BROADBAND COMMUNICATIONS SATELLITE ANTENNA TECHNOLOGY FOR THE EMERGING KA-BAND MARKET

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ABSTRACT

Numerous antenna trade studies have addressed the Ka-Band broadband market needs. High effective isotropic radiated power (EIRP), wide bandwidth, and low-noise communications systems must have configurable spot beams to meet flexible distribution demands of bandwidth and power into high traffic areas. The antenna systems required to satisfy these system demands go significantly beyond the antenna technology employed by current wide area coverage transponder systems.

TRW has developed a new generation of broadband communications satellite antennas—the first of which is currently in production. Testing demonstrates the capability for:

- Ka-Band (30/20 GHz) operation
- Performance using 2.5 GHz of available spectrum
- High-gain, multiple-hopping spot beams
- National, regional and global coverage
- Global high beam quality
- Low sidelobe and cross-polarization
- High degree of flexibility

This family of precision high-gain satellite antenna addresses future needs of the Ka-Band market. Performance results exceed those previously shown for other systems. Since future markets may develop in unforeseen ways, this family of antenna has design features flexible enough to adapt to future market demands.

INTRODUCTION

As the demand for satellite capacity has steadily increased, multiple-beam antennas (MBA) have become commonplace in satellite communication systems. MBA systems enable frequency reuse—maximizing capacity while minimizing required frequency allocation. MBA systems allow the service provider to concentrate the coverage in high demand areas rather than provide coverage for a large area that may include areas of little or no demand. Many new MBA systems operate in the Ka-Band frequency region.

Several key performance parameters differentiate MBA systems.

1. Antenna gain affects DC power, capacity, and terminal size. A high-gain antenna minimizes power consumption and terminal size while maximizing capacity.
2. Carrier-to-interference ratio—or C/I—is another key parameter. High C/I enables maximum frequency reuse, thereby maximizes capacity. A high degree of frequency reuse and tight beam spacing sets stringent cross-polarization and sidelobe level requirements on MBA systems. For many MBA systems, system performance is limited by composite interference from other beams (C/I) rather than noise. In these cases, the coverage area must have limitations—resulting in decreased capacity—or penalties must be imposed on the terminal design. Also, MBA gain and C/I performance typically degrade as the angle off-boresight (scan angle) increases, limiting most MBA systems to regional or sub-regional coverage.

3. Coverage flexibility—or the ability of the antenna to provide high performance coverage across a wide field-of-view (FOV)—is another key performance parameter. Antennas with excellent coverage capability allow flexibility in deployment, sparing, and recovery planning to the satellite service provider.
4. Accommodation—or the compatibility of the antenna with spacecraft bus—is the last key parameter. An antenna with excellent accommodation characteristics enables multiple antenna-spacecraft bus combinations. Spacecraft accommodation issues may be due to spacecraft bus or launch vehicle restrictions or the existence of other antenna systems. In these cases limitations must be put on the antenna design that may adversely affect antenna gain and C/I performance. The performance restrictions may ultimately affect the profit generating potential of the system through reduced capacity and increased satellite and terminal cost.

TRW's Gen*Star line of antennas was developed to address limitations of traditional MBA systems. The Gen*Star antenna is a new MBA that offers the service provider the opportunity to provide high gain, high C/I coverage anywhere in the full Earth FOV. Over the past five years, TRW has developed this innovative Gen*Star antenna concept into a mature, proven design. The antenna system provides the highest performance levels and alternate spacecraft accommodation methods.

GEN*STAR ANTENNA DESIGN AND PERFORMANCE

The Gen*Star antenna uniqueness stems from the capability to cover the entire Earth FOV from geosynchronous orbit with the same performance that previous systems covered—a regional area in an antenna that stows for launch into a very compact space. This outstanding performance is enabled by a side-fed, dual reflector antenna system.

The Gen*Star antenna design is based on design and development efforts that began in 1995. Highlights of this development activity are shown in Figure 1. Early in the development process, TRW invested significant internal resources to study alternative antenna approaches suitable for the densely tiled narrow spot beam architectures needed by the emerging Ka-Band systems.

