Next Generation of Satellite Communications

By Lt. Col. Stacy Godshall

This article explores technological advancements that may enhance satellite communication (SATCOM) via transmitting in the Terahertz (THz), also known as the Tremendously High Frequency (THF),[1] portions of the radiofrequency (RF) spectrum and via reflectarray antennas to achieve a more robust, adaptable and efficient geocentric military satellite communications (MILSATCOM) network architecture. This article then discusses the current Technology Readiness Levels (TRLs) of THz hardware and systems as well as that of reflectarray antennas. Lastly, possible implementations are suggested for this technology for a geocentric SATCOM network architecture.

Characteristics and Capabilities of THF Range

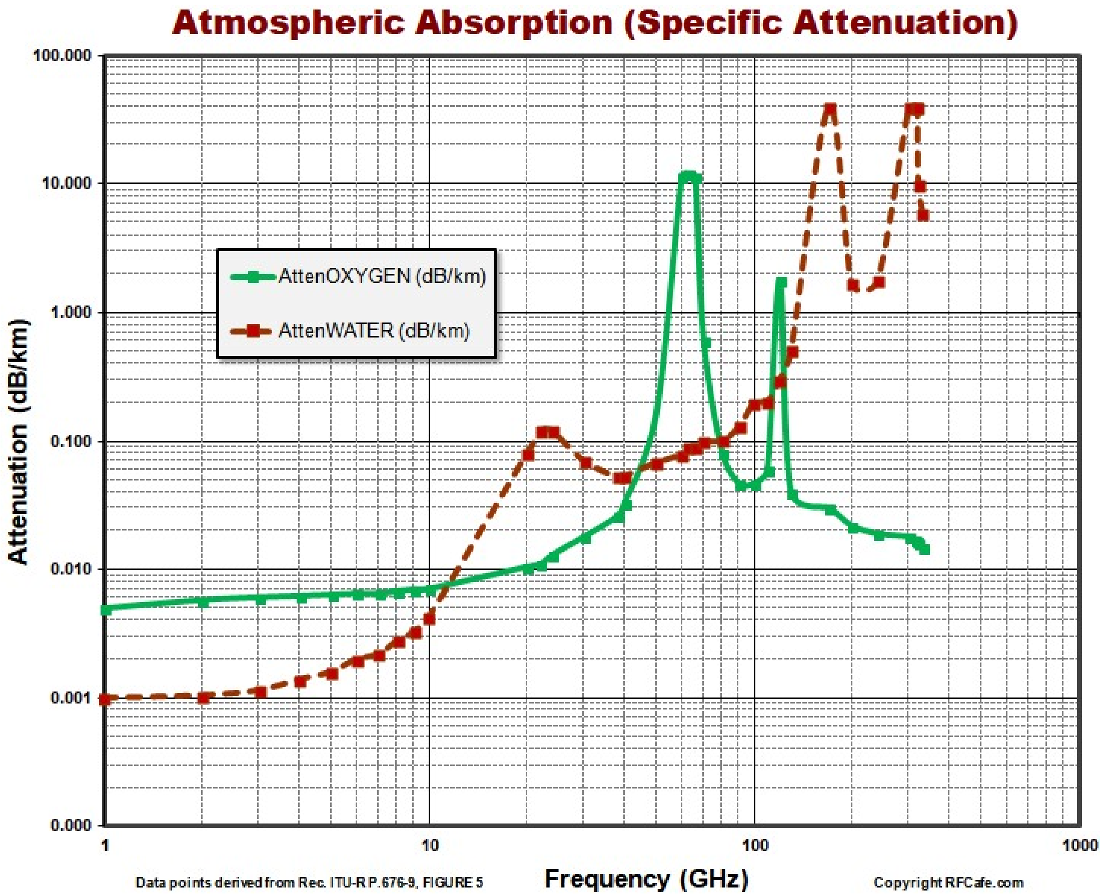
Numerous studies have theorized and modeled the possibility of significantly higher data rates by utilizing unique materials and devices in order to transmit RF signals in the THF range for wireless networks, local area networks and SATCOM.[2] In the next 10 years, several technologies will have an incredible impact on the communications industry and possibly on MILSATCOM if the Department of Defense becomes more proactive in investigating these technologies.[3]

Some of these advances include the use of unique materials such as graphene and metamaterials as the basis for antennas that are able to transmit and receive in the THF range.[4] Developing networks which operate in the THF range would present significant SATCOM improvements such as mitigating the congested electromagnetic (EM) spectrum, reducing intentional and unintentional RF interference (RFI), improving data rates and creating a network of dynamically adaptable SATCOM data links.

