WHITE PAPER

mmWave Materials Testing

SUMMARY

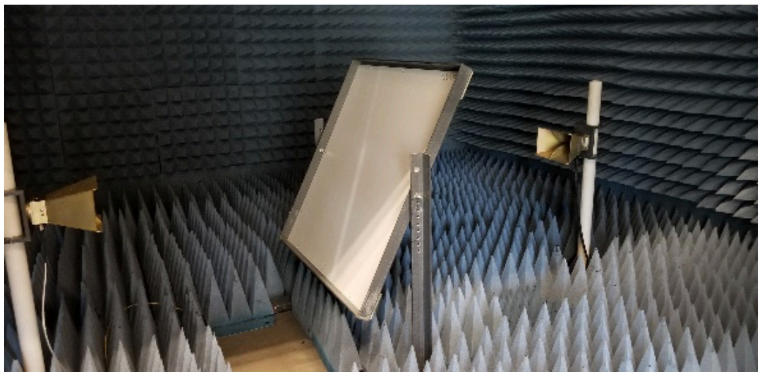
Concealments will be unavoidable with mmWave/5G deployments. Estimates are for site densities that are 10X of 4G that will be deployed at low heights more visible to the public. Local jurisdictions also have expectations that RF transparent materials are readily available to conceal antennas. While the best option is to not conceal a mmWave antenna, this paper addresses the test methods and requirements to determine suitable Concealment materials for those locations that will require it as Concealment materials used today will not perform well at mmWave frequencies.

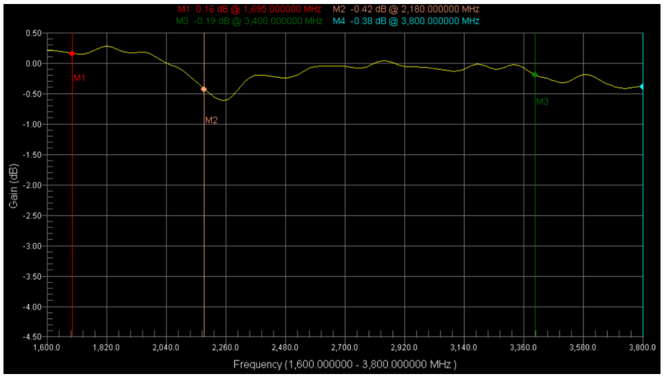
RADOME/CONCEALMENT BASICS

A Radome is a dielectric cover that comes with the OEM antenna and is designed to protect it from the environment while minimizing impact to the antenna's performance (transmission loss and antenna pattern). A Concealment is an additional dielectric material used to hide the OEM antenna/Radome that must be designed to minimize impact to the OEM antenna's performance and meet environmental requirements. RF energy lost through a dielectric material is due to reflection and absorption that varies with frequency, angle, and polarization. Key properties of a dielectric material are its dielectric constant, loss tangent (dissipation factor), and its thickness. An "electrically thin" Concealment is one with a thickness ≤ 0.1 wavelength and is lowest loss over the widest range of angles and polarization. An "electrically thick" Concealment is where the thickness is >> 0.1 wavelength and loss due to reflection is minimized at frequencies where the thickness is multiples of ½ wavelength. Another key factor impacting antenna performance is the distance between the antenna and the Radome/Concealment as it's typically in the Near Field of the antenna and has a "lensing" effect on the antenna.

Far Field Transmission Loss – "Traditional" Test Method for Concealments

The traditional way of validating a Concealment material at current sub-6 GHz frequency bands is to make Far Field Transmission Loss measurements by placing the Concealment material in the Far Field ($2D^2/\lambda$) of the measurement antennas and measuring at different frequencies, angles, and polarizations.





