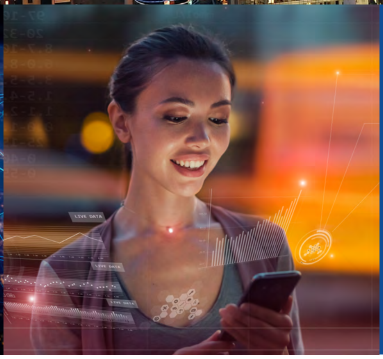

SAINT-GOBAIN
WHITE PAPER

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SHEERGARD®
Radome solutions for 5G mmWave

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Over the next 5 years, the 5G network will continue to grow to meet the unprecedented demand that enhanced mobile broadband and IoT initiatives will require. By leveraging mmWave, it will be able to provide unparalleled capacity at near zero latency to unlock many exciting new use cases and applications.

Introduction

The fifth generation of cellular network technology is beginning to take shape. Starting before its commercial roll out in 2019, service providers and integrators alike have been designing a 5G network that would revolutionize the industry and pave the way for a new era of communication. The network is still in its infancy, and isn't expected to be complete until 2025. As it progresses, it will provide never seen before functionality that will launch a variety of use cases and new applications.

At its core, 5G intends to do four things:

- Provide 1,000x higher data volumes
- Service 10-100x more connected devices
- Handle 10-100x higher user-data rates
- And do so at 5x lower latency

This network isn't being built as an exercise. It is being built to answer the growing demand of data requirements from users' equipment's (UE) and the sheer volume of UE that is expected to go online. The number of connected devices has been growing steadily since the first online message was sent in 1969, however, that steady growth has been recently accelerated by the Internet of Things (IoT) and the advanced functionality of mobile broadband. IoT can be defined as beginning in 2008/09 when the number of connected devices first outnumbered the number of connected people on the internet. And since then, its growth has been exponential. As of 2019 there were over 20 billion connected devices and that number is expected to increase 3x by 2029. It's not as if these devices are consuming less data to offset their increase in numbers. High definition video streaming and AR/VR applications are still only beginning to take root and their data needs are only set to increase as their popularity grows.

Use Cases

A system of this magnitude will open the door to a variety of use cases, primarily revolving around the Internet of Things and enhanced mobile broadband. IoT leverages the efficiency of virtual device-to-device communication to provide a tangible benefit to society. Smart cities and autonomous driving initiatives are great examples of IoT projects. And in their context, it's easy to understand why a real-time, reliable data network is a necessity. Lower latency combined with limited radio propagation also enables Industry 4.0 activities to take shape. The strong signal coverage delivered over predefined areas allows for the realization of smart factories which are forecast to create a substantial number of new jobs and bring in a new era of improved safety into the work place.

Mobile broadband services are set to be enhanced via the increase in achievable data rates of a 5G system that will help compliment the last mile fiber or copper solutions already in place. When fully built-out, this 5G network will usher in high capacity connectivity into densely populated areas such as stadiums and cities via street macro and small cell sites.

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The 5G Infrastructure

The infrastructure required for 5G will be different to what's come before it; however, in order to provide a gradual implementation, we will see it evolve from what is currently in place. In many cities across the U.S., we have already seen the 5G icon appear on our smartphones and have perhaps been frustrated why our video content has not appeared instantaneously as promised. This is due to two things: the network's infancy and the frequency it is currently operating at. Infancy will be solved as the network upgrades, but it is key to understand the frequencies 5G is operating at to understand the complexities this has on the required infrastructure.

5G is being deployed across three frequency bands. 5G low-band typically operates between 0.6GHz – 2.6GHz and is what is currently in use. It operates in parallel with the existing 4G infrastructure as it shares a similar frequency range, and is well-suited for providing wide range coverage to a geographic area. 5G mid-band, commonly referred to as 5G sub-6, operates as the name suggests, below 6GHz. Currently 3.5GHz is the most common with service providers. This band is well suited for MIMO (multiple-input, multiple-output) arrays to offer improved capacity due to their higher throughput. And lastly, high-band 5G (or mmWave) can be found considerably further up the frequency spectrum and operates between 24 and 40GHz. At this frequency, a signal has the highest possible bandwidth and so can deliver the most data possible at any given time. The higher frequency results in lower wavelengths and so although capacity is increased, the coverage of that capacity is significantly reduced. The three-pronged approach of the 5G rollout gives it the flexibility to cover wide geographical areas and the capacity to handle the anticipated spike in data usage in densely populated areas.

