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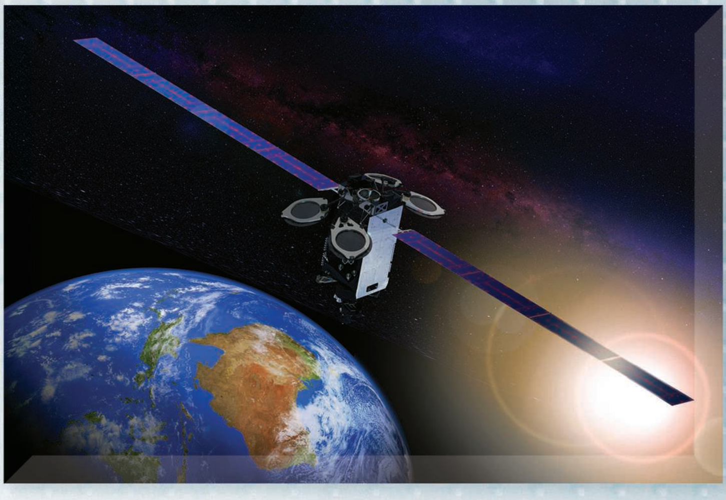

Feed Network Design Using NewSpace Techniques

Meeting mass, size, cost, and schedule requirements.

NewSpace is a term used to describe a new methodology for modern space ventures. This article presents traditional, modern, and NewSpace design methods. Significant reduction in size and mass of satellites can be achieved using NewSpace methodologies.

INTRODUCTION

NewSpace describes a paradigm shift from traditional methods of producing communication satellites to one that is focused on entrepreneurship and does not rely on governments or large prime satellite manufacturers. The goal of many NewSpace ventures is to develop cheaper access to space in a shorter schedule when compared to traditional methods for satellite production.

Typical budgets for NewSpace ventures are a fraction of traditional space program budgets. One way this is being achieved is by using many small satellites (smallsats), which can be launched at a much lower cost than traditional large school bus-sized satellites. Advancements in communication payloads have also increased smallsat capabilities. By using many smallsats, which feature advanced payloads, performances comparable to much larger large traditional satellites can be achieved.

Because of its reduced cost and satellite size, NewSpace ventures can provide satellite access to areas where traditional large spacecraft would not be economically viable. With smallsats, operators can optimize their numbers and positions, allowing them to provide services at a fraction of the cost when compared large traditional satellites. By using the proper

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placement of smallsats, areas such as Alaska as well as small nations can have access to affordable satellite services.

For nearly every satellite, size, mass, and performance are always key design drivers. With smallsats, size and mass are even more critical. One way to reduce size and mass is to use multiband feeds, which eliminate the need for separate antennas. Another way to accomplish this is to integrate as many components as possible (including filters such as harmonic reject that not traditionally part of the antenna) into the antenna feed.

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This integrated approach also helps reduce costs and schedules by reducing the number of vendors and assembly/test times. Another benefit of the integrated approach is that the antenna performance can be improved significantly by designing the reflector [4] system along with the feed.

HERITAGE DESIGN METHODOLOGY

A wide array of sophisticated precision radio-frequency (RF) CAD tools are currently available to antenna designers. Some of the most widely used include: CHAMP, FEKO, WIPLD, GRASP, POS, μWave Wizard, Computer Simulation Technology (CST) Microwave Studio, WASPNET, and high-frequency structure simulator (HFSS).

Some of the most effective tools used to reduce design cycle time for feeds are tools such as μWave Wizard. These tools are based on the highly efficient mode-matching (MM) technique and work in conjunction with other methods such as boundary contour MM and the 2D/3D finite-element method (FEM) to ensure peak accuracy and efficiency in the design and optimization of waveguide components and antenna feeds. For arbitrary cross-sections and structures, CAD tools based on FEMs such as the popular CST Microwave Studio and Ansys HFSS, can be utilized.

Even with these widely available tools, some engineers design feed components separately. In this approach, each component requires a complete RF and environmental specification, margins for design, manufacturing, and test. Then the components are sourced from a vendor or developed in house. The components then need design reviews, qualification testing, and source inspection. All of these separate steps add significantly to the schedule, cost, and overhead required to build, integrate, test, and deliver an antenna.

Although this design approach can result in adequate RF system performance, it often leads to antennas that are large, complex, and expensive. With this method, the antenna feed can be more than four-times larger than feeds designed using modern or NewSpace methodologies for design and manufacturing. Modern design methods can reduce the negative aspects of the individual component design approach.

MODERN DESIGN OF ANTENNAS AND FEEDS

A more modern design process typically begins with an appropriate choice of components that meets RF requirements, envelope, and waveguide port interface locations. Other important considerations in the choice of design components include multipaction [1], operating and survival temperature, and passive intermodulation (PIM) products requirements. PIM [2] often drives the manufacturing approach and the choice of features used in each component.