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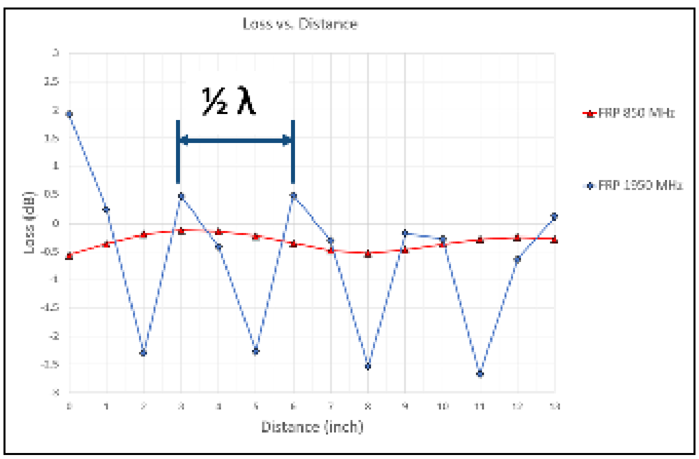
The current frequency bands have long wavelengths in free space compared to the thickness of most Concealment materials and are considered "electrically thin", ≤ 0.1 wavelength, as shown in the chart below for ¼" FRP. Loss in an "electrically thin" Radome/Concealment is generally low across a wide range of incidence angles and the thinner the material, the less sensitive it is to the incidence angle.

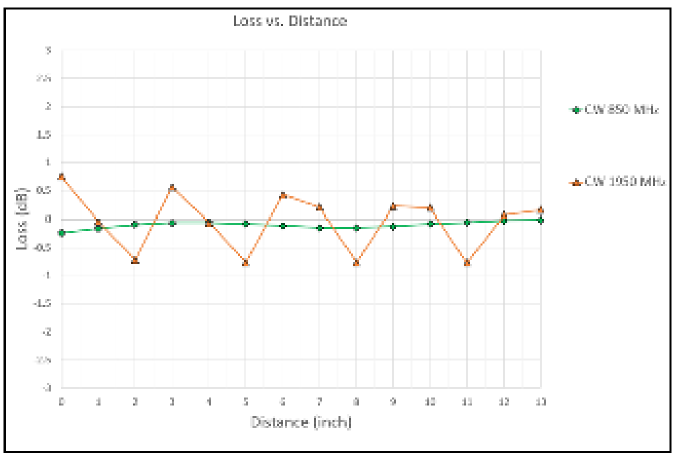
Frequency (MHz)	**600 - 700**	**850**	**1900-2100**	**3500**	**5500**
Wavelength (in)	17.00	14.00	5.00	3.30	2.15
FRP thickness (in)	0.25	0.25	0.25	0.25	0.25
Ratio of thickness/wavelenth	0.01	0.02	0.05	0.08	0.12

But Concealments are generally in the Near Field of the antenna where they become part of the antenna design and have a "lensing" effect. Shown below is the Near Field Transmission Loss for ¼" FRP and ½" ClearWave measured at 0 to 13" from the antenna in 1" increments at 850 and 1950 MHz:

FRP (0.25-inch)



clearWave (0.50-inch)



The result of being in the Near Field with the Concealment material is a periodic change in Transmission Loss (more apparent at 1950 MHz than 850 MHz in the plots above) based on the distance. A location of the Concealment material can even be chosen that results in gain, which is really the effect of "lensing" the antenna pattern. However, current wireless systems use broad beamwidth antennas (50 to 90 deg) and propagation environments with a large amount of reflections/multipath such that the changes in the antenna performance caused by the Concealment material are typically not noticeable. So, while the Near Field effect on the antenna is present, the use of Far Field Transmission Loss to qualify Concealment materials at current frequency bands is sufficient to ensure good performance.