Table 1 Key characteristics of the different generations of wireless technology

	Freq. GHz	**Download Speed** Mbps	**Signal Latency** ms	**Distance** miles
3G	0.8 – 2.1	8	100	20-30
4G	0.6 – 2.5	50	20-30	10-20
5G low-band	0.6 – 2.6	50	20-30	~10
5G Sub-6	2.3 – 6.0	200	4-5	~5
5G mmWave	24 – 40	1,000	1	< 1

How it works

To operate at mmWave frequencies, antenna manufacturers have made substantial enhancements to their products. In 4G systems, manufacturers often used separate antenna and RF modules. However, for 5G systems these are typically integrated into one Massive MIMO antenna.

MIMO antennae are at the heart of the 5G network. They operate by sending multiple signals from the transmitter to the receiving UE to increase robustness and increase the data rate. Data transmission becomes more robust as the same data is transmitted over multiple streams and so creates redundancy and an increased signal-to-noise ratio at the receiver. Increased throughput is achieved through spatial multiplexing as the same data is divided across several streams. As these streams are transmitted simultaneously, the UE receives an increase in data rate and so achieves a higher throughput. How much it increases depends on the receiving MIMO array.

The key difference between 4G MIMO systems and 5G Massive MIMO systems is the amount of elements being used. The physical size of the arrays is comparable despite the name, however as the individual antenna element size has decreased, the magnitude in which

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the above benefits are realized grows dramatically. For reference, a 4G MIMO antenna typically uses fewer than 10 elements to transmit a signal, whereas its 5G counterpart will utilize over 100.

A unique feature of mmWave is how it is being auctioned. We have seen similar news headlines to that released in July of this year, *"Canada's 5G auction raises $7.2 billion"*, but the devil is in the details. Spectrum allocations for the mmWave are being allotted at much wider bandwidths than previous auctions. This means that a service provider is often given 800MHz or more in which to operate at. The impact this has on our expected level of service is that it gives providers the ability to deliver high capacity service at peak rates by expanding the number of options they have to transfer the data.

To ensure these high performing systems operate as planned, they must be protected from the elements. The complex phased arrays must survive the same temperature, wind and snow as the residents to which they serve. The protective housing is typically called a radome, a shroud or an enclosure.

Radome Options

The best radome is no radome. But when one is needed, it is required to protect the underlying electronic equipment from the outdoor environment.

Their effectiveness is determined by three functions:

- their RF transparency,
- their structural integrity, and
- their ability to conceal within their surroundings.

Radomes are not new inventions; but the frequency and scale at which small cell sites will be embedded into a cities' architecture puts new pressure on their construction. Typically, there are three construction options: 1) single layer composites such as glass reinforced thermosets or thermoplastics, 2) multilayer sandwich composites that use an electrically invisible core sandwiched between two structural skins, and 3) structural fabrics tensioned across a supporting frame.

Each system has its benefits and compromises on either economy or performance based upon the application. A monolithic composite requires the most material to meet the structural requirements compared to the other two systems.

A sandwich composite varies the thickness and separation of the structural skins to match one quarter of the signal's wavelength to improve RF performance while still meeting its structural requirements.

A tensioned fabric uses a Kevlar®† or Fiberglass weave to provide very high strength and so places the least amount of signal blocking material in front of an array.