After the design and optimization of each component in the network is completed, the entire feed (network and horn) is analyzed to account for interactions between each component across a wide range of frequencies. Optimization can also be performed at the feed system level to further improve RF performances and reduce overall size. Modern RF CAD tools can include copolar and cross-polar pattern optimization with and without the reflector system [3], which is an especially useful capability for the antenna or feed designer. An example of a feed that uses this process is shown Figure 1 [6].

This feed provides right-hand circular polarization (RHCP) and left-hand circular polarization (LHCP) operation over both transmit and receive bands simultaneously. Measured performances for this compact high-performance C-band feed is listed in Table 1.

To avoid the need for design validation employing prototypes, which can be schedule and cost-prohibitive, analysis using an alternate solver such as CST can be performed instead. CST is a FEM-based solver that includes a variety of different numerical electromagnetic solvers tailored to different component types. It is typically much slower than pure MM tools for optimization but is effective as

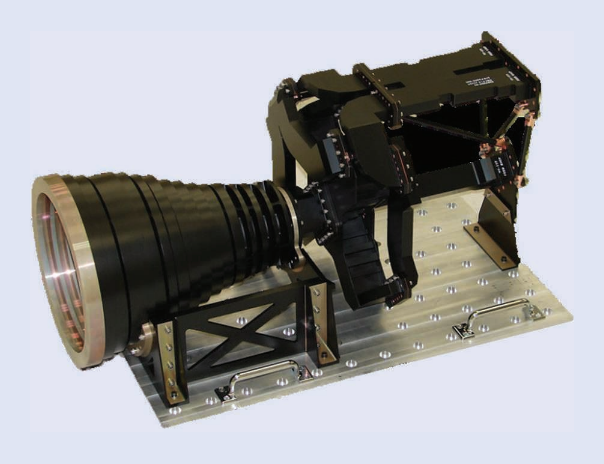

FIGURE 1. A space-qualified, C-band dual-CP, dual-band four-port feed.

an analysis tool for most feeds and components. Correlation between the simulated results from both CAD tools is generally enough proof that the design has been validated. In addition, by using related particle physics-based tools (including Spark3D), multipaction concerns can be well understood and alleviated early in the design process.

Designing antennas and feeds for NewSpace employs all of the modern antenna and feed design philosophies.

With these modern design tools, antenna and feed designers can take advantage of previously unused waveguide space to add functionality within a restricted envelope. Figure 2 shows a network [6] where the typically unused waveguide sections are utilized with functional components (in this case, filters). Table 2 lists the measured performances for this network. Functions that are traditionally realized using separate components (e.g., test couplers) or even separate feeds such as monopulse tracking, can now be included in a single-feed structure. Figure 3 displays an example of a K/Ka communication network with an integrated multimode tracking network. Similar measured performances for this network are presented in Figure 2 for the communication bands; however, it also includes monopulse tracking functionality.

In addition to stand-alone integrated multifunction feeds, complex multifrequency feed arrays can be analyzed and optimized along with a related shaped reflector to produce sophisticated multiple-spot beam systems with advanced frequency and polarization reuse schemes. Although these types of systems are typically used for traditional large high-throughput satellites, precision beamshaping and advanced topologies are being applied in

TABLE 1. C-BAND DUAL-CP, DUAL-BAND FOUR-PORT FEED PERFORMANCE.

Parameters	Measured Performance
Frequency (GHz)	Tx: 3.625–4.2 Rx: 5.85–6.425
Axial ratio (dB)	<0.2 on axis
Insertion loss (dB)	Tx: < 0.15 Rx: < 0.05
Return loss (dB)	Tx: > 28 Rx: > 32
Isolation (dB)	RHCP ⟷ LHCP > 25 Rx ⟷ Tx > 60
Peak power (kW)	10 multipaction simulated
PIM (dBm)	<–140 dBm, seventh order
Edge taper	20 dB (±30°) typical
Cross-polar levels	<–38 dB (±30°), relative to peak
Feed size (in)	28.5 × 12 × 12.7
Feed mass (Kg)	<12 (with brackets)

Tx: transmitter; Rx: receiver.

TABLE 2. K/Ka DUAL-CP, DUAL-BAND FOUR-PORT NETWORK PERFORMANCE.