Terahertz radiation exists between the infrared and microwave portions of the EM spectrum, at frequencies from 300 to 3000 GHz (0.3 to 3.0 THz). The THF range has been identified by the International Telecommunication Union. Allocation by the Federal Communications Commission for experimental/academic purposes has begun as well.[5]

As more researchers pursue THz technologies and applications, the Federal Communications Commission will begin to allocate additional THz frequencies of the EM spectrum. Devices designed to operate in the THF range would have a significant advantage (such as exclusivity, higher data rates, reduced size and reduced mass) over current devices that utilize other portions of the spectrum.[6] The most formidable challenge with THF is the fact that the atmospheric attenuation for the THz region of the RF spectrum is significant due to water vapor as depicted in Figure 1.

Figure 1



Source: RFCafe.com

This significant atmospheric attenuation for the THF range is not a concern for satellite crosslinks operating above the effected attenuation region, i.e., above 100 kilometers (~330,000 feet) where the concentration of oxygen and water vapor decreases.[7, 8] Despite atmospheric attenuation, researchers from Duke University and the University of California, Santa Barbara are investigating and modeling the possibility of transmitting THz from the Earth's surface to geocentric satellites. Their models indicate that data rates of one Terabit per second (Tbps) are possible from dry terrestrial locations with a very large aperture antenna.[9]

Researchers in China also modeled a high-altitude, ground-based, massive array antenna which they proposed be located in Tanggula, Tibet.[10] That model illustrates that "1Tbit/s is attainable in the 0.275-0.37 THz spectral window in Tanggula."[11] The modeling by Suen et al. in 2015 also indicated that smaller aperture antennas mounted on aircraft or high-altitude balloons also could possibly exceed one Tbps.[12] This model of an air-based antenna, similar to balloon-mounted communications links achieved by Project Loon, may have more feasible applications than a ground-based terminal (such as being more affordable, sustainable, reusable, mobile and deployable).

Japanese researchers also are making progress toward THz transmission capabilities, announcing ". . . the development of a terahertz (THz) transmitter capable of transmitting digital data at a rate exceeding 100 gigabits (0.1 terabit) per second over a single channel using the 300-GHz band."[13]

