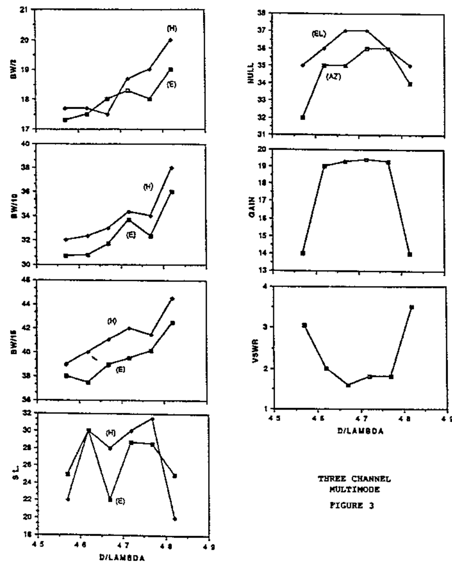
The dual mode waveguide section propagates the $TE_{1,0}$ and the $TE_{2,0}$ modes at different phase velocities, resulting in different phase slopes; this would ultimately cause tracking errors. The phase slope for the $TE_{2,0}$ mode approximates 60 degrees/inch and the $TE_{1,0}$ mode approximates 33 degrees/inch. Phase slope correction is accomplished within the comparator by introducing a compensating length of WR10 waveguide in both the sum and elevation channels. The phase slope calculation must be made for all components in the assembly propagating both modes. In this assembly, the compensation permitted channel-to-channel phase tracking of 1.1 degree.

Comparator

The comparator is a classical four hybrid assembly using magic tees in a tiered planar configuration. The magic tee was selected for its broadband characteristics and associated high isolation levels; this eliminates the need for tuning after assembly. The magic tee used in this application operates over the full waveguide band of 75-110 GHz with a maximum VSWR of 1.5:1 at any port, isolation of > 30 dB between sum and difference arms, and an insertion loss of 0.3 dB. Maximum VSWR and minimum isolation occur at the band edges. Waveguide distribution networks providing the interface to the transceiver were included within the comparator. The comparator was NC machined and oven brazed, using silver migration. This assembly process uses no flux and results in no fillets or obstructions in the waveguide. The finished comparator demonstrated a VSWR of 1.20:1, isolation of 35 dB, and an insertion loss of 0.8 dB.

Assembly Performance

Measured data for the three channel monopulse multimode feed assembly is displayed in Figure 3.



THREE CHANNEL MULTIMODE

FIGURE 3

IV. FOUR CHANNEL CIRCULAR POLARIZED FEED

The four channel circular polarized feed is used in a multiple frequency reflector system as a prime focus feed. Monopulse operation in both right hand and left hand circular senses is required. The feed assembly is not allowed to increase the existing blockage of the main reflector, and the system boresight should be coincident with the axis of the reflector. The four output channels are required to interface with existing WR10 waveguide flanges. The reflector focal point and blockage, and the waveguide interfaces define the physical configuration of this feed package.

The feed assembly consists of five components, as noted in Figure 4. These segments include the feed, field former, polarizer, transformer, and comparator. The overall dimensions of this assembly are noted in Figure 5.

FOUR CHANNEL DUAL CIRCULAR POLARIZATION

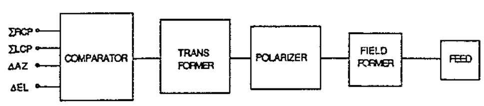


FIGURE 4

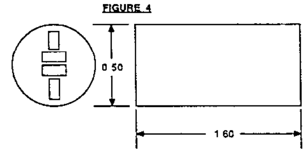


FIGURE 5

Feed

The feed horn for this assembly is a wide flare corrugated conical horn with operational characteristics similar to those previously described for the three channel multimode feed. This application requires the feed to effectively propagate circular polarization.

This requirement, along with the need to effectively illuminate the unblocked reflector area, requires a symmetrical feed.

Since this is a prime focus system, a wide radiated beam is required. The corrugated feed is a type of wide flare feed, having an aperture which increases in diameter as the beamwidth increases. Definition of the optimum flare angle and minimum aperture diameter for the desired illumination characteristics results in a feed diameter of 0.5 inches. This diameter was much less than the existing blockage diameter which shadowed it.

Field Former

The field former is an interface between the square waveguide in the polarizer and the circular waveguide in the corrugated feed. It must provide an impedance match, while maintaining field linearity and axial ratio, and suppressing higher order modes. The space allocated for this component was minimal, therefore, a symmetrical step transformer section with a reactive field linearizer preserved the axial ratio and transferred the circular polarization effectively. The transformer suppressed higher order mode formation while providing an impedance match.

