Multibeam Antennas for Boosting Capacity and Handling High Data Throughput

Introduction

As wireless data demand continues to surge, communication systems must deliver higher capacity, lower latency, and greater spectral efficiency. Multibeam antenna technology solves high density, high throughput challenges by generating multiple directional beams simultaneously to deliver significantly more capacity and data throughput than traditional antenna solutions.

Conventional single-beam macro or small-cell antenna systems can saturate under high load in high density and data utilization. Even mMIMO 64T64R antennas can see throughput degradation in high traffic situations. The resulting cell-sector saturation means that the spectrum becomes insufficient to handle the user traffic. These factors lead to slower data rates, dropped calls, and connection failures. This problem becomes especially evident during large public events such as concerts, sporting events, and festivals, or busy city centers or landmarks where thousands of users simultaneously stream video or access high-bandwidth applications, pushing network capacity to its limits and degrading overall performance.

Figure 1: Example use cases with higher capacity requirements.

To address these challenges, vendors have used multibeam antennas to boost capacity. This whitepaper outlines the principles, benefits, and applications of multibeam antenna systems for high-capacity applications. It also presents a detailed comparison of Galtronics' multibeam antenna systems with alternative solutions, such as legacy panel multibeam, and lens-based multibeam.

Multibeam Antennas

A multibeam antenna is a single antenna aperture that generates multiple simultaneous beams within a given sector. In this way, the given coverage area (60° to 120°) is divided into multiple smaller sectors for higher order sectorization (HOS). Multibeam antennas multiply the capacity by dividing a traditional sector into multiple smaller simultaneous multibeam sectors.

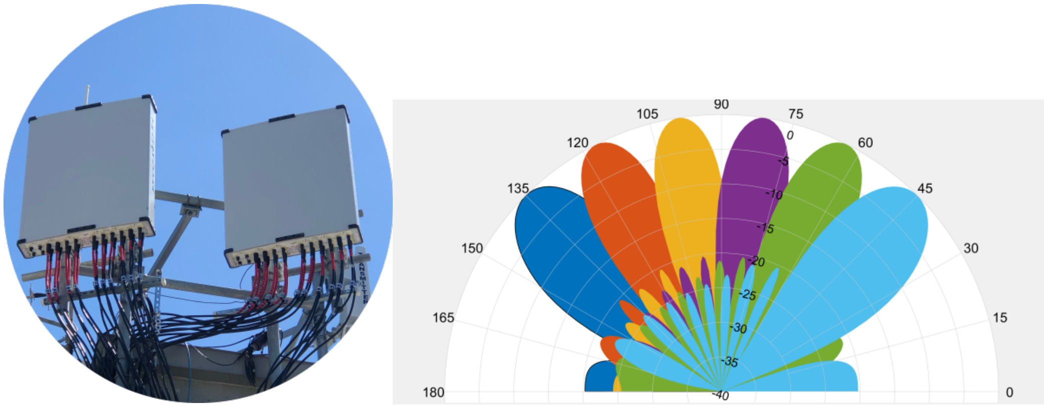

Figure 2: An example of multibeam antenna aperture and pattern (6-beam).

Multibeam antennas are deployed at both permanent and temporary sites to increase capacity. Permanent installations include large venues as well as replacing a single sector on a saturated macro tower. When installed temporarily, they are mounted on a cell-on-wheel (COW) or a cell-on-truck (COLT). While multibeam weight and size are key deployment factors for any deployment, they are critical for COWs and COLTs, which can handle only a limited weight.

Figure 3: Galtronics temporary multibeam deployment at F1 in Montreal.

Figure 4: Galtronics permanent multibeam deployment at Times Square, NYC.

Multibeam RF Design Technologies

There are several ways to make multibeam antennas, but there are two technologies that are widely used in Cellular communication:

- Lens-based multibeam
- Circuit-based multibeam

Lens-Based Multibeams

A lens is a dielectric material that converts spherical waves from each feed into a collimated beam in a different direction, so each feed corresponds to one beam. Multiple feeds placed across the focal region allow simultaneous multibeam generation. The most common and widely used design is a Luneburg lens. A Luneburg is a spherical dielectric structure used in multibeam antennas to focus electromagnetic waves through a radially varying refractive index. They convert diverging waves from feeds into collimated beams, enabling multiple simultaneous beams by placing feeds around the lens surface.