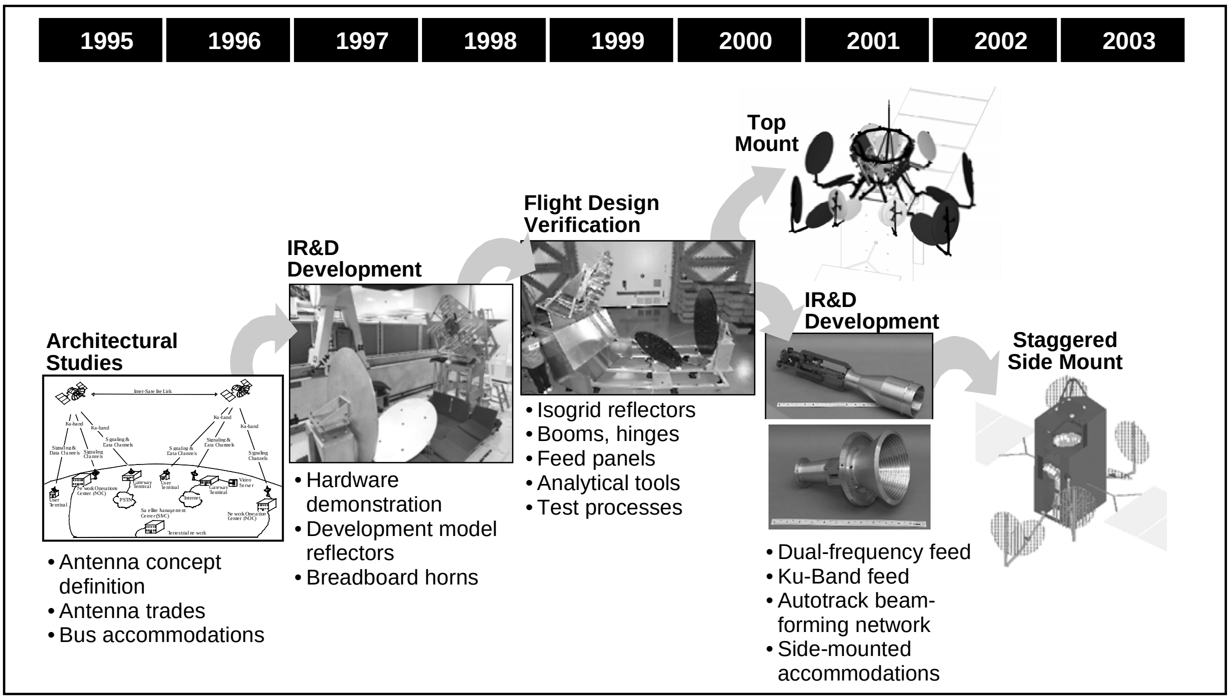

Figure 1. Gen*Star Antenna Development

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We examined the four best reflector geometries (Figure 2): the single offset reflector, the offset reflector with a splashplate, the top-fed Cassegrain, and the side-fed Cassegrain. The single offset reflector—the simplest of the antenna candidates—can be easily stowed but has serious scan limitations. The offset reflector with a splashplate is marginally better, but still inadequate. The remaining candidates with multiple reflectors have excellent scan loss