Polarizer

The polarizer uses a dielectric vane in square waveguide to provide phase quadrature to the component vectors of a time varying field, converting left and right hand circularly polarized signals to linear signals. The output of the polarizer consists of a pair of slot arrays; each pair is oriented orthogonal to the other and is coupled to one linear polarization. A dielectric vane set 45 degrees to the orientation of each slot array should result in the desired conversion. This is true for the in-phase condition or the monopulse sum, where the dielectric vane is located in the maximum field, but when the out of phase condition exists or the monopulse difference is sampled, the vane is located in the minimum field. Therefore, a single dielectric vane does not result in equal axial ratios for the sum and difference channels. This has been corrected by the introduction of a second vane and the positioning of the two vanes such that they are 45 degrees to all four slots. This change has resulted in nearly equal axial ratios in both sum and difference channels; a maximum axial ratio of 2 dB has been measured.

The vane position, alignment, orientation, shape and material are all critical for maintaining symmetry and beam pointing. The fixed symmetrical positioning of the vanes also requires accurate positioning of the crossed slot arrays and their coupling fields. The polarizer is the largest component in the feed assembly lengthwise, but maintains the 0.5 inch diameter.

Transformer

The transformer is the interface between the polarizer and the comparator and couples between four WR10 waveguides and a single square waveguide. It contains a quarter wave section consisting of four slots with the two slot pairs oriented orthogonally. The transformer basically reduces the slot size and moves their phase centers closer together in order to reduce the array factor effect.

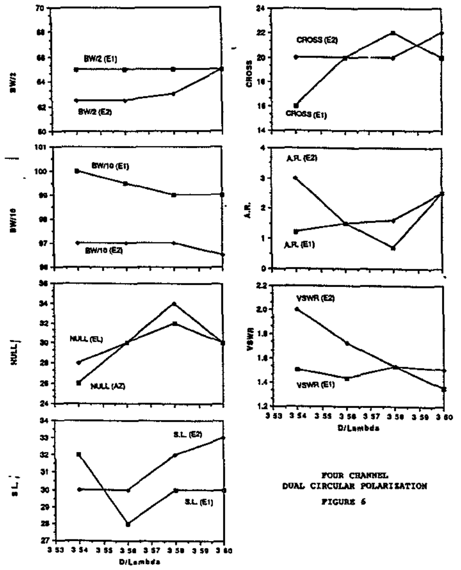
Comparator

The comparator uses two magic tees; one tee is connected to a pair of waveguides for vertical polarization, while the other tee connects to a pair of waveguides for the horizontal polarization. These pairs of waveguides are oriented to produce a pair of two-slot arrays which are orthogonal to each other. The comparator output contains a vertical sum, a horizontal sum, a vertical difference and a horizontal difference; the sum outputs correspond to the circular polarized signals at the feed input.

The crossed slot arrays make it difficult to connect the magic tees; a waveguide orienting section is introduced to correct this problem. The magic tees are then connected in a folded manner: one above the other. The design of the orienting section is not a trivial matter since it must maintain phase and amplitude balance while confined to the 0.5 inch diameter. The sections were NC machined, pin aligned and oven brazed using the silver migration technique. The result is a monolithic package. The comparator insertion loss was 0.55 dB.

Assembly Performance

Measured data for the four channel circularly polarized feed is shown in Figure 6.



FOUR CHANNEL DUAL CIRCULAR POLARIZATION

FIGURE 6

V. SIX CHANNEL DUAL LINEAR POLARIZED

The six channel dual linear polarized monopulse feed is used in a cassegrain antenna system. In this case the feed design is tailored for the specified sub reflector illumination taper. The sub reflector focal point, transceiver interface and the mechanical constraints of the reflector with its support structure define the physical configuration of this feed package.

The feed assembly consists of six major segments, as noted in Figure 7. These segments include the feed, field former, transmission line, orthomode transition, and two comparators. The overall dimensions for this assembly are noted in Figure 8.

SIX CHANNEL DUAL LINEAR POLARIZATION

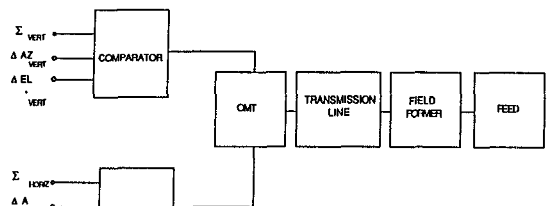


FIGURE 7

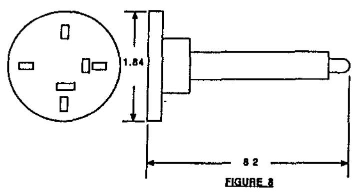


FIGURE 8

SIX CHANNEL DUAL LINEAR POLARIZATION

Feed

In this assembly, the feed must handle dual linear polarizations, thus, circular symmetry becomes extremely desirable. The corrugated conical horn is the obvious selection for this element. Operational requirements for this component are nearly identical to those of the horn for the three channel multimode assembly described earlier.