Figure 1 Schematic showing the types of radomes available for mmWave applications

Monolithic Composite

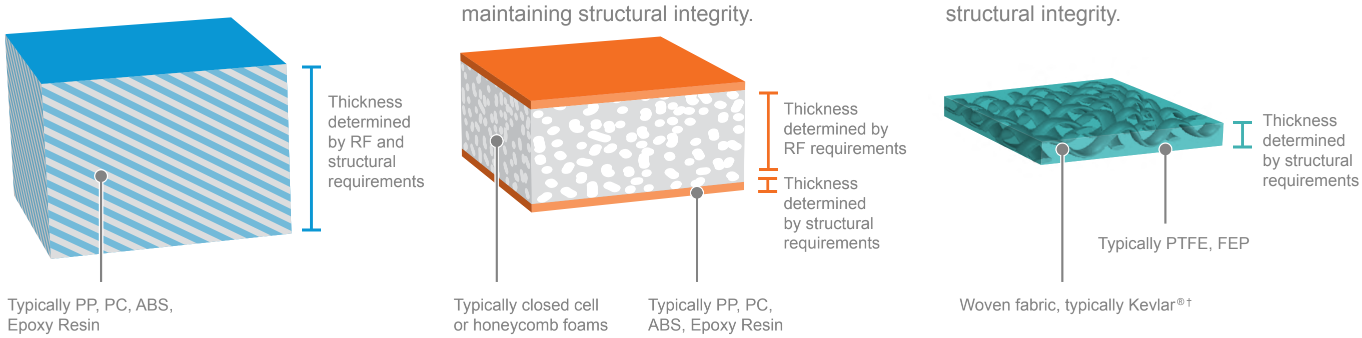
A solid laminate of a single material typically used in generic housing.

Sandwich Composite

A multi-layer composite that replaces signal blocking material with foam to improve signal attenuation while maintaining structural integrity.

Tensioned Fabric

An extremely thin structural fabric that minimizes all signal blocking material while maintaining structural integrity.



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Radome Design Considerations

As the operating frequencies increase to the mmWave, the radome's ability to meet its RF requirements becomes more challenging. In its simplest form, a radome must allow as much signal as possible to pass through to the receiver. Its effectiveness at this task impacts the distance a mmWave signal can travel, and so governs how many small cell sites are required to cover a given area. For those in charge of designing these systems, that problem has four distinct components.

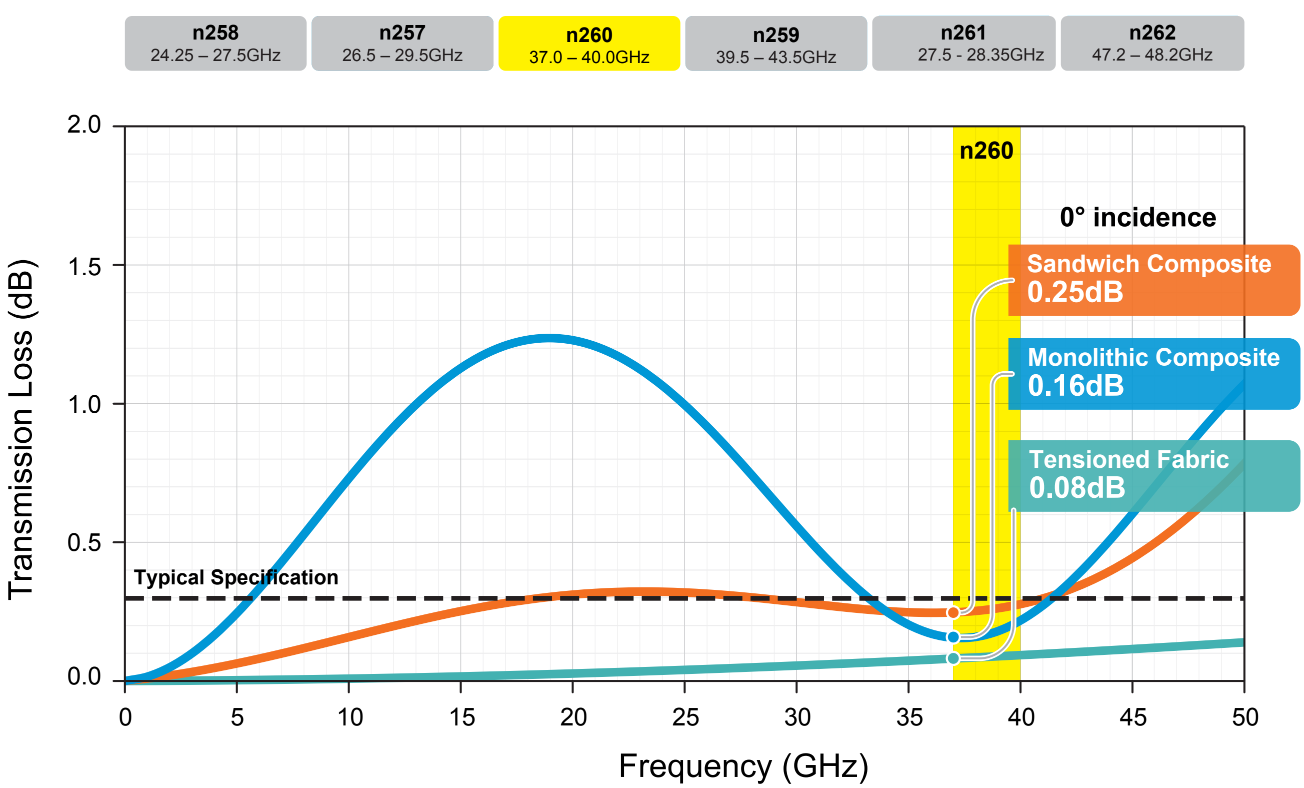
1. What is the minimum signal loss achievable under perfect conditions?
2. How to mitigate against detuning at high incidence (or scan) angles?
3. What frequency range or ranges can be accommodated by one radome?
4. How to ensure rain, snow or ice does not block the passing signal?