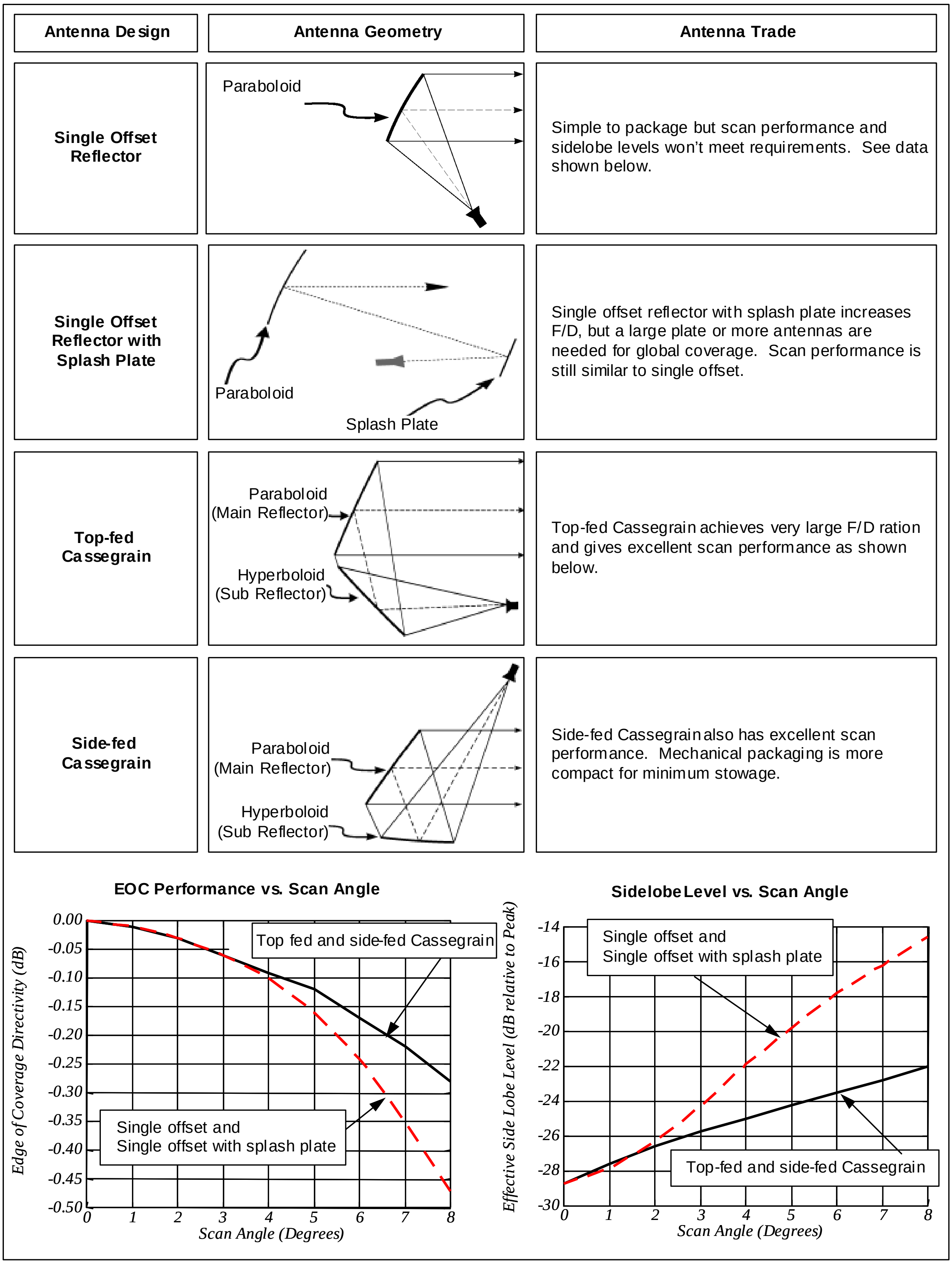

Figure 2. Antenna Trade Summary

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characteristics due to the ability to achieve large focal length-to-diameter (F/D) ratios. Top-fed and side-fed Cassegrain designs share outstanding electrical performance; however, we found the side-fed option to be superior for the following reasons: it (1) stows more compactly; (2) delivers wide-angle scanning with consistent high gain across the entire Earth FOV; (3) maintains low sidelobes and low cross-polarization as a result of its inherent large-focal length-to-diameter ratio; and (4) has the added benefit of desirable stowage.

To validate the selection of the side-fed dual reflector, a development model antenna was built and tested. Precision range measurement of the Gen*Star preproduction unit (Figure 3) shows the excellent performance achieved with this design.

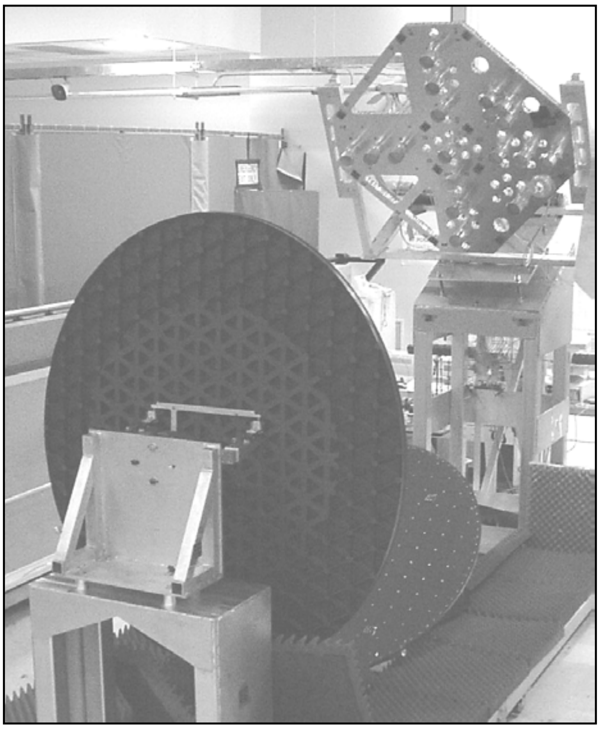

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Figure 3. Preproduction Gen*Star Aperture in Range Measurement