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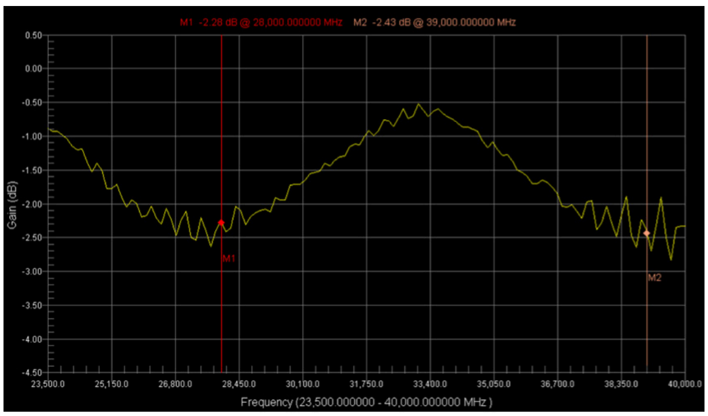
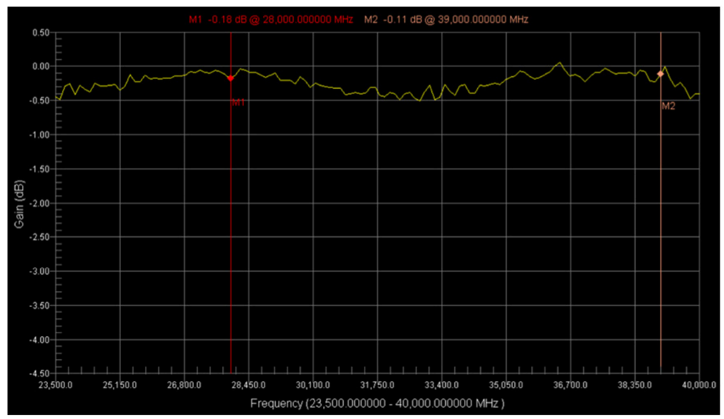
CONCEALMENTS AT mmWave FREQUENCY BANDS

However, mmWave frequencies have significantly smaller wavelengths than the current frequency bands and Concealments at mmWave will almost always be “electrically thick”, >> 0.1 ratio of material thickness to wavelength in the material as shown for ¼” FRP below.

Frequency (MHz)	28000	39000
Wavelength (in)	0.42	0.30
FRP thickness (in)	0.25	0.25
Ratio of thickness/wavelenth	0.6	0.8

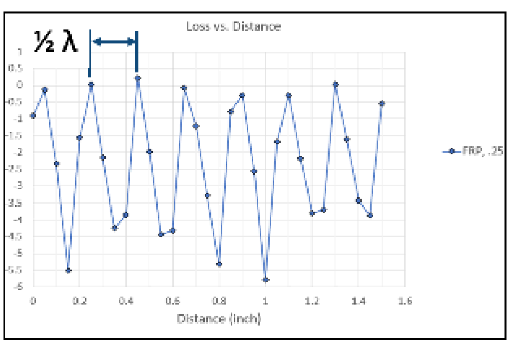
An “electrically thick” thick Concealment has higher loss, except where the Concealment thickness is a multiple of ½” wavelength, and varies highly with incidence angle. Below is a plot of Far Field Transmission Loss for ¼” FRP (left) and CW S500 (right) at mmWave frequencies showing these effects.





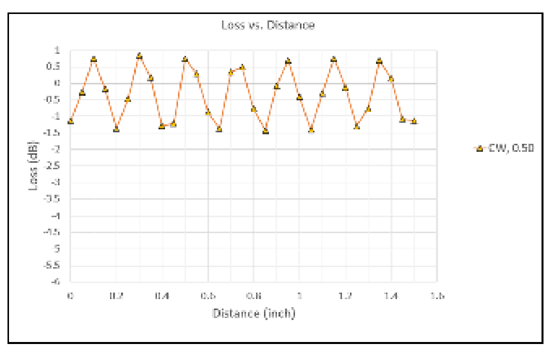
The Concealment material will be in the near field of the mmWave Antenna where it becomes part of the antenna design and has a “lensing” effect on the antenna. This results in changes in transmission loss vs distance that are even more sensitive at mmWave due to the short wavelength. This is shown below for ¼” FRP and ½” clearWave measured at 0 to 1.5” from the antenna in 0.05” increments at 28 GHz. Small movement of .05” in distance can result in several dB change in transmission loss.