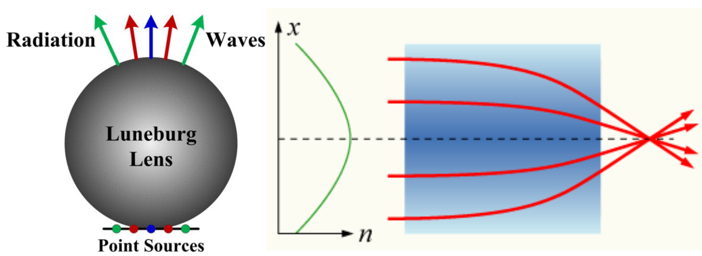

Figure 5: Luneburg lens concept.

Although lens antennas provide high gain and low loss, and well-defined low-sidelobe beam patterns, they face some inherent drawbacks for modern 4G/5G macro deployments:

- **Bulky and Heavy Construction:**

Lens structures require large dielectric volumes and mechanical housings, resulting in antennas that are heavy, fragile, and costly to manufacture and ship. Their weight significantly increases the tower load and installation complexity. This becomes an issue when zoning regulations do not allow beyond a certain size and weight. It limits their application to permanent deployments. Temporary deployments require lighter and more robust antennas, such as panel multibeam antennas.

- **Frequency-Specific Designs:**

Each lens must be precisely shaped for a particular frequency range-e.g., low band (617–960 MHz), mid band (1695–2690 MHz), or C-band (3300–4200 MHz). Because of this, the same aperture cannot support multiple bands and forces the use of separate lenses or stack assemblies. This increases size and cost.

- **Mechanical RET Mechanism:**

Traditional lens systems can incorporate remote electrical tilt (RET) only through mechanical means—by physically shifting the feed source behind the lens to change beam elevation. This approach is slow, mechanically complex, and less reliable under environmental stress.

- **Limited Flexibility and Maintainability:**

Once deployed, a lens system offers little adaptability. Reconfiguration requires physical adjustment or replacement, leading to higher maintenance costs and longer service downtimes.

Circuit-Based Multibeams

Circuit-based multibeam antennas use passive microwave networks like Blass matrices, Butler matrices, Rotman lenses, or switches to distribute signals from a single input (or few inputs) to an array of radiating elements, forming multiple simultaneous beams.

Circuit-based beamforming networks (BFNs) consist of power dividers, directional couplers, crossovers, fixed phase shifters, and transmission lines to apply the required amplitude and phase tapers for each beam.These networks connect one input port per beam to multiple output ports feeding the antenna array elements. Circuit-based multibeam antennas are more compact and lighter than lens multibeam antennas.

Legacy (non-Galtronics) circuit-based multibeam antennas use the Butler matrix as a feed network. This is shown below:

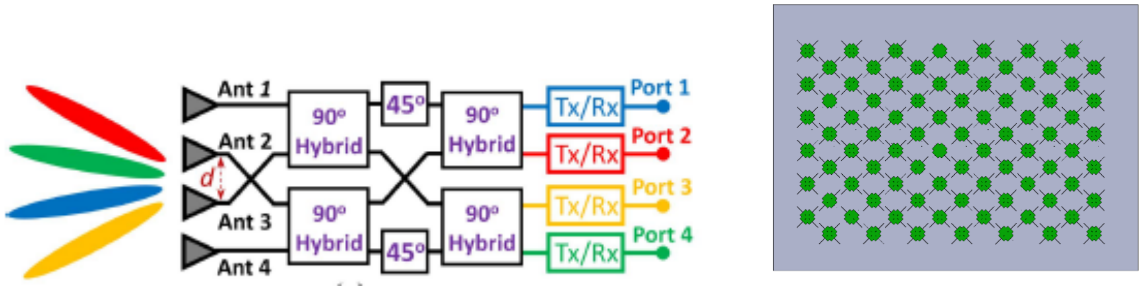

Figure 6: Circuit-based Butler concept.