The measured patterns show very low beam shape change over the full Earth FOV from geosynchronous orbit. Previous systems produce beams that spread as the scan angles increase beyond 4 degrees (Figure 4). This broadening results in lower peak gain and higher interference to neighboring cells. Yet, the Gen*Star antenna design provides high gain, low sidelobe and low cross-polarization patterns with little change at scan angles to 10 degrees (Figure 5). In addition, performance over frequency enables continuous spectrum availability.

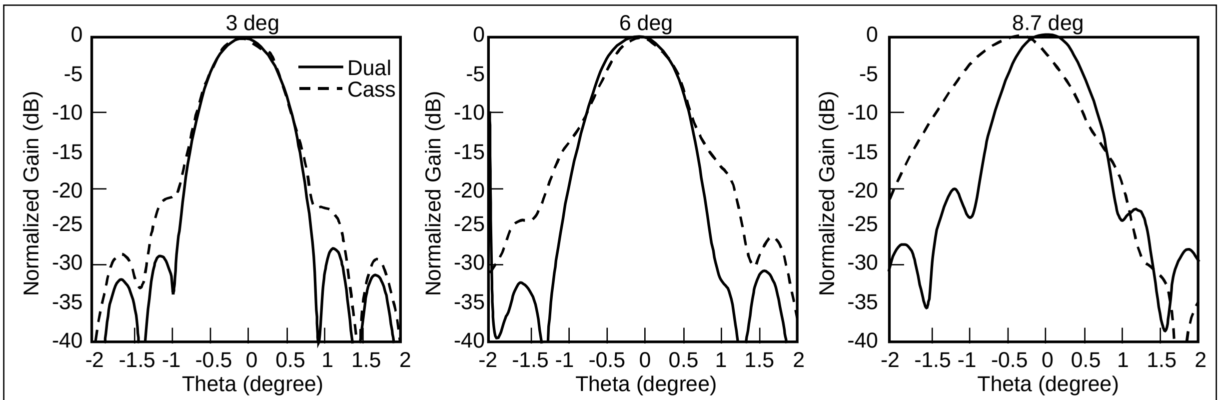

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Figure 4. Comparison of Scan Performance of Genstar Compared to Cassegrian and Gregorian

GEN*STAR ANTENNA FLEXIBILITY

The Gen*Star antenna architecture has a high degree of flexibility. The configuration can be easily customized for a specific mission requirement. The foremost enablers of this flexibility are:

- Standardized components
- Capability to use any polarization or combination of polarizations
- Frequency insensitivity enables other frequency bands to be integrated
- Compact design enables many packaging options