Parameters	Measured Performance
Frequency (GHz)	K band: 17.7–20.2 Ka band: 27.5–30
Axial ratio (dB)	K band: < 0.34 Ka band: < 0.13
Insertion loss (dB)	K band: < 0.4 Ka band: < 0.2
Return loss (dB)	>28
Isolation (dB)	RHCP ⟷ LHCP > 30 Ka ⟷ K > 70
Peak power (kW)	>3.8 multipaction simulated
Size (in)	<2.1 diameter × 4.7
Mass (g)	<300 (flight)

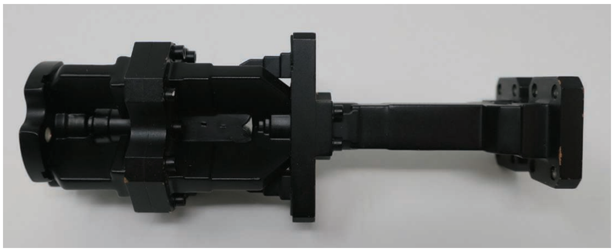

FIGURE 2. A space-qualified, K/Ka dual-CP, dual-band four-port network.

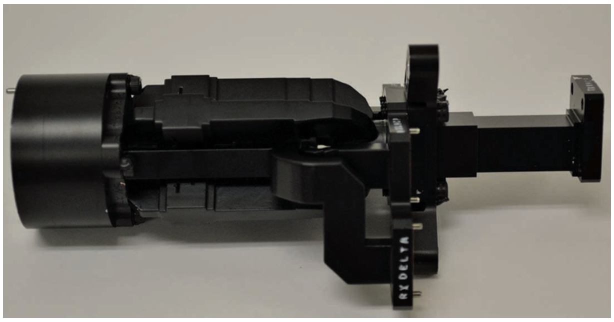

FIGURE 3. A space-qualified, K/Ka dual-CP, dual-band four-port network with multimode monopulse tracking.

the NewSpace environment for smallsat applications.

NEWSPACE DESIGN OF ANTENNAS AND FEEDS

Designing antennas and feeds for NewSpace employs all of the modern antenna and feed design philosophies. Moreover, a higher level of component integration, advanced optimization of the feed and reflector antenna, and more attention to design for manufacturability are required. Another aspect that is not always considered is choosing design and manufacturing approaches that eliminate the need for tuning screws. Using tuning screws add time to assembly and test processes and can limit power handling and PIM performances while reducing reliability.

To achieve a small package size and reduce manufacturing time, the advanced integration of RF components must occur during the design process.

To achieve a small package size and reduce manufacturing time, the advanced integration of RF components must occur during the design process. This advanced integration considers the concept that some components can be optimized together to eliminate features that can be common between components, which can greatly reduce the size of the antenna feed. Figure 4 depicts a K/Ka network that was designed using this approach, and Table 3 lists the measured performances for this network. With this approach, components optimized together have better performance over wider bandwidths than if they were designed independently. Figure 5 shows a highly integrated network with wideband performance at the Ku band; the size and mass of this network

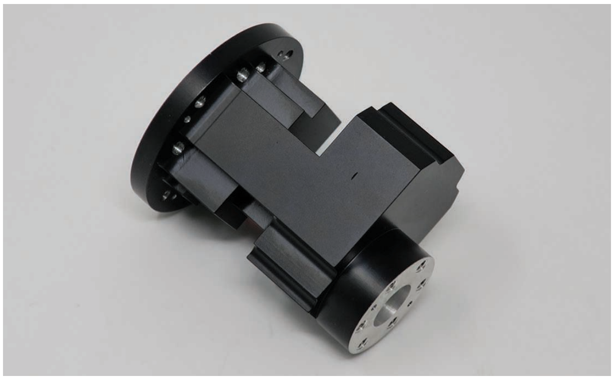

FIGURE 4. A space-qualified, K/Ka dual-CP, dual-band four-port network.

TABLE 3. NEWSPACE K/Ka DUAL-CP, DUAL-BAND FOUR-PORT NETWORK PERFORMANCE.

Parameters	Measured Performance
Frequency (GHz)	K band: 5.8% bandwidth anywhere between 17.7–20.2 Ka band: 27.5–30
Axial ratio (dB)	K band: < 0.5 Ka band: < 0.3
Insertion loss (dB)	K band: < 0.4 Ka band: < 0.2
Return loss (dB)	>25
Isolation (dB)	RHCP ⟷ LHCP > 23 Ka ⟷ K > 60
Peak power (kW)	>3 multipaction simulated
Size (in)	<1.9 diameter × 2.3
Mass (g)	<123 (flight)

FIGURE 5. A space-qualified, Ku linear polarization (LP) dual-band network.

TABLE 4. Ku LP DUAL-BAND NETWORK PERFORMANCE.