FRP (0.25-inch)



Frequency	Ave. Loss	Range
28 GHz	-2.3 dB	6.0 dB

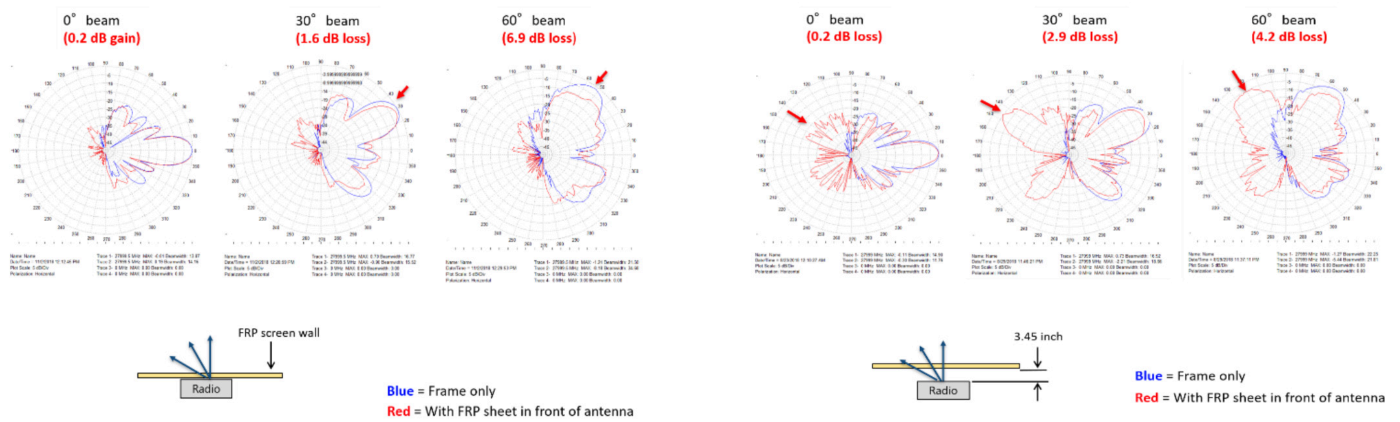
clearWave (0.50-inch)



Frequency	Ave. Loss	Range
28 GHz	-0.4 dB	2.3 dB

Phased array antennas used at mmWave are significantly different than the antennas used at the current frequency bands. Array beamwidths are 10-20°, with scan angles of +/- 60° in azimuth and +/- 30° in elevation. The propagation at mmWave is significantly different too; path loss is higher; far more sources of high absorption and reflections are more specular and narrower such that distortion of the antenna pattern by the Concealment may have noticeable impact on performance.

The effects of ¼" FRP located at 0" and 3.45" from a 28 GHz phased array antenna of 15° beamwidth scanned at 0°, 30°, 60° in azimuth are shown below:



The blue line on the plots is the base antenna pattern and the red line is with the ¼" FRP. The three patterns on the left are with the ¼" FRP right against the array and show minimal impact when the beam is at 0° but some loss and distortion as the beam is steered to 30° and 60°. The three patterns on the right are with the ¼ FRP at 3.45" from the array and show significant backlobes and sidelobe growth at all three beam angles that severely distort the pattern. This clearly shows that a Concealment material like ¼" FRP will not be acceptable at mmWave and that only using the traditional Far Field Transmission Loss test for a Concealment will not be adequate to ensure good performance. Therefore, a new testing method is needed to validate performance of mmWave Concealments.