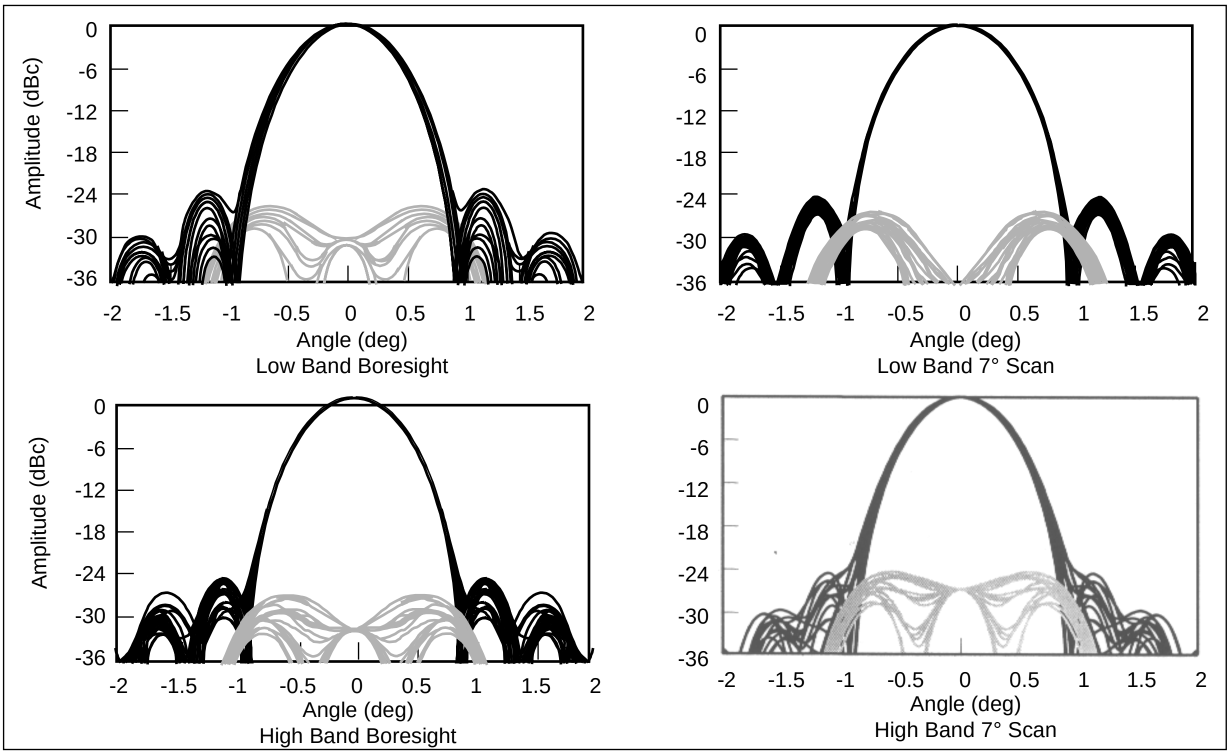

Figure 5. Gen*Star Performance Measurements Over Scan

This architecture makes maximum reuse of component designs. Standardization of components reduces hardware changes with coverage. In fact, the only unique elements within the antenna system are the feed clusters—customers can specify final coverage late in the program cycle.

Linear (H and V) and circular (RHCP and LHCP) polarizations have been measured to address flexibility in polarization. Circular polarization shows near 30 dB cross-polarization and linear has shown in excess of 35 dB cross-polarization response. In either polarization sense, the system produces very low interference to or from neighboring cells.

Another feature is the ability of the antenna system to support other frequency bands. Configurations have been developed that provide outstanding spot beam performance at Ka-Band and Ku-Band simultaneously. The side-fed, dual-reflector antenna system stows naturally in a compact configuration. This compact stowage enables many mounting options on the spacecraft.

Two primary configuration options are (1) a top-mounted antenna suite with very easy accommodation that is currently in flight production and (2) a side-mounted configuration. Side mounting provides a benefit of reduced waveguide runs, therefore, increased EIRP. The reduction in apertures and side mounting may benefit customers with difficult spacecraft or launch vehicle accommodation.

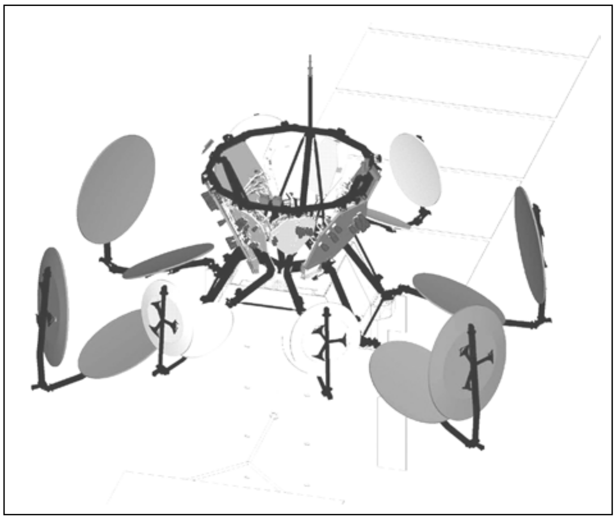

Figure 6. Deployed Gen*Star Antenna

The top-mounted Gen*Star antenna (Figure 6) has eight, dual-reflector multi-beam apertures (four uplink and four downlink) that multiplex spot beams into continuous ground coverage areas. The top-mount configuration enables very simple integration onto the nadir-facing surface of the spacecraft bus. Four apertures enable optimum performance and coverage in a region of densely packed cells.

Each reflector assembly is independent and stows into the compact space of a 4-meter fairing (Figure 7). The top-mount antenna system is in flight production for the Astrolink program. An antenna integration simulator was developed using flight components and flight processes to validate construction and integration of top-mount Gen*Star antenna (Figure 8).