Minimizing losses

Transmission loss is a function of the material's electrical properties (Dielectric Constant [D_k] and Dissipation Factor (Loss Tangent) [D_f]), the configuration of the blocking material, and the thickness of all layers. To minimize the signal loss, a radome needs to strike a balance between the structural and electrical requirements. The structural requirements want more material to improve overall strength, but the electrical requirements want less to provide zero blockage. To balance these requirements, a radome should use materials with low D_k and D_f values and minimize thickness wherever possible.

Monolithic and sandwich constructions modify the thickness of the materials to tune for a specific frequency. Tensioned fabrics rely on minimizing thickness to optimize losses over a wide range of frequencies. The chart below shows typical performance at 37GHz, the start of the n260 band.

Figure 2 Three types of radome performance at the bottom of n260 band with 0° incidence



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Mitigating Against Detuning

Regardless of construction, thickness tuning is a good solution when designing for a beam passing perpendicular to the radome; however, massive MIMO antennae utilize active beam steering in both azimuth and elevation directions to target specific receivers. This steering reduces signal interference at the receiver but often creates an incidence angle between the direction of the beam and the radome it passes through. I.e. it is no longer perpendicular.

When a signal passes through a radome at an angle, it must now pass through more material than it was tuned for. The higher the incidence (or scan) angle, the more material the signal is blocked by and the more loss it experiences.

The chart below shows the same three typical radomes, this time scanning at 60° rather than 0°. 60° has been selected because when combined with two additional antennae, the system is capable of providing full 360°.