Parameters	Measured Performance
Bandwidth	Ku band Tx: 17.5% Ku band Rx: 6.5%
Insertion loss (dB)	Ku band Tx: < 0.1 Ku band Rx: < 0.2
Return loss (dB)	>23 dB
Isolation (dB)	Tx ⟷ Rx at Tx > 110 Rx ⟷ Tx at Rx > 55
Size (in)	3.34 diameter × 2.18 × 3.8
Mass (g)	<108 (flight)

would not be possible without integration of the filter into the orthomode transducer. This network has 60% reduction in mass as compared to a traditional network working over the same band. Table 4 shows the measured performances of this Ku band network.

Designing for manufacturability is also crucial for schedule, mass, and cost reduction. Several manufacturing techniques, such as conventional milling, turning, electrodischarge machining, brazing, sheet metal forming, laser welding, and electroforming are considered during the design process. The most schedule- and cost-effective solution is chosen and often drives the design. Typically, conventional milling, sheet metal, and turning are the least expensive techniques; however, they may limit the level of integration that can be achieved using the design. In some cases, manufacturing by electroforming may be required to reduce the size of the feed to the smallest form factor, eliminate joints in critical areas for PIM concerns, or achieve tolerances not possible using other manufacturing methods.

Electroforming [5] is a process in which a component is manufactured by using electrodeposition on a mandrel (Figure 6). Once the electrodeposition is complete, the mandrel is removed leaving only the shell, with the desired internal features remaining. This method is not only highly accurate but also allows for extremely complex designs. Figure 7 shows a network that utilizes electroforming to realize the complex filter arms; most of the components are directly machined to reduce mass and schedule. Table 5 lists

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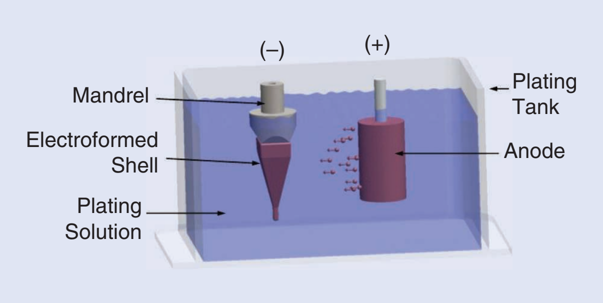

FIGURE 6. The electroforming process.

TABLE 5. NewSpace C BAND DUAL-CP, DUAL-BAND FOUR-PORT NETWORK PERFORMANCE.

Parameters	Measured Performance
Frequency (GHz)	Tx: 3.625–4.2 Rx: 5.85–6.425
Axial ratio (dB)	<0.2 on axis
Insertion loss (dB)	Tx: < 0.2 Rx: < 0.1
Return loss (dB)	Tx: > 25 Rx: > 25
Isolation (dB)	RHCP ⟷ LHCP > 23 Rx ⟷ Tx at > 60
Peak power (kW)	2 multipaction simulated
PIM (dBm)	<–145, seventh order
Network size (in)	9.5 × 13.3 × 11.9
Network mass (Kg)	<3.7

FIGURE 7. A space-qualified, dual-band dual-CP four-port C-band network using the NewSpace approach.

FIGURE 8. A Ka band antenna designed using the NewSpace approach.

TABLE 6. THE Ka-BAND ANTENNA'S PERFORMANCE.

Parameters	Measured Performance
Frequency (GHz)	30–36
Aperture efficiency at 34.5 GHz	74.1%
Axial ratio (dB)	<0.5 on axis
Return loss (dB)	Tx: > 34
Antenna size (in)	34 (diameter) × 11.2 (axial length)

FIGURE 9. Step aperture integrated radiating elements in a seven-element array configuration.

the measured performances for this network. To help with manufacturing, COMSOL Multiphysics modeling software is used to predict the electroforming outcome. This tool allows a designer to identify the optimal plating setup and address potential issues before the electroforming process is started to reduce setup and cycle time.

NewSpace designs may also benefit from designing the feed with the reflector to create an even more optimal antenna system. Figure 8 shows a 34-in reflector antenna designed at the Ka band with an efficiency of greater than 74%. One benefit of this is that the feed performance can be optimized with the reflector to provide the required pattern performance for the system. Table 6 lists the Ka band antenna's performance. This method can also reduce time for assembly and integration testing. By optimizing these simultaneously, a designer can reduce the size of the feed and see an overall reduction in antenna size. This method can also be applied to antenna arrays. Figure 9 shows the step aperture integrated radiating antenna [7]. The element has been reduced in size considerably as compared to previous antennas that perform the same function. This antenna also includes an advanced filter to provide rejection, which is required for its mission. None of these improvements would be possible if the NewSpace philosophy had not been used during the design process.

SUMMARY AND CONCLUSIONS

The demand for NewSpace is changing the way feeds and antennas are designed. Heritage design methodologies are no longer adequate, and modern methods must be adopted to meet NewSpace requirements. NewSpace feeds must be more integrated so as to meet mass, size, cost, and schedule requirements.

AUTHOR INFORMATION

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