Some satellites have limited space available on the nadir face of the S/C bus. In these cases, the folded optics design naturally accommodates mounting on the side of the spacecraft. The compactness of the design allows mounting along the side of the spacecraft (not limited to feeds on top and reflectors on the bottom). This allows staggering of the feed trays, which opens up many more routing options from the TWTAs. The side-mount configuration also lowers the satellite center of gravity. The result is minimum waveguide length, minimum waveguide loss, and maximum EIRP. A minor change-out of the transmit feed clusters with dual-frequency feeds produces identical coverage performance with only four antennas (Figure 9). Closed-loop tracking based on an uplink beacon signal provides excellent pointing performance. The dual frequency aperture eliminates any possibility of uplink-to-downlink coverage misalignment.

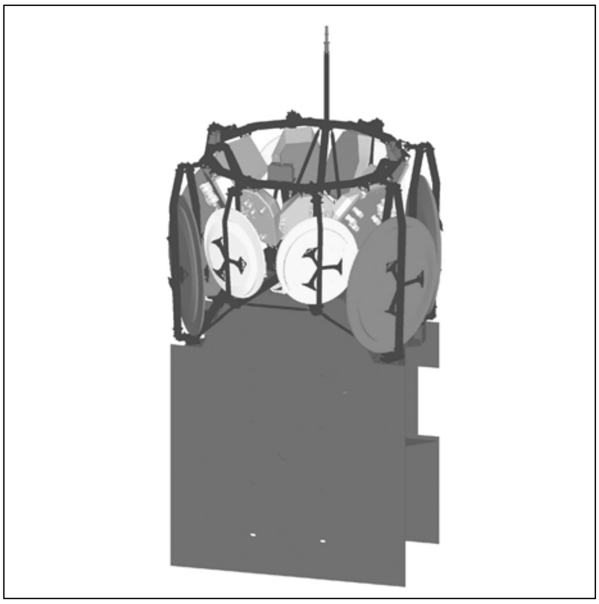

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Figure 7. Stowed Gen*Star Antenna

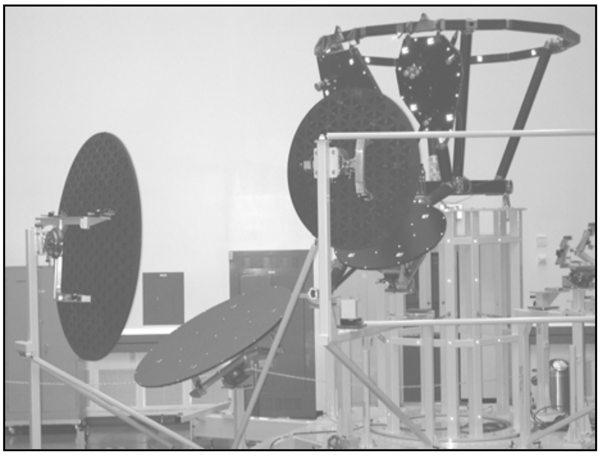

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Figure 8. Antenna Integration Simulator

