HIGH PERFORMANCE ANTENNA FEEDS AND COMPONENTS

FOR SPACE APPLICATION

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ABSTRACT

This paper describes how Custom Microwave Inc, CMI, combines its expertise in RF design with precision manufacturing to produce innovative high performance antenna feeds and components for space application. Several examples from L-Band to 1.2 THz are presented to demonstrate what can be realized.

1. INTRODUCTION

The availability of commercial precision RF CAD tools for the design of waveguide components is changing the development cycle and possibilities for antenna feeds. Without these CAD tools, engineers use rules of thumb and engineering approximations to create hardware that is often painstakingly tuned on the bench to meet specifications. This approach is not only very time consuming but has severe limitations when it comes to high performance hardware. With precision CAD tools, the development cycle is reduced to the point where prototypes are often not required. Performance is no longer limited by modelling but by what is practical to manufacture with precision.

2. RF DESIGN

RF design is performed at CMI using primarily commercial off the shelf precision CAD tools, such as µWave Wizard™ from Mician GmbH and CST from Computer Simulation Technology. These are used to optimize the performance of each component in the feed. The integrated feed assembly can also be optimized to improve system level performance. These tools provide the engineer with the ability to accurately predict RF performance of the antenna feeds and components without the need to build prototypes. In addition to CAD tools, the engineer needs a good understanding of and access to precision manufacturing.

3. MANUFACTURING

All of us have heard of "Design for Manufacturing" yet few truly practice the art. When it comes to high performance hardware, the engineer must have a good understanding of the limitations and possibilities of various manufacturing techniques. Unfortunately few engineers have exposure to manufacturing. knowledge of Geometric Dimensioning & Tolerancing (GD&T) is also not common. Yet this is the language with which the engineer conveys to manufacturing how to realize the hardware.

A good grasp of the various manufacturing techniques along with GD&T allows the engineer to take his or her design to a higher level of performance by incorporating this knowledge at the beginning of the design cycle.

CMI uses conventional machining on a CNC mill or lathe, Electro-Discharge Machining (EDM) by WIRE or Plunger, and/or Electroforming to manufacture high performance antenna feeds and components. The latter technique is less well known, but is well suited for very high precision manufacturing.

3.1. Electroforming Process

Electroforming is a process where a metal component is fabricated by electro deposition on a mandrel in a plating bath. Subsequent removal of the mandrel results in a shell with the desired internal features. The main steps can be summarized as follows:

1. A precision mandrel is machined from Aluminum, Stainless Steel, or Plastic
2. Plating (Gold, Silver, or Nickel), if required, is electro deposited on the mandrel
3. Copper, Silver, Nickel, or Nickel/Cobalt is then electro deposited to the desired thickness depending on structural requirements
4. The mandrel is removed mechanically or chemically
5. The final product exactly replicates the mandrel geometry.

3.2. Benefits of Electroforming

For space applications, it is often desirable to have high RF performance, low PIM, high power handling, low mass and small size. High RF performance is achieved by combining innovative concepts, precision design and precision manufacturing. Significant reduction in PIM generation is achieved by minimizing joints and eliminating tuning screws. The absence of tuning screws also helps to increase power handling capability. Small size can be achieved by close integration of the various components of the feed. Electroforming can provide many desirable features for space hardware. These can be summarized as follows:

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1. Very High Precision (±.0002" [5 µm])
2. Seamless construction of complex hardware
3. Integration of components into a single piece with no joints
4. Lightweight
5. Integral flange attachment with aluminum core for mass savings if required
6. Uniform internal plating
7. Excellent internal surface finish
8. Inspection of internal features on mandrel

For the past 40 years, CMI has been supplying hardware for space applications that offers the benefits listed above.

4. HARDWARE EXAMPLES

The following subsections provide examples of high performance antenna feeds and components produced by CMI.

4.1. L-Band Feed

CMI recently completed the Engineering Unit for an L-Band feed for space application. The challenge is to realize a design that is as compact as possible while still maintaining high electrical performance. Excellent agreement was achieved between simulation and measurement. The feed is shown in Fig. 1. Measured performance is listed in Tab. 1.