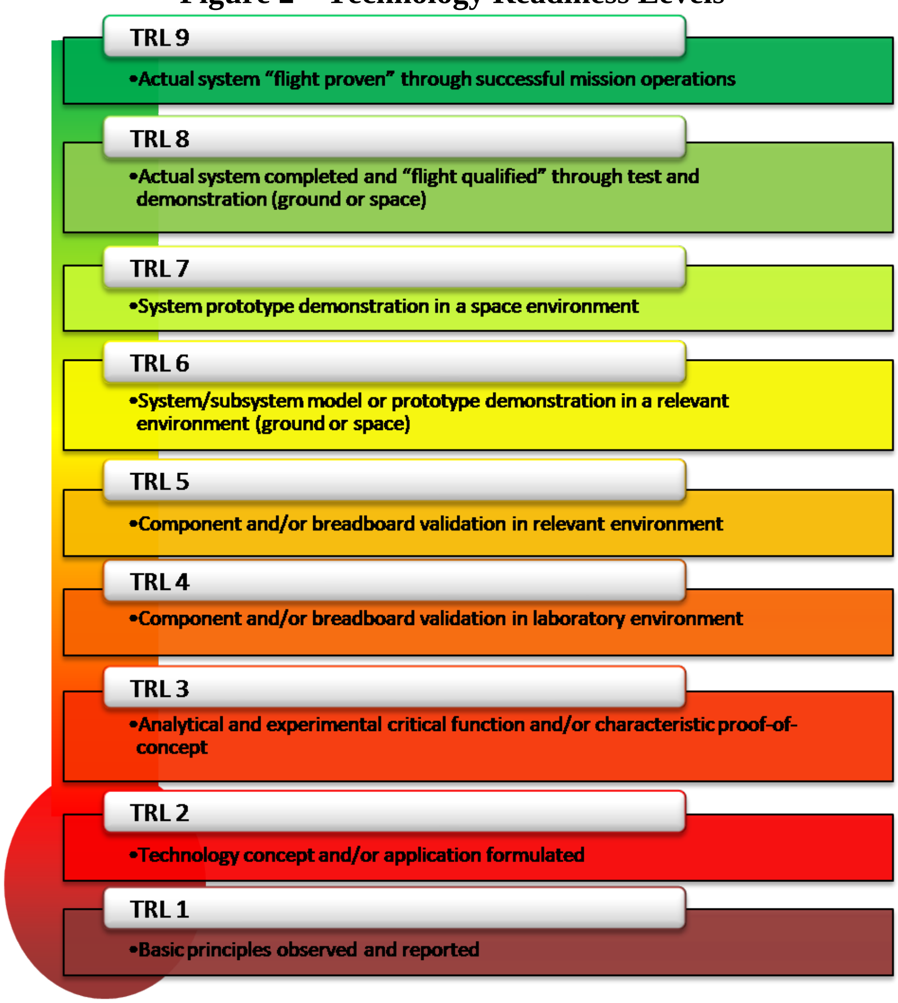
With all these researchers and nations investigating the THF range aggressively, the United States should increase its own research efforts in this area of SATCOM. This level of activity illuminates another issue beyond the aforementioned atmospheric attenuation; there may be a race to THF technologies predicated on developing them and placing them into orbit. The Department of Defense may lose that race to THF and the associated benefits that THF could offer to SATCOM if this formidable challenge is not recognized and addressed.

Technologies Enabling Transmission in the THF Range

There are many new technologies and techniques that are enabling THz RF transmission to come to fruition; too many to list and elaborate on for this article.[14, 15, 16, 17, 18] These technologies would facilitate a THz satellite crosslink architecture enabling low Earth orbit satellites to crosslink not only with each other but with satellites in medium, high and geostationary/geosynchronous orbits as well.

These technologies are at Technology Readiness Level (TRL) 4 with potential higher TRLs easily accessible. Figure 2 shows the definitions and gauges of the nine TRLs.

Figure 2 – Technology Readiness Levels



Source: NASA

TRL 4 for THz technologies is evident due to the fact that they have been validated only in laboratories and not yet tested specifically as a crosslink type antenna system in the space environment. If these innovative material antennas were developed for TRLs 7 to 9 and deployed, there would be no immediate impact since an entire constellation would need to have these antennas. However, with current development and deployment timelines for future systems, this is a technology which should be incorporated into future constellations by including them into current designs and build schedules.

Reflectarray Antennas

A reflectarray is the combination of a phased array and a feed horn similar to that found in a parabolic antenna. By combining the technologies of the phased array with the feed horn device from a parabolic antenna, the reflectarray "combines all the advantages of a parabolic reflector with the planar design of a phased array of antennas."[19]

A reflectarray would be a very capable, yet compact, antenna that can provide the needed greater flexibility with an antenna that can achieve high gain, electronic steering and electronic beam shaping. An example of a reflectarray antenna, transmitting in the Ka-band of the Super High Frequency portion of the EM spectrum, is the NASA Jet Propulsion Laboratory Integrated Solar Array and Reflectarray Antenna (ISARA) which was launched into orbit in November 2017. It is rated TRL 7 as a result of being on orbit for 12 months and having initiated on-orbit testing in March 2018.[20]

The goal of this cubesat reflectarray antenna is that "it increases downlink data rates for CubeSats from the existing baseline rate of 9.6 kilobits per second (kbps) to more than 100 megabits per second (Mbps)."[21] The ISARA is mentioned at this point to illustrate the form factor that a pioneering material THF reflectarray antenna could have in order to achieve the network architecture design discussed in the next section.