The most common panel multibeam antenna uses a Butler feed network, but Butler feed networks suffer a fundamental beam squint issue.

Azimuth beam squint-the frequency-dependent shift of the main-beam direction in the azimuth plane-can cause serious system-level degradation, particularly in wideband or multiband antennas. The effect becomes more pronounced in multibeam antennas, where each beam has a much narrower azimuth beamwidth than a conventional 65°or 90°sector panel. For example, a 90° sector divided into six narrow beams (≈ 15°each) can experience substantial performance loss due to beam shifting in a multibeam with Butler, as shown below. In such cases, users may move out of the beam's high-gain region at some frequencies, resulting in uneven coverage and degraded throughput. The following is a summary of beam squint issues:

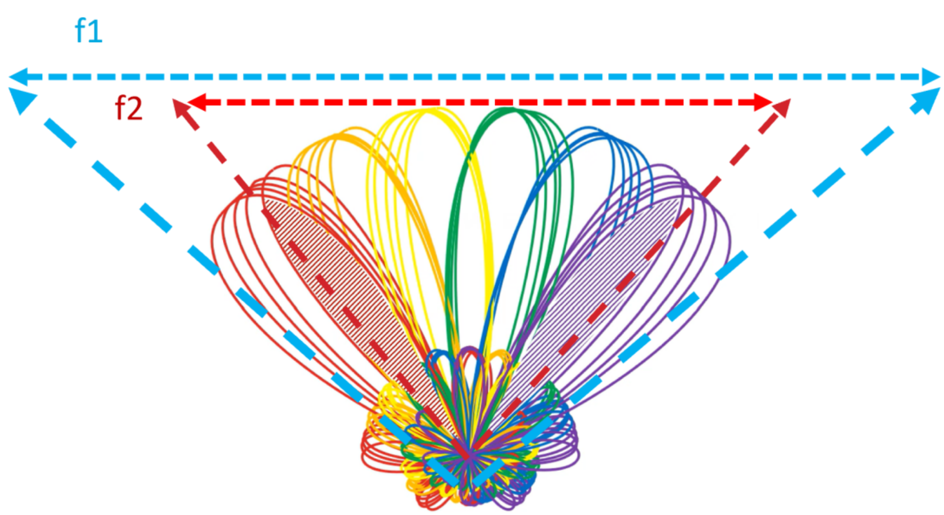

Figure 7: Legacy Butler-based multibeam beam squint and azimuth sector size change.

- **Downlink (DL)/Uplink (UL) mismatch in FDD systems**

Because the DL and UL frequency bands differ, the downlink and uplink beams point in different directions. This results in a path loss in the communication channel. When the frequency gap between UL and DL is larger (e.g., AWS with UL 1700 MHz and DL 2100 MHz), this becomes more critical.

- **Sector size changes with frequency**

Multibeam antennas operate in different bands simultaneously. For example, a multibeam covering 1695-2690 MHz operates simultaneously in the PCS (1850-1990 MHz), AWS (1695-2200 MHz), and BRS (2496-2690 MHz) bands. When an antenna is planned for an event, an unstable sector size will be an issue when different bands have different coverage areas.

- **Carrier aggregation issue**

Sector size variation and beam direction movement will be issues for carrier aggregation across different bands.

- **Signal Misalignment and Reduced Gain**

The main-beam direction varies with frequency; different OFDM subcarriers or bands radiate in slightly different azimuth directions. Users located at a fixed azimuth are no longer aligned with the peak-gain axis across the entire band, reducing effective gain and link budget.

- **Interference and SINR Degradation**

Frequency-dependent beam direction leads to inter-beam and inter-sector leakage. The resulting interference lowers the Signal-to-Interference-plus-Noise Ratio (SINR), especially near beam boundaries or in multi-user scenarios. In the example shown above for a 6-beam antenna covering 1695-2690 MHz, the sector size changes by up to 30 deg when designed using the Butler matrix.