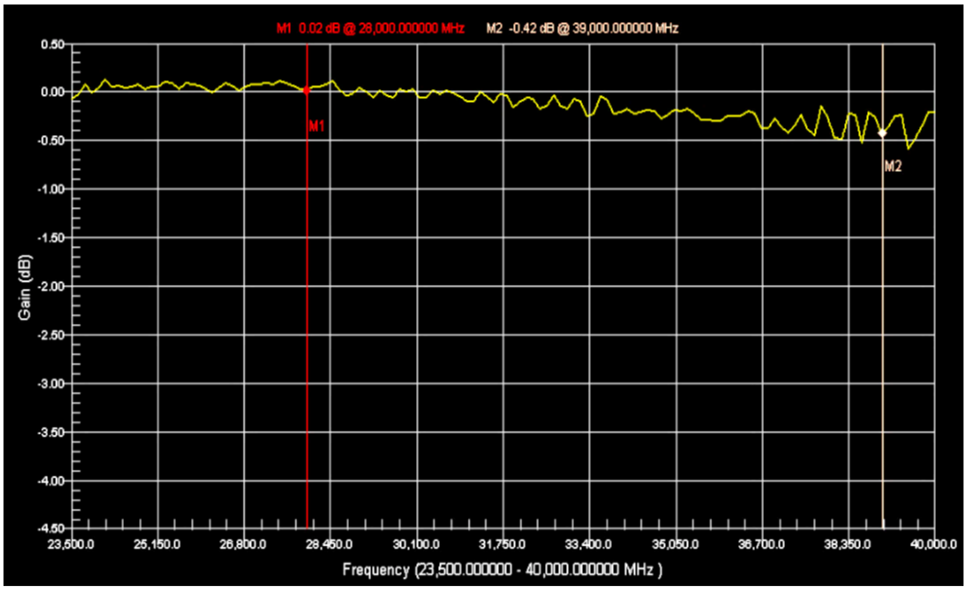
CONCEALFAB'S mmWave CONCEALMENT TESTING SOLUTION

The design goals of a mmWave Concealment are to minimize transmission loss and distortion of the OEM array antenna pattern. An added challenge is to do this over a wide frequency range (24-40 GHz) to support the 28 and 39 GHz mmWave bands. In order to be a complete solution, a mmWave Concealment must meet environmental and structural integrity requirements, as well as thermal performance specifications for the enclosed OEM antenna/radio unit.

ConcealFab has done extensive in-house testing and analysis with Concealment materials at mmWave frequencies; developing the following test methods for validation of mmWave Concealment solutions. Testing must account for all components of the Concealment solution, including any coatings (films, paints, etc) applied to the Concealment material.

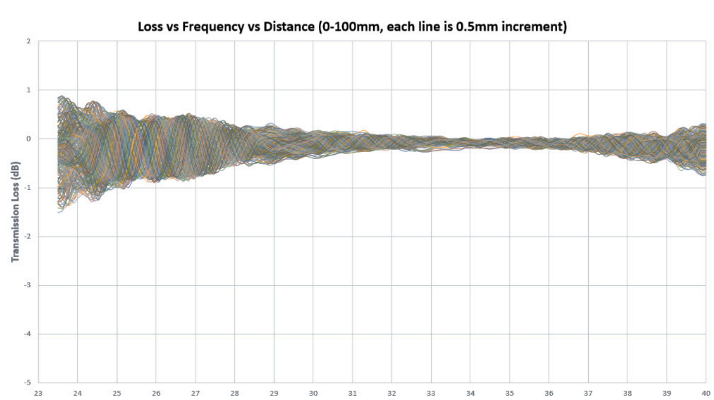
Far Field Transmission Loss (TL) with the Concealment material in the Far Field of the measurement antenna is used for basic loss characteristics and initial elimination of materials.