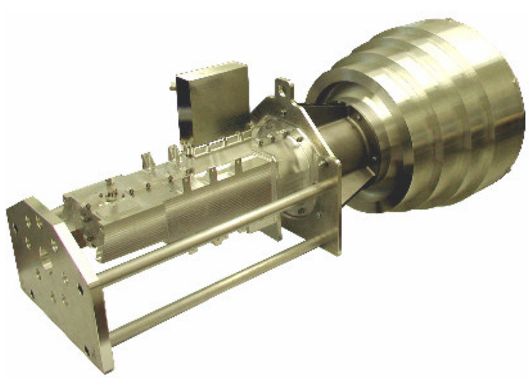

Figure 1. L-Band Feed-Courtesy NASA/ JPL

Table 1. L-Band Feed Measured Performance

Parameters	Measured
Frequency	1.25 – 1.46 GHz
Gain	> 16 dBi
Cross-Polar Isolation	> 35 dB
Sidelobe Level	> 29 dB
Return Loss V & H	> 20 dB
Isolation V to H	> 50 dB
Diameter	50 cm Max
Length	89 cm Max
Mass	8.3 Kg
RF Interface	Type N

4.2. S-Band Feeds

Several dual circularly polarized S-Band feeds have been developed to address the need for very compact layout, low mass and high power handling. These feeds are produced by conventional machining. Tab. 2 and Tab. 3 summarizes performance for two examples.

Table 2. S-Band Feed 1

Parameters	Performance
Frequency	2.32 – 2.33 GHz
Polarization	RHCP & LHCP
Gain	18.4 dBi
Sidelobe Level	> 32 dB
Cross Polar Isolation	> 40 dB
Return Loss	> 30 dB
Port-to-Port Isolation	> 30 dB
Peak Power	> 54 kW Multipaction
Length	45 cm
Diameter	37 cm
Mass	< 5.5 Kg

Table 3. S-Band Feed 2

Parameters	Performance
Frequency	2.32 – 2.33 GHz
Polarization	RHCP & LHCP
Gain	14.5 dBi
Sidelobe Level	> 32 dB
Cross Polar Isolation	> 38 dB
Return Loss	> 30 dB
Port-to-Port Isolation	> 30 dB
Peak Power	> 40 kW Multipaction
Length	42 cm
Diameter	23 cm
Mass	< 3 Kg

4.3. Extended C-Band Feed Network

A fully functional dual band, dual circular polarization C-Band feed network was designed, built, and tested in six months. The performance of the horn was accounted for in the design to ensure overall feed performance is met. This tuningless high performance electroformed network met all specifications without any design iterations. Three fully space-qualified feeds of the same design were then built and tested within another 6 months. The challenge faced in addition to the tight schedule was to design a unit with very low axial ratio within one-sixth the volume of the incumbent design.

Electroforming was used to achieve the tight tolerances required for this tuningless high performance device. The use of electroforming also allowed this complex network to be built with a minimum number of flanged joints.

Tab. 4 summarizes measured performance. The feed network is depicted in Fig. 2. Comparison between measured and simulated axial ratio performance is shown in Fig. 3 and Fig. 4 while Fig. 5 and Fig. 6 shows correlation for port to port isolation for the Tx and Rx bands respectively. Excellent agreement was achieved between measurement and simulation for all electrical parameters.

Table 4. C-Band Feed Measured Performance

Parameters	Measured
Frequency	Tx: 3.625 to 4.2 GHz; Rx: 5.85 to 6.425 GHz
Axial Ratio	Tx: < 0.2 dB Rx: < 0.1 dB
Insertion Loss	Tx: < 0.15 dB Rx: < 0.05 dB
Return Loss	> 30 dB
Isolation	Tx to Tx > 28 dB Rx to Rx > 28 dB Rx toTx > 60 dB
Peak Power	9 kW Multipaction
PIM	< -140 dBm
Size	30 cm^3
Mass	< 5.5 Kg