- **Inter-Carrier Synchronization and Scheduling Issues**

Beam misalignment across carriers complicates resource scheduling and MIMO precoding. The baseband may treat carriers as if they share identical beam patterns, resulting in inefficient power allocation and link adaptation.

- **Poor Multi-User and Multi-Carrier Performance**

In multi-user or multibeam scenarios, frequency-dependent beam overlap causes inter-user interference and uneven coverage across carriers.

In short, azimuth beam squint produces frequency-dependent pointing errors that degrade SINR, coverage uniformity, and throughput-key performance indicators for LTE, 5G, and upcoming 6G radio access networks.

Galtronics Beam Stabilization Technology

To overcome these limitations, Galtronics has developed and patented beam stabilization technology-a proprietary system integrated into its multibeam antennas. This innovation eliminates or compensates for beam squint across a wide operating bandwidth, ensuring that all subcarriers and frequency bands maintain consistent beams. Galtronics' solution employs novel phase-correction circuitry and frequency-compensated beamforming networks embedded within the feed network. The solution aligns the electrical phase response across frequency, preserving the same azimuth pointing direction over the entire operational band. This solution fundamentally enhances multibeam performance by maintaining stable beam pointing across wide frequency ranges, providing uniform coverage, achieving higher SINR, improving spectral efficiency, and enhancing energy efficiency. The following Figure. 8 shows the first Galtronics solution pattern, 6-beam mid-band covering 1695-2690 MHz. As shown, beam directions do not change with frequency. In addition, the azimuth sector size is stable over frequency (changing by only a few degrees).

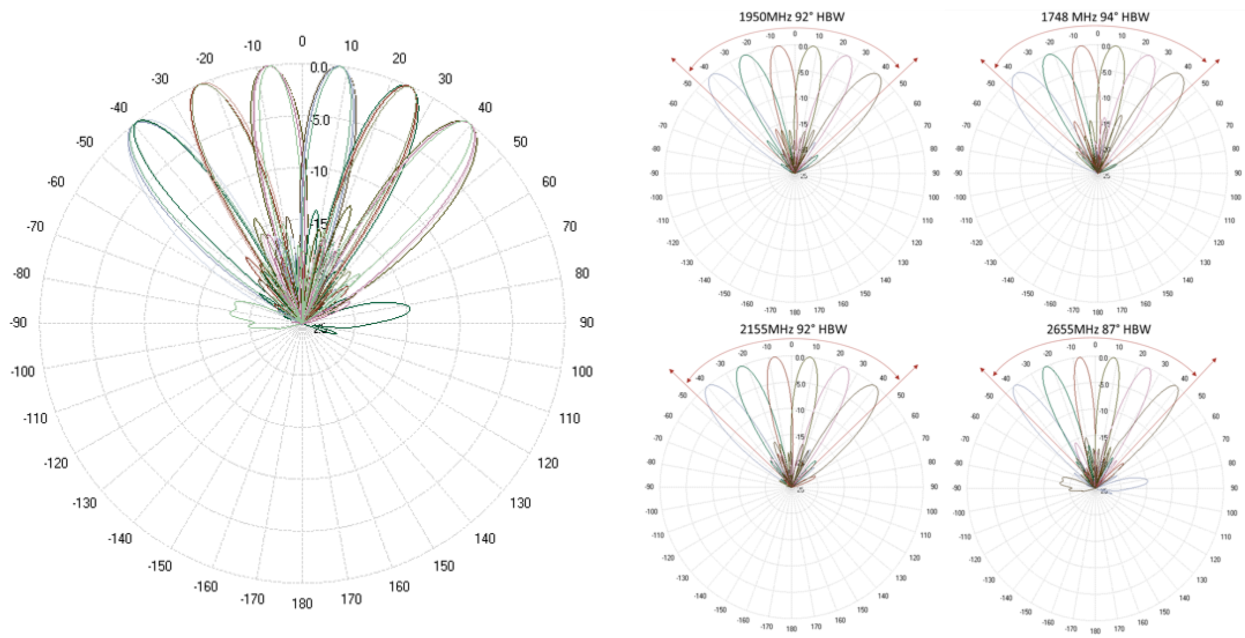

Figure 8: Galtronics Beam Stabilization Technology implemented in 6-beam multibeam antennas.