Field Former

The field former for this application is a transition section converting from square waveguide to circular waveguide. The sub reflector focal point location requires a relatively long length of transmission line between the comparator assembly and the feed. This permits the introduction of a multiple wavelength transition, producing a gradual change in impedance with minimal field distortion. The section is symmetrical, supports orthogonal fields, and presents a uniform field to the feed aperture.

Waveguide

A section of square waveguide is the interface between the field former and the orthomode transition of the comparator assembly. The single square guide is oversize; symmetry must be maintained to prevent moding. The advantages of the square guide over other types include lower transmission loss, presence of a common path for controlled pre-comparator phase, and the preservation of internal field orthogonality.

Orthomode Transition

The orthomode transition (OMT) is the principal component contributing to the proper operation of the feed system. At the input of the OMT the oversize square waveguide is transformed to four smaller square guides. Each of these square guides is then coupled to two WR10 rectangular guides. The resulting eight WR10 waveguide ports at the output of the quad OMT subassembly are configured in subgroups of four waveguides for connection to two comparators. In designing the OMT the impedance mismatch at the junctions must be minimized; efficiency of coupling to the orthogonal modes in the square waveguide will then be optimized. Isolation between the orthogonal modes must be maintained, and phase and amplitude balance should be sustained between the paths through the assembly.

Maintenance of phase balance between the eight output paths in the quad OMT assembly is crucial to system tracking performance. This need indicated a planar configuration with four input square waveguides located about a common axis and eight rectangular waveguides centrally located on the outer wall of each square waveguide.

Typically, an OMT has an axial port and a radial port feeding a common output port. The axial port is symmetrical while the radial port is not. The coupling method noted above uses all axial ports and would normally result in reduced isolation between ports unless an axial offset were introduced. Offsetting, in this case, would change the phase relations and relative mismatch between polarizations. The need to offset the radial ports was eliminated through the introduction of a multi-faceted back short resulting in a totally symmetric structure ahead of the comparators. This short structure, when properly located, also results in 30 dB isolation between orthogonal arms of each quadrant OMT and a 1.25:1 VSWR at each WR10 waveguide port.

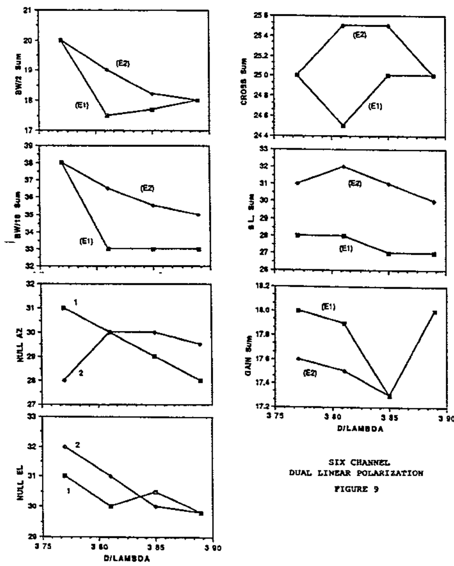
Packaging needs dictated the addition of H bends to all eight rectangular waveguide ports. This required segmentation of the OMT to permit NC machining of the H bends. The segments were fixtured in a common mounting flange and silver brazed, creating a monolithic package.

Comparator

There are two comparators required; one for horizontal linear polarization, the other for vertical linear polarization. The comparators are of the classical four hybrid design using magic tees in a tiered planar configuration. The two comparators required three tiers; the first tier contained four magic tees, while the remaining two tiers contained two magic tees each. The operation and construction of the comparators is as previously described in the three channel multimode section.

Assembly Performance

The response of the six channel dual linear polarized monopulse feed is shown in Figure 9.



SIX CHANNEL
DUAL LINEAR POLARIZATION
FIGURE 9

Conclusion

The retrofit process for subassembly design requires a great deal of design flexibility. Lower development and production costs dictate the use of existing techniques and designs wherever possible, however, system physical and electrical restraints can create the need for new designs in some portions of an assembly. The subassemblies described in this paper demonstrate this design process; the various feeds to a large extent rely on repackaging of existing components. However, the three channel multimode feed required a unique mode launcher, the four channel circular polarized feed required a unique polarizer, and the six channel dual linear feed required a unique quad planar orthomode transition.

These three systems, although employing many common components, do not operate with identical results. This can be seen by examination of Figures 3, 6, and 9. Interactions between components tend to modify the anticipated results; these interactions must be carefully evaluated during the design process to assess their likely impact on system performance. Retrofit engineering for microwave and millimeter wave system design is a creative process which must be adaptable to restrictions imposed by existing systems.

References

[1] P.J.B. Clarricoats and A.D. Oliver, corrugated horns for microwave antennas, Peter Peregrinus Ltd, 1984.