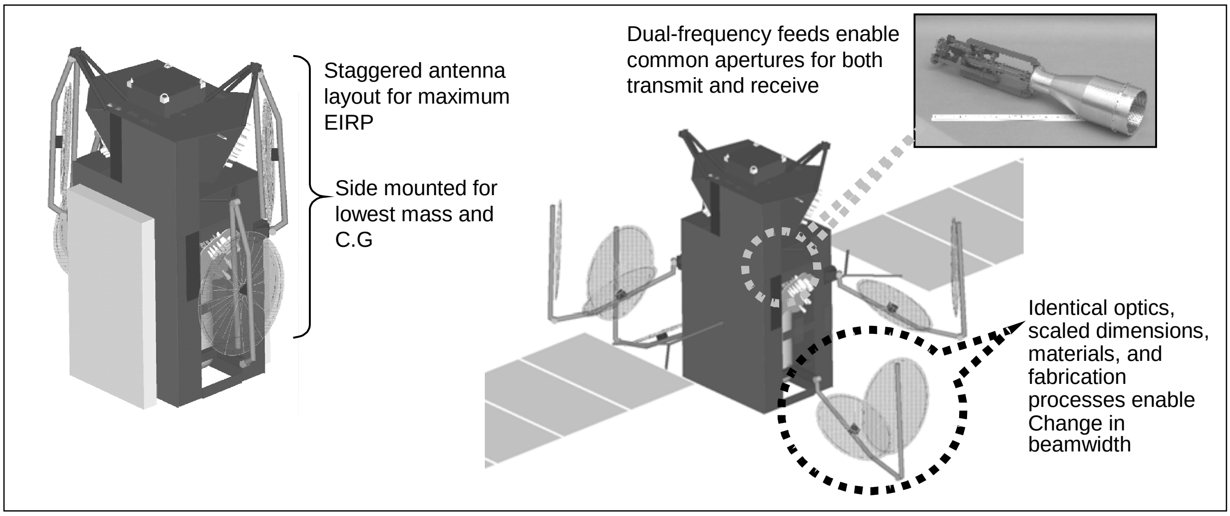

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Figure 9. Side-Mount Gen*Star Antenna Configuration

SYSTEM ADVANTAGES OF THE GEN*STAR ANTENNA

The Gen*Star antenna is designed to deliver the high performance necessary to support multibeam Ka-Band systems. In each phase of the design process the Gen*Star antenna was optimized for performance. The result is the first antenna to offer excellent gain and C/I performance anywhere in the full Earth FOV.

C/I performance enables maximum capacity. A significant advantage of the Gen*Star antenna is the excellent C/I performance. In many MBA systems interference rather than noise limits capacity. In order to minimize interference, coverage patterns must be defined such that interference is reduced to acceptable levels. Typically the optimization of the coverage pattern to reduce C/I results in more separation between coverage cells and fewer co-polarization interfering channels, which results in a decrease in system capacity. With the Gen*Star design, satellite service providers have the ability to densely space coverage cells and optimize the coverage pattern for maximum capacity. Maximizing capacity translates directly into service revenue and profit for the satellite service provider.

Uniform EIRP and gain/temperature (G/T) for all cells enables standard terminal design. The excellent scan performance of the Gen*Star antenna translates into uniform EIRP and G/T for all coverage cells. Terminals for the Gen*Star antenna can be standardized for all coverage cells, which minimizes terminal cost and thus increases the affordability of the system to the end user.

Full Earth FOV minimizes time to global coverage. The ability of the Gen*Star antenna to provide high performance coverage over the full earth FOV reduces the number of satellites required for global coverage, which allows the service provider to reach global coverage with fewer launches and less time. The improved time to market and reduced launch costs may translate into improved revenue and profit for the satellite service provider.

Coverage flexibility enables high value approaches to service rollout, sparing, and service restoration. Homogeneous gain and sidelobe performance over the entire Earth field-of-regard translates into high levels of coverage flexibility. In addition to regional coverage, the Gen*Star antenna can provide multi-region and multi-slot coverage, as illustrated in Figure 10. For both types of coverage the antenna is configured to provide coverage for multiple regions. The multi-region antenna provides coverage from the same slot while the multi-slot antenna is configured to provide coverage for multiple slots. Upon launch, the beams for the selected slot are activated and the remaining feeds remain dark.

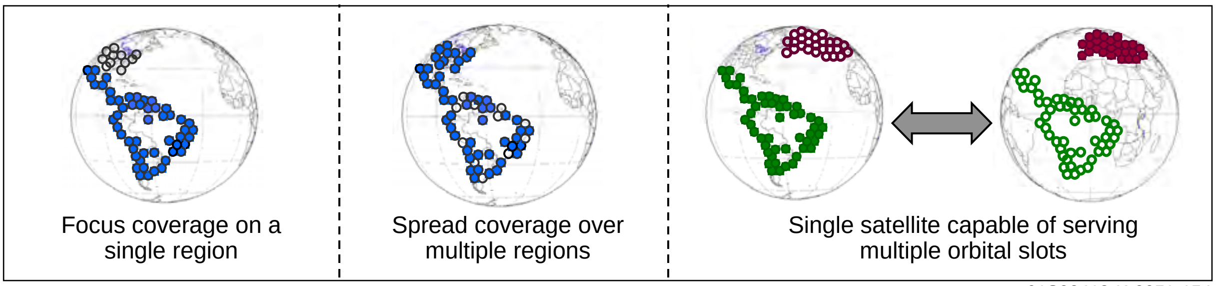

Figure 10. Coverage Flexibility Enabled by the Gen*Star Antenna

Multi-region and multi-slot coverage capabilities enable high value approaches to service rollout and sparing. With the capability to cover multiple regions and service multiple slots, the satellite service provider has much more flexibility in deployment. Rather than customizing the satellite for a specific coverage area, the service provider can select multiple coverage options and wait until launch to make the final selection. This additional flexibility allows the service rollout to be based upon the latest market data. Multi-region and multi-slot coverage also enable high value sparing and service restoration approaches, as illustrated in Figure 11. Rather than expensive one-for-one sparing, the service provider can configure