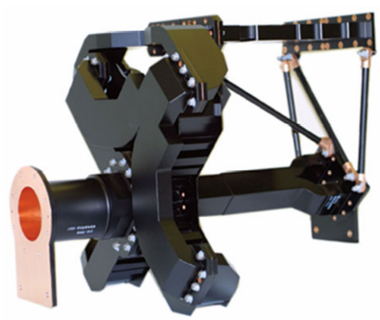

Figure 2. Extended Dual CP C-Band Feed Network

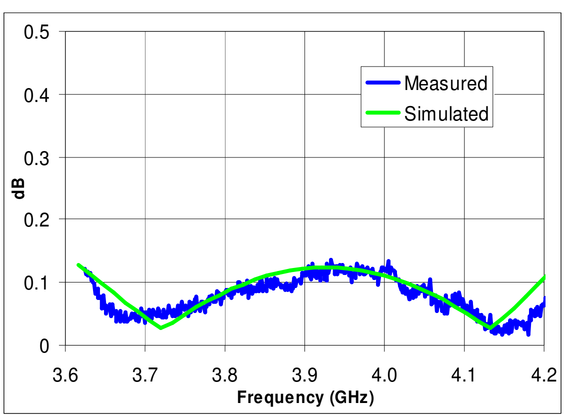

Figure 3. C-Band Feed Axial Ratio at Tx

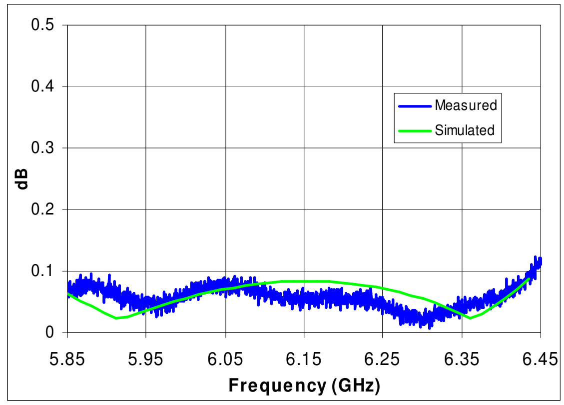

Figure 4. C-Band Feed Axial Ratio at Rx

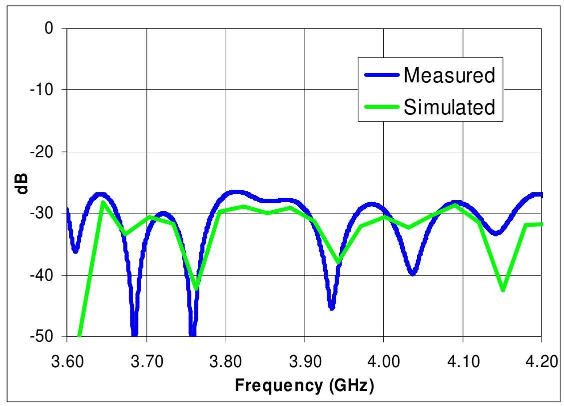

Figure 5. C-Band Feed Tx to Tx Isolation

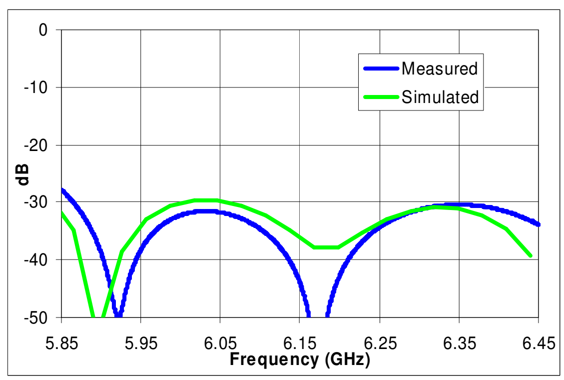

Figure 6. C-Band Feed Rx to Rx Isolation

4.4. X-X-Ka band Feed

This tri-band feed produced for NASA/JPL for the Deep Space Network can transmit dual CP at X-band, receive dual CP at X-band and provide dual CP sum and tracking signals at ka-Band. Electroforming was used where necessary to integrate components to achieve a low profile and to realize tight tolerances for internal features. It is worth noting that other manufacturing methods such as brazing was unsuccessfully used by JPL to manufacture the Ka-Band Tracking coupler. By using precision machining and electroforming, CMI was able to produce twelve working units with no rejects. The null depth for the difference pattern consistently measured > 35 dB for all units tested. Fig. 7 shows the X-X-Ka feed and Fig. 8 shows a close up of the Ka-Band Tracking Coupler.

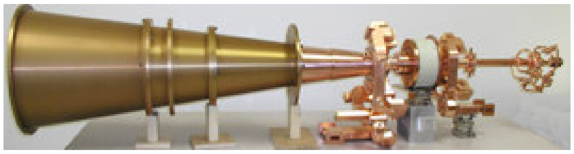

Figure. 7 X-X-Ka Feed- Courtesy NASA/JPL

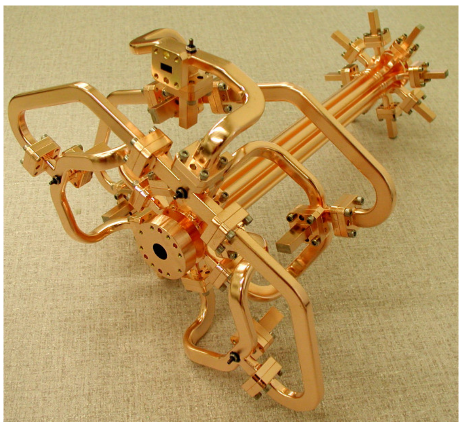

Figure. 8 Ka-Band 8-Way Tracking Coupler Courtesy NASA/JPL

4.5. K-Ka Band Network

A compact prototype K and Ka band, dual circular polarization network was designed, built and tested in 3 months. Thirty space-qualified units followed within 6 months. Measured performance for all 30 units was very consistent. This is a common trait associated with precision machining and electroforming, and good process control. Fig. 9 shows the feed network. The extension in front of the network was to accommodate existing layout. Measured performance is summarized in Tab. 5.