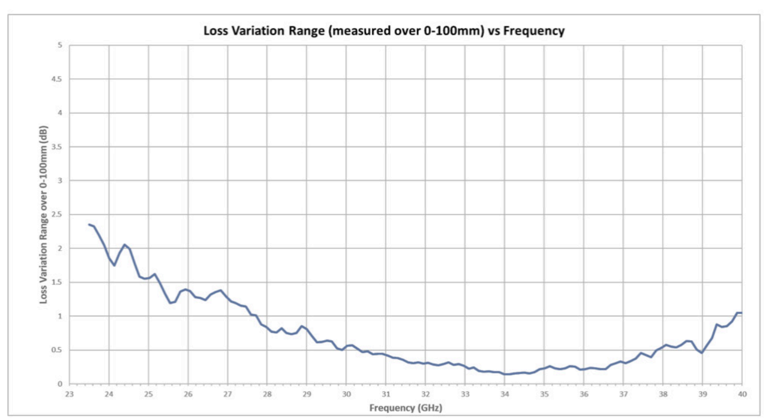
- TL from 23 to 40 GHz
- Incidence angles of 0°, 30°, 60° at both Perpendicular and Parallel polarizations
- Criteria: < 0.5 dB TL at 28, 39 GHz frequency bands.



Near Field Transmission Loss (TL) vs Distance with the Concealment material at a variable distance in the Near Field of the measurement antenna to show the variation of loss vs distance and further narrow down acceptable Concealment materials. ConcealFab has developed a new “Cyclone Plot” that shows the loss vs distance over the frequency range. This is a key capability in evaluating Concealment material TL performance in the Near Field.

- TL from 23 to 40 GHz
- Incidence angle of 0°
- TL sweeps taken at 0.5mm increments over the range of 0 to 100 mm distance between the Concealment and the measurement antenna – the overlay of all these is the “Cyclone Plot”
- Criteria: < 1.0 dB TL variation in the 28, 39 GHz frequency bands.





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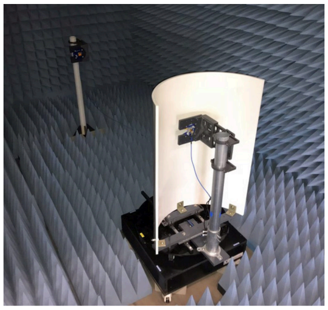
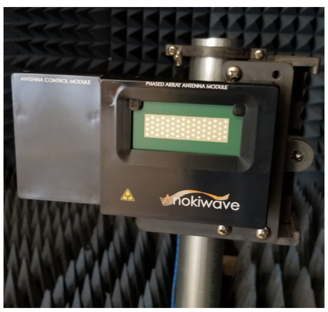
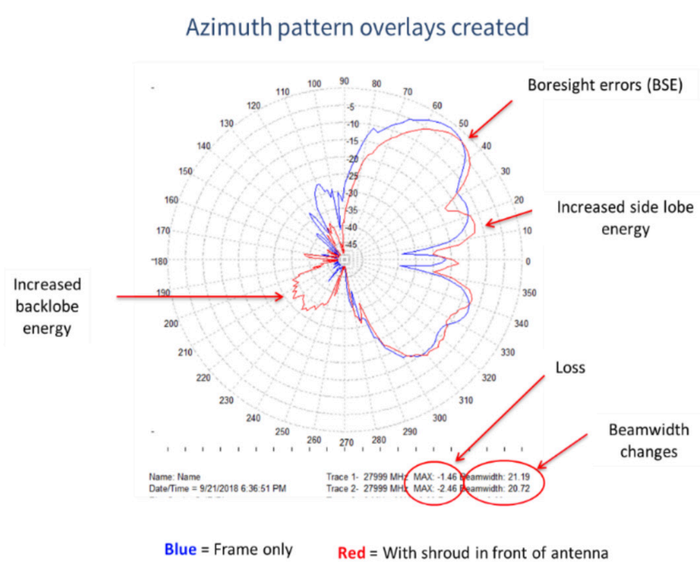
Array Antenna Pattern Measurements with the Concealment material in the Near Field of a mmWave array to show the impact on the antenna pattern. This is another key capability needed to verify that Concealment materials which have good performance in the Near Field TL tests will have good performance with a mmWave array antenna. ConcealFab has acquired a 28 and 39 GHz array antenna and has in-house antenna pattern measurement capability in order to test Concealment materials with an array antenna similar to the OEM antenna arrays.