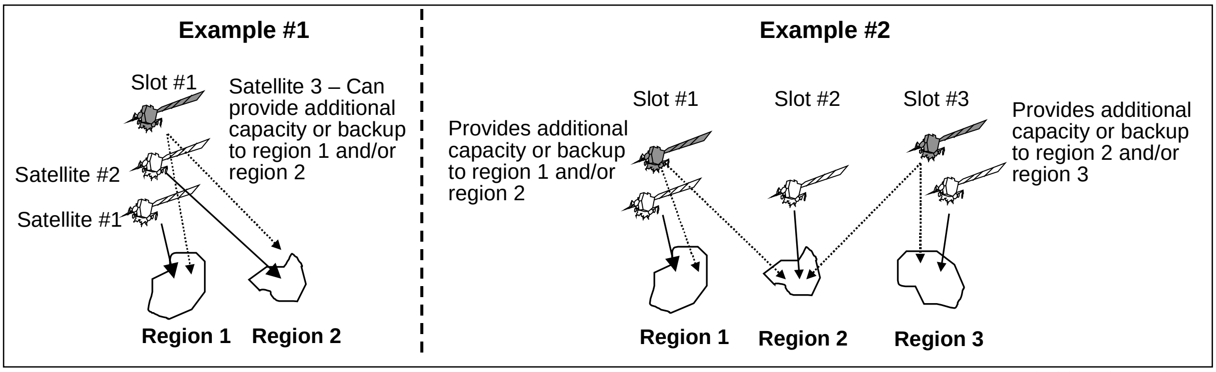

Figure 11. Sparing/Service Restoration Flexibility Enabled by the Gen*Star Antenna

spares to support multiple regions. Upon a failure, the spare can be configured to provide the coverage of the failed spacecraft. Sparing requirements can be reduced dramatically, depending on the coverage requirements and available orbital slots. In addition, the spare satellite can be dark or configured to provide additional capacity. Upon a failure of another spacecraft, the capacity can be re-allocated as necessary.

High heritage antenna design minimizes risk: The Gen*Star antenna is a mature design that offers high performance with very low levels of risk to the satellite service provider. The Gen*Star design has been verified and qualified for flight and all manufacturing processes have been proven. The antenna is currently in flight production. In addition, TRW has ample experience in the design, integration and test of Ka-Band antenna products for government customers.

ADDITIONAL ADVANTAGES OF THE SIDE-MOUNT GEN*STAR ANTENNA CONFIGURATION

The side-mount Gen*Star antenna is designed to improve system performance and ease integration onto the satellite bus.

Good Antenna Accommodation Characteristics Increase Bus and Launch Vehicle Compatibility. Low weight, low center of gravity, low volume and side-mounting ease accommodation of the antenna on the spacecraft bus. The increased bus compatibility and low antenna volume enable more flexibility in launch vehicle selection, which allows the service provider more freedom to select the launch vehicle best suited to the specific program. Alternatively, a larger reflector system can be employed to produce increased gain in each beam area. In addition, the reduced weight of the side-mount DFF antenna may translate into increased available power, and thus higher capacity.

High Antenna Gain and Side Mounting Maximize EIRP. A significant advantage of the side-mount Gen*Star antenna is high EIRP. Side mounting of the antenna allows the TWTAs to be placed closer to the feed array, which minimizes waveguide losses. As mentioned above, side mounting also enables the use of larger reflectors within launch vehicle constraints. These two advantages combine with the Gen*Star antenna low scan loss to produce excellent EIRP. The result is reduced terminal size and increased total payload capacity and profit.

CONCLUSION

The TRW Gen*Star family of precision high-gain satellite antennas addresses the future needs of the Ka-Band market. The Gen*Star antenna provides superior performance, flexibility and capacity and is the clear choice for high capacity applications. Performance results of a high fidelity design verification model exceed that previously shown for other designs. The first Gen*Star antenna is currently in flight production. The family of antennas has many flexible design features to adapt to the future market demands.