Figure. 9 K-Ka Band Dual CP Feed network

Table 5. K-Ka Band Dual CP Feed Performance

Parameters	Measured
Bandwidth	K-Band: 5% Ka-Band: 3%
Axial Ratio	K: < 0.2 dB Ka: < 0.1 dB
Insertion Loss	< 0.1 dB
Return Loss	> 30 dB
Isolation RHCP to LHCP	> 30 dB
Isolation	Ka to K > 50 dB
Power Handling	> 3.8 kW Multipaction
PIM	< -140 dBm
Size	< 10 cm^3
Mass	< 150 g

4.6. K-Ka Band Network for Feed Array

A low profile K and Ka band, dual circular polarization network has been developed for tight packaging in a feed array configuration. A fully functional tuningless prototype was designed, built, and tested within six months. The prototype feed network is depicted in Fig. 10. Measured performance is summarized in Tab. 6. A similar low profile K-Ka band dual CP feed network with tracking capability is currently under development at CMI.

Figure 10. Low Profile K-Ka Dual CP Feed Network

Table 6. Low Profile K-Ka Band Dual CP Feed

Parameters	Measured
Bandwidth	K-Band: 10% Ka-Band: 6%
Axial Ratio	K: < 0.34 dB Ka: < 0.13 dB
Insertion Loss	K: < 0.4 dB Ka: < 0.2 dB
Return Loss	> 28 dB
Isolation RHCP to LHCP	K: > 25 dB Ka: > 28 dB
Isolation	Ka to K > 75 dB
Power Handling	> 3.8 kW Multipaction
PIM	< -140 dBm
Diameter	< 5.6 cm
Length	< 15 cm
Mass	< 0.3 Kg

4.7. Flexible Waveguides

CMI produces a range of high performance flexible waveguide from WR137 to WR15 for space application. These are produced by electroforming copper (FWC) or an alloy of Nickel/Cobalt (FWN). Return loss is better than 30 dB across the entire waveguide band and insertion loss is very low, e.g. 0.1 dB/ft at Ku Band. Flanges with optional aluminum core are integral with the flexible waveguide to provide a truly seamless construction for high power low PIM application.

FWCs can be hand formed and will maintain its bent shape. They are used to accommodate tolerance stack up and to decouple vibration and thermal stresses. They are also much more flexible than beryllium copper or brass flex waveguides. FWN are ideal when extreme flexibility is required. They are well suited for deployment and scanning application.

Both FWC and FWN can be combined with rigid waveguides to eliminate interconnecting flanges. Fig. 11 shows some examples of electroformed flex waveguides with different internal and external finishes. The extreme flexibility of a WR51 Ni/Co electroformed flexible waveguide is illustrated in Fig. 12.

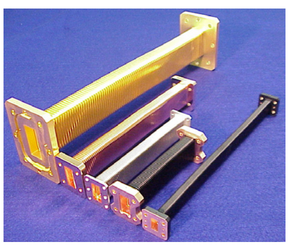

Figure 11. Examples of Electroformed Flex Waveguides

Figure 12. Extreme Flexibility of Nickel/Cobalt Flex

4.8. High Frequency Components

The following examples further demonstrate what can be realized by precision design and manufacturing. Fig. 13 shows a mandrel for a G-Band diplexer next to the copper electroform. Excellent agreement between measurements and simulation was achieved. Fig. 14 shows a 650 GHz corrugated feed horn for the EOS/MLS instrument. The input waveguide was 300x150 μm. Pattern measurements performed at JPL showed good symmetry and low sidelobes. Fig. 15 is a 40 mm x 20 mm array with 139 elements operating at 1.2THz. The input waveguide diameter is 150 μm and the feed element is about 20 mm long. Several arrays from 300 to 1.2THz were produced for NASA/JPL for the SPIRE instrument.

Figure 13. G-Band (166-183 GHz) Diplexer

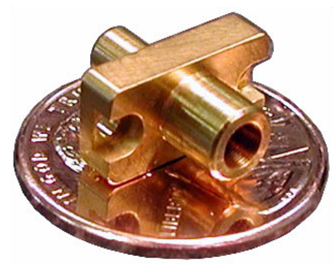

Figure 14. 650 GHz Corrugated Feedhorn Courtesy NASA/JPL

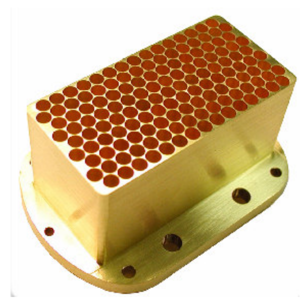

Figure 15. 1.2 THz Feed Array -Courtesy NASA/JPL

5. CONCLUSION

It has been demonstrated that high performance antenna feeds and components can be produced on the first attempt through the use of precision RF CAD tools and the appropriate choice of manufacturing technique. This drastically reduces the development cycle and often eliminates the need for prototyping.

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