- Phased array antenna for 28/39 GHz, ≤ 15° beamwidth, steerable to +/- 60° in azimuth
- Antenna patterns taken with the Concealment material at 0 and 1-inch distance from the array to simulate an OEM antenna behind the Concealment
- Since the 39 GHz band is 3 GHz wide (37-40 GHz), patterns taken at a minimum of two different frequencies (ex: 38 and 39 GHz) to verify good performance over the entire band
- Criteria: Compare antenna patterns with and without the Concealment material -- no more than the following variation with the Concealment material:



Main Beam	0°	30°	60°
Main Beam Bore Sight Loss	≤ 1.0 dB	≤ 1.5 dB	< 2 dB
Main Beam Bore Sight Error	+/- 2°	+/- 5°	+/- 10°
Main Beam 3 dB Beamwidth change	+/- 1°	+/- 3°	+/- 5°
1st Sidelobe Gain Increase	< 5 dB	< 5 dB	< 5 dB
Backlobe/Reflected Lobes Gain Increase	< 15 dB	< 15 dB	< 15 dB



OEM Array Antenna Measurements with a representative section/mockup of the actual Concealment solution in the Near Field of an OEM array antenna. This is the ultimate test in verifying a mmWave Concealment solution. ConcealFab is working with the OEM antenna vendors to have this test performed at their antenna test facilities.

ADDITIONAL CONCEALMENT DESIGN CONSIDERATIONS

General Environmental Performance must be designed into a Concealment to meet all necessary provisions within GR-487 including all hardware/components used to attach the Concealment to the substrate pole or rooftop.

Structural Integrity must be designed into all hardware/components used to attach the Concealment to the substrate pole or rooftop and meet all structural requirements detailed in the latest revision of TIA-222 “Structural Standard for Antenna Supporting Structures & Antennas,” be stamped by a licensed Professional Engineer for the jurisdiction where the Concealment will be located, and meet any other local permitting provisions.

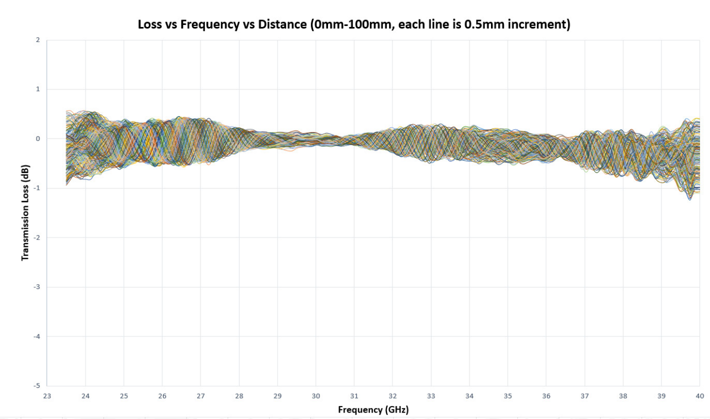
Thermal Performance for the mmWave OEM antenna is a critical item that must be accounted for in the Concealment design. The mmWave OEM antennas are active devices that generate considerable heat. The Concealment must be thermally certified by the radio OEM or tested by a reputable third-party testing firm to meet GR487 thermal standards.