Multibeam Antenna Mechanical and Deployment Aspects

Multibeam antennas, whether lens or circuit-based, are larger and heavier than standard macro or small cell antennas because they use larger planar arrays rather than linear ones. On the other hand, multibeam antennas must often be installed on COWs and COLTS, which are more limited in the size and weight of antennas they can support. Therefore, the following are some essential mechanical considerations.

- **Integration of different bands**

It is crucial to reduce the antenna count on the tower, stadium, or COW/COLT by integrating different frequency bands into a single antenna. Reducing antenna count lowers both OPEX and CAPEX.

- **Antenna weight and size**

Antenna weight, size, and wind load characteristics are factors in deciding which antenna is selected for a given site. COW or COLT deployments have weight limitations and wind load requirements. Many stadium owners have limitations on the maximum antenna weight and size allowed for installation due to structural reinforcement cost, visual, safety, and installation difficulty concerns. Macro towers have size, weight, and wind loading requirements as well.

- **Ruggedization and substantiality**

For temporary deployments, it is vital to increase an antenna's useful lifetime. As antennas can be deployed and taken down many times during the year, it is essential to make them more ruggedized to extend their lifespan.

- **Ease of deployment, and storage**

Since these antennas may be re-deployed many times and stored, it is important to add features to make life easier for the deployment team and reduce stress on the antenna.

To address the above, Galtronics has added many features:

- There are bumpers around the antenna and connector protectors to increase their lifetime.
- Galtronics antennas commonly incorporate multiple frequency bands into a single antenna, with multiple different variations available. This allows maximum flexibility for an RF designer. Additionally, customers who want both 5G and LTE for higher order sectorization can use a single antenna regardless of underlying technology.
- Galtronics antennas are lighter and smaller than the corresponding lens solutions.
- Lift handles and hoisting points are added to make life easier for the deployment team during deployment, take-down, and movement.
- An optional hard case is provided to provide safe housing for the antenna during transportation and storage, further increasing product lifetime.

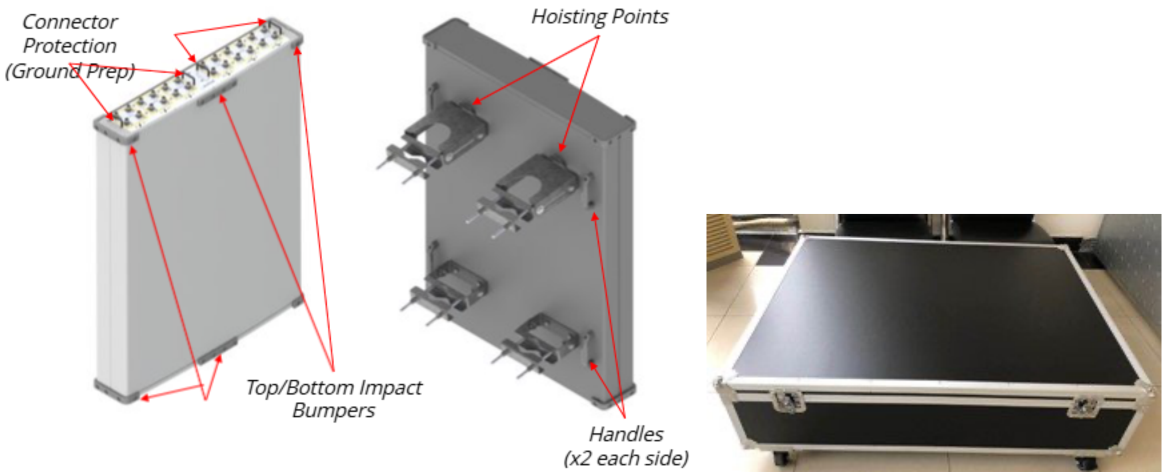

Figure 9: Galtronics ruggedization features.