Figure 3 How incidence angle changes the amount of signal blocking material

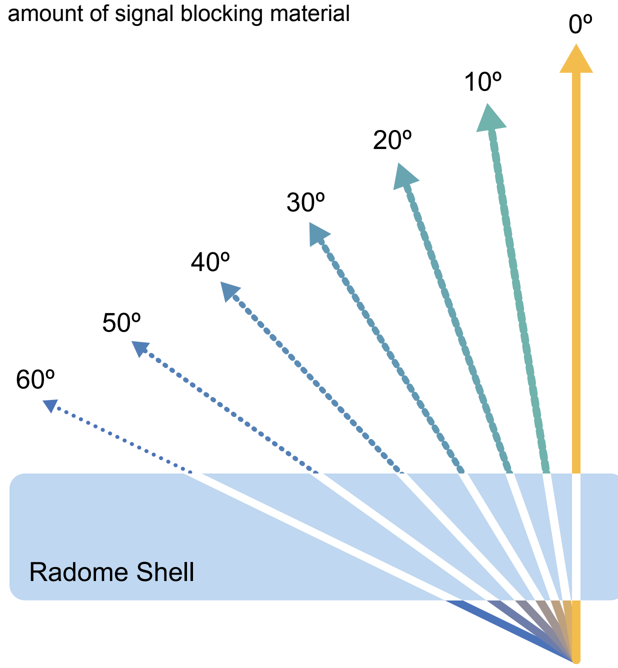
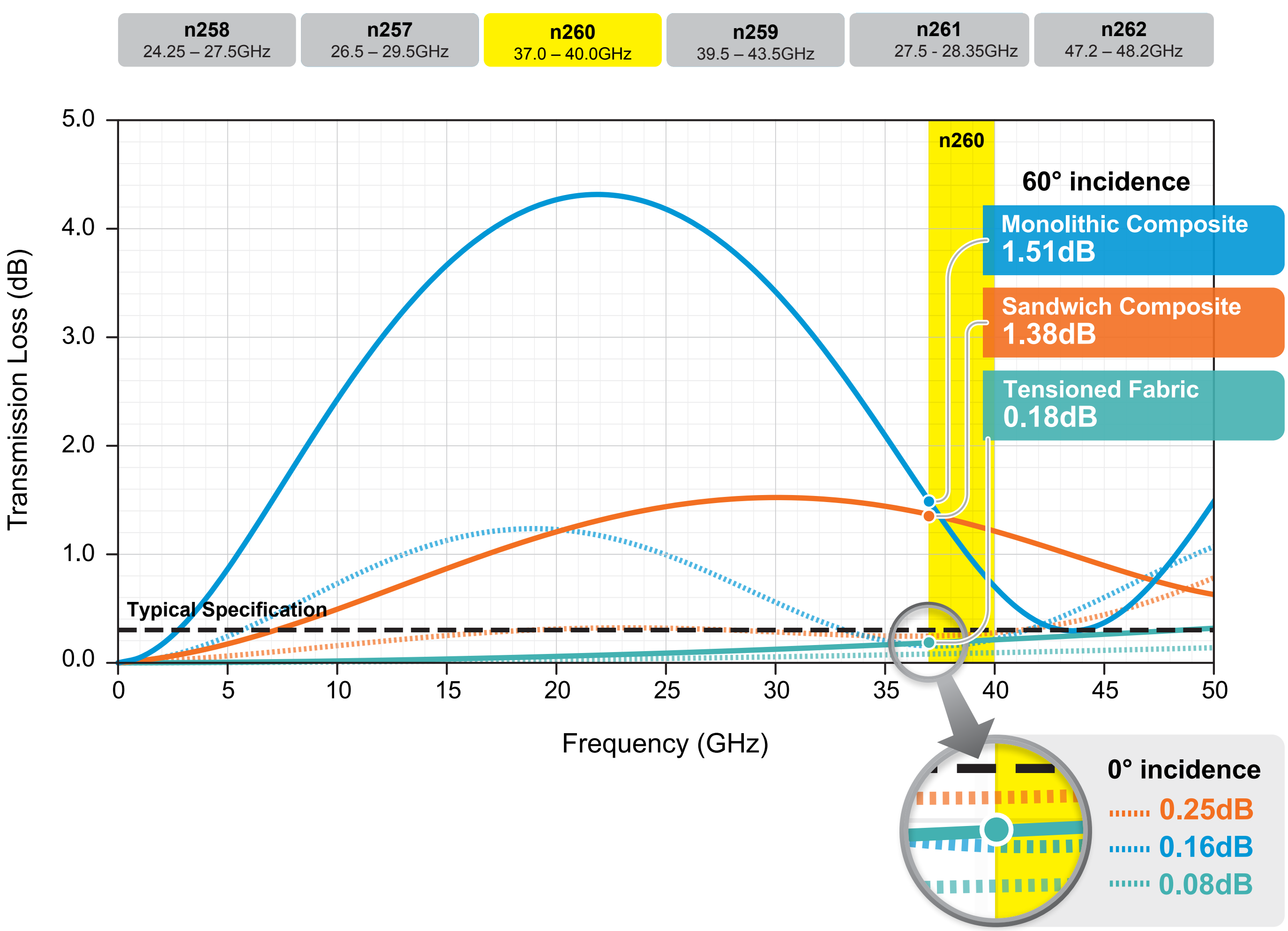


Figure 4 Three types of radome performance at the bottom of n260 band with 60° incidence vs. n260 band with 0° incidence



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Covering Multiple Bands, Wide Bands & Multiple Systems

The ability to protect a wide range of systems has obvious advantages. Wide bandwidth systems can be used to increase capacity or to separate the uplink and downlink frequencies. But multiple bands are also going to be extremely common.