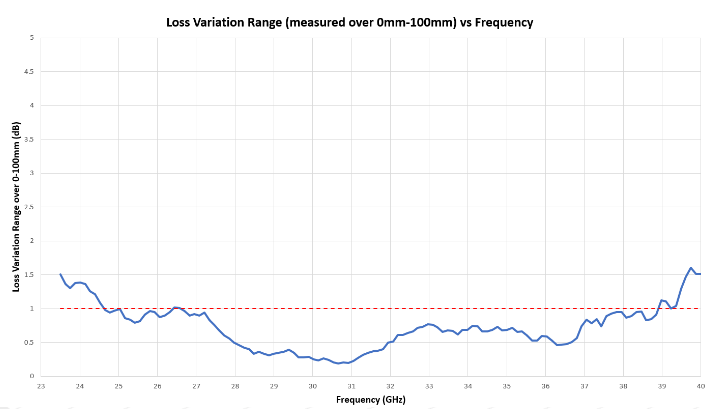
CONCEALFAB mmWave CONCEALMENT SOLUTIONS

ConcealFab has a long record of design expertise in Concealments for the wireless industry and has expanded this expertise to solutions for mmWave Concealments. Extensive testing by ConcealFab has shown that what worked yesterday as a Concealment material for sub-6 GHz frequency bands will not work well today at mmWave. Simply using the traditional Far Field Transmission Loss test is not adequate at mmWave so ConcealFab has developed Near Field Transmission Loss vs distance and array antenna pattern testing to optimize the design of Concealments for the mmWave band (24 – 40 GHz). ConcealFab’s investment in this capability allows all testing to be done in-house for quick evaluation and prototyping.

clearWave™ S140

Using these new test methods, ConcealFab has developed its clearWave™ S140 material to provide excellent RF performance over the 24 – 40 GHz range.





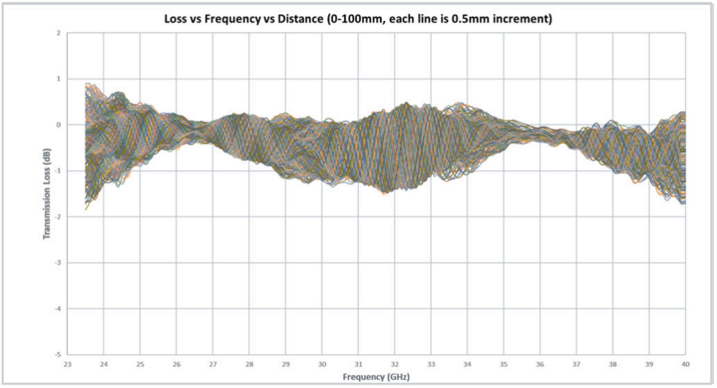
clearWave™

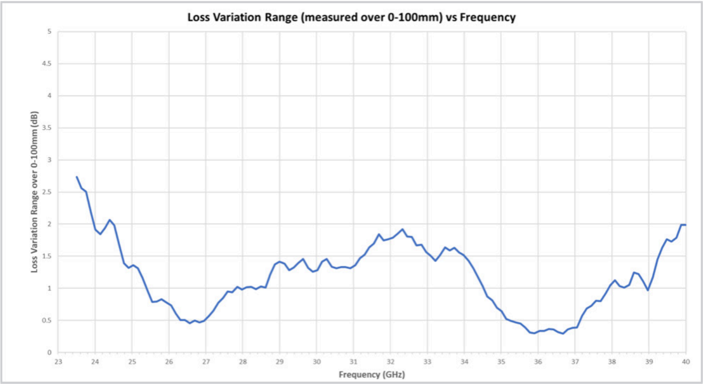
clearWave™ S140 Solutions

ConcealFab has worked closely with the OEM vendors to develop Concealment solutions specific to the OEM antennas using clearWave™ S140 for Pole mount, Wall mount, and Rooftop. These Concealments meet not just the RF performance requirements, but all environmental/structural/thermal requirements as well to ensure a complete solution.

clearWave™ S500

ConcealFab also has its clearWave™ S500 that provides excellent RF performance over the sub-6 GHz frequency range and performance superior to FRP over a wide range of mmW frequencies. S500 is “electrically thick” at mmWave; the “Cyclone chart” below shows that at frequencies with high variation in loss more care must be taken to optimize screen location for good performance.





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