Figure 10: Galtronics antenna is taken out of the hard case for the Taylor Swift concert in Canada 2024.

Galtronics antennas come in single-, dual-, and triple-band models, supporting 2x2 and 4x4 MIMO. This will reduce the number of antennas on the tower. Galtronics' multibeam portfolio spans 2- to 12-beam configurations across single-, dual-, and triple-band models, covering the entire FR1 range (FDD + TDD). The solution is optimized for macro and hotspot deployments requiring high capacity, low latency, and efficient spectrum reuse. By combining shared-aperture integration with passive beamforming, Galtronics provides a high-performance, low-cost, and sustainable alternative to legacy lens systems. Operators benefit from reduced CAPEX and OPEX, and faster deployment-without sacrificing RF performance or coverage quality.

Table 1: Galtronics multibeam beam counts and combinations.

Low Band (617-896 MHz)	Low Band (698-896 MHz)	Low Band (698-960 MHz)	Low Band (617-960 MHz)	Lower Mid-Band (1695-2690 MHz)	Upper Mid-Band (*formerly* C-Band) (3300-4000 MHz)
3 Beam - 2x2	3 Beam - 2x2	3 Beam - 2x2	2 Beam - 2x2	3 Beam - 2x2	3 Beam - 2x2
3 Beam - 4x4	3 Beam - 4x4	3 Beam - 4x4	2 Beam - 4x4	3 Beam - 4x4	3 Beam - 4x4
			3 Beam - 2x2	4 Beam - 4x4	4 Beam - 4x4
			3 Beam - 4x4	6 Beam - 2x2	6 Beam - 2x2
			6 Beam - 2x2	6 Beam - 4x4	6 Beam - 4x4
				9 Beam - 4x4	9 Beam - 4x4
				12 Beam - 4x4	RET

Galtronics Multibeam vs Lens Solution

Galtronics' multibeam architecture addresses all these limitations by replacing the physical lens with a compact RF beamforming network and shared-aperture phased-array design. This enables electronically controlled, fixed, or switchable beams with precision comparable to lens-based designs—while dramatically improving practicality and cost efficiency.

Key Advantages:

- **Comparable pattern formation and Sidelobe Performance:**
  Advanced phase-shifting and amplitude-control networks achieve beam characteristics similar to lens systems, including low sidelobes and high inter-beam isolation.

- **Compact, Lightweight, and Cost-Efficient:**
  Galtronics' design eliminates bulky dielectric lenses, yielding antennas that are significantly lighter, smaller, and less expensive to produce and install. Tower load and wind-load requirements are reduced.

- **True Multiband Shared Aperture:**
  Through patented shared-aperture technology, Galtronics integrates low-band (LB), mid-band (MB), and C-band (CB) radiators into a single aperture without compromising performance. This unique integration minimizes the antenna's physical footprint and simplifies site deployment.

- **Fast and Reliable Electrical RET:**

Unlike mechanical lens-tilt mechanisms, Galtronics implements electrical remote tilt control, enabling fast, precise, and reliable beam-tilt adjustments with no moving feed parts—improving longevity and operational reliability.

- **Ease of Installation and Maintenance:**
  Lightweight construction, simplified cabling, and standardized mounting interfaces reduce installation time and maintenance costs, improving total cost of ownership (TCO).

- **Ruggedized and Sustainable Design:**
  Galtronics antennas incorporate robust environmental sealing, corrosion resistance, and material durability-enhancing sustainability and operational life compared to both panel and lens alternatives.

Table 2: Galtronics Multibeam solution vs Lens solution.

Feature	**Lens Solution**	**Galtronics Multibeam**
Beamforming Principle	Dielectric lens focusing	Phased-array passive network
RET Mechanism	Mechanical (feed movement)	Electrical (fast, reliable)
Multiband Support	Separate lenses per band	Shared aperture (LB + MB + CB)
Weight / Size	Heavy / Bulky	Lightweight / Compact
Cost	High	Moderate
Maintenance	Difficult	Easy
Sustainability	Great in power efficiency, limited in terms of material sustainability	Great in terms of material sustainability, good power efficiency