Improved Future MILSATCOM Network Architectures

A conceptual, improved MILSATCOM network using these technologies possibly would utilize ground stations and terminals that would only transmit and receive to and from high-altitude (stratospheric) platforms in order to have the THz RF signal successfully traverse the atmosphere. Then the stratospheric platform, equipped with THF range equipment, would transmit and receive to and from low Earth orbit (LEO) satellites. In turn, those satellites would be equipped with THF reflectarray antennas able to link with all other low, high, medium and geostationary/geosynchronous THF-enabled satellites.

In addition to THF transmitters, the constellation satellites would need to include routers in order to route the signal and data to and from the appropriate orbit. This would facilitate the routing of signals and data to and from the corresponding orbit rapidly and responsively at times when the satellite in question may be experiencing RFI.

For example, if a satellite in high Earth orbit gathers some data and is not currently over the ground station/terminal, or over the stratospheric platform functioning as the terrestrial station, then that high-orbit satellite will transmit the data to a LEO satellite directly in its field of view. In turn, if that LEO satellite does not have the ground station/terminal, or the stratospheric platform functioning as the terrestrial station, in its field of view, then the LEO satellite will forward the data to a LEO satellite that does have the stratospheric platform in its field of view.

This type of dynamic routing would be complex but is achievable with on-board routers and THF-enabled reflectarray antennas. Imagine each future satellite used for intelligence, surveillance, reconnaissance, missile warning, satellite communications and environmental monitoring, connected to every other satellite in its respective constellation via this THF SATCOM network. Each of those satellites is able to route data at a rate of Tbps via small, agile THz capable reflectarray antennas to cubesats in LEO, and then to stratospheric platforms above an active theater. This rate of data being transmitted directly into an active theater would greatly enhance data processing and analysis and associated responses.

Conclusion and Future Study

Satellite communications should and can be like the passing of an ice hockey puck; making progress with transmissions to intermediate objectives, avoiding defenders, not committing excessive time and resources toward attempting to block a defender, not shutting down without passing, not skating around waiting for an open player and not shooting right at the goalie when the goal is in sight. The past and current mindset and SATCOM architecture are configured to pass the puck (the data) to a designated player (another satellite or ground terminal) with little or no deviation of the transmission path.

The THF reflectarray-enabled SATCOM architecture proposed here would enable the United States to have “strong hockey puck passing” with the data needed to transmit unabated to the end destination. In other words, this relay architecture provides expedited service and redundant paths, and like terrestrial counterparts, makes better use of available resources.

There are many researchers getting closer to TRL7 to TRL9 solutions for THF RF communications. The Department of Defense should strongly consider investigating these capabilities more and accelerating the pace toward implementation of THF and reflectarray technologies into SATCOM programs that are being developed, tested and deployed now and in the future.

The intelligence, surveillance, reconnaissance, missile warning, communications and environmental monitoring satellites of the future should have THF-enabled reflectarray antennas and be supported by a mega-constellation of THF SATCOM satellites in LEO. This approach would achieve a more robust, adaptable and efficient data transfer and communications network to mitigate RFI and support the need for improved data rates, more flexible links and more secure communications.

If adversaries are going to utilize space-based jammers[22] as their proverbial goalies and defenders, the United States ought to be playing good hockey and should pass strongly and not shoot right at the defender or goalie when the goal is in sight. The fact that the THF range and reflectarray antennas will be utilized is not in question. The question is whether the Defense Department will be the first to obtain Federal Communications Commission approval to operate and invest in deployment into new spaced-based assets in the THF range and the Y band (this article’s proposed name for the THF band that will be utilized) and thus gain the ultimate high ground of the EM spectrum and that of the SATCOM architecture.

In addition, more diligent consideration should be given to the possibility of adding THF to the mission of the SATCOM Integrated Operations Environment operations center within the Joint Forces Space Component Command. The U.S. military has realized the importance of leapfrogging U.S. capabilities past international peers by using technological advancements.

THF communication coupled with reflectarray antennas is one such example of vaulting capabilities in support of the space mission.

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