In the current phase of implementation, 5G low- and mid-band systems are already being implemented alongside existing 4G and LTE infrastructure and so today's radomes are already protecting systems over multiple frequencies. It is here that sandwich and tensioned fabric systems have an advantage over its monolithic counterparts. By minimizing the amount of signal blocking material, they are able to provide coverage over a much larger range of the spectrum. Currently, 5G remains in the sub-6 deployment phase and so the damage caused by this additional material is at least minimized. As mmWave systems begin to share the space behind the radome, this requirement is going to become ever more important.

The need to protect multiple systems is likely the requirement furthest away from where we are today. Each provider is allocated an approximate 800MHz range within each 5G spectrum it bids on. This simply means that a small cell site will eventually have to handle a range of spectrum allocations to suit each provider. This phenomenon is true today, but at today's low frequencies, the impact is minimal. In the mmWave spectrum, it is quick to see that this one-size fits all approach may unintentionally favor one service provider over another depending on the sweet spot a thickness tuned radome was designed for.

Water impact

A lot of effort goes into ensuring that the materials for antenna housings are compatible for an RF application. This is the reason why even 3G or 4G radomes will use materials with low electrical properties to not block the signal. The following chart shows typical Dielectric Constant values for radome materials, as well as a few others for reference.

Table 2 Typical electrical properties of common materials

Typical Materials	Dielectric Constant
Air (Vacuum)*	1.00059
PTFE (Teflon™‡)	2.0 – 2.1
PP	2.2 – 2.4
ABS	2.7 – 3.2
PC	2.9 – 3.2
PVC	3.0 – 4.0
Kevlar®†	3.5 – 4.5
D/E Glass	3.8 – 6.4
Water*	~ 80
Metal*	Infinite

* Non-standard radome materials, values given for reference

This is a heavily simplified way to assess signal loss, but what it shows quite clearly is that any thickness of water in front of an array will have a detrimental impact on performance. To prevent this, it is critical that water, snow or ice does not accumulate on the surface. There are several ways to help mitigate this.

Shape is perhaps the easiest and simplest way to design for water and so enclosures should add curves and other geometry that encourages run-off.

Once installed, a radome's **positioning** will greatly impact water accumulation. A flat enclosure scanning vertically will be more heavily impacted than if it were pointed horizontally.

Active prevention can be implemented to help prevent snow or ice and usually take the form of internal heaters or vibration mechanisms. These systems become important when accumulation is inevitable.

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Lastly, **surface hydrophobicity** is commonly selected to provide a non-stick exterior barrier that actively prevents water accumulation. A hydrophobic surface is defined as a surface that creates a >90° contact angle with a water droplet on its surface. This repellency of the polar-water molecule creates a force that promotes beading-up rather than sheeting of the water. This effect is commonly seen on frying pans or vehicles post carwash, and works to clear water from the surface and create a constant pathway for the signal to pass through. These surfaces are typically achieved using fluoropolymers such as PTFE (Teflon™‡) or FEP.

Figure 5 Water droplets on hydrophobic fabric

Support Services & Co-Development

Saint-Gobain has been making radomes for 70 years under their SHEERGARD® brand. They design, fabricate and customize all styles of radome solutions for multiple markets including Aerospace, Radar, Weather, Satellite Communication and 5G macro and small cell applications.

A SHEERGARD® radome solution will tailor one of the three systems described above to the specific requirements of an individual project. Their solutions specialize in offering permanently hydrophobic performance for solid laminate, sandwich construction, or tensioned fabric radome systems.

Saint-Gobain has celebrated over 350 years of operational excellence and currently has manufacturing facilities in over 70 countries, five of which are equipped for radome production. With a dedicated team of mechanical and electrical engineers, they look forward to co-developing any radome solution for tomorrow's communication needs.

This article was supplied and written by **Alex Blenkinsop**, Business Development Manager, SAINT-GOBAIN

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