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REAL ESTATE IN FREQUENCY SPACE

The ephemeral 'advanced propulsion'

Strategic bombers—relevant again

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Real estate in frequency

by Mark Williamson
Contributing Writer

The air around us is criss-crossed with invisible radio waves from TV transmitters, cell-phone masts, and satellites. Invisible because our eyes have evolved to detect wavelengths of what is called, for obvious reasons, the visible spectrum—'light.'

Those radio waves, the light from a TV screen and a host of other phenomena such as microwaves, heat, and UV rays, have more in common than most people realize. They are all part of the electromagnetic spectrum, a continuum of wavelengths from the ultralong waves of the radio spectrum to the ultrashort waves of the X-ray and gamma-ray spectrum, with the tiny window to which our eyes are sensitive somewhere in between.

Today, in the established field of satellite communications, the production of radio waves is as important as ever, but the challenge now is to utilize shorter wavelengths, or their inverse higher frequencies.

Frequency bands

In October 1957, when the first satellite, Sputnik, was launched, it announced its existence by means of an iconic 'beep-beep' in the earphones of radio amateurs and professionals around the world. The radio frequencies that produced these sounds were approximately 20 MHz and 40 MHz, toward the lower limit of what we know as the VHF, or very high frequency, band.

Since then, largely to avoid interfering with terrestrial transmissions, satellites and other spacecraft have gradually been developed to use higher and higher frequencies—not in the megahertz range but in the higher, gigahertz range.

This part of the spectrum has been divided into subbands, such as the familiar C-band and Ku-band. To an extent, the history of these divisions also provides a timeline for the development of satellite communications frequencies.

The first band widely developed for commercial fixed-receiver satellite communications services, such as trunk telephony and TV distribution to cable head-ends, was C-band (defined by the IEEE as spanning 4-8 GHz). The

Global Xpress, comprised of Inmarsat-5 satellites, will mark the first use of Ka-band by a commercial operator of a global satellite system.

As satellite services have grown more popular, the frequency spectrum available at currently used bands has been steadily filling up. This has created a need to develop new 'real estate' at higher-frequency bands, and to advance the technologies required for operating there. Technical challenges remain, but more and more satellite companies are beginning to invest in Ka-band systems.

driver for this was the relative ease with which the satellite and ground station hardware could be manufactured: The physical dimensions of antennas, feeds, and waveguides are intimately related to the wavelength of the radio waves, and because the relatively low frequencies of C-band equate to longer wavelengths, the waveguide dimensions are larger.

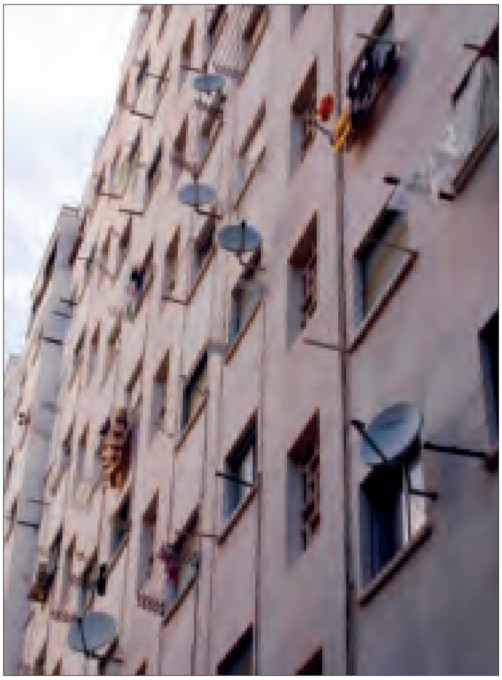
Put simply, in the 1960s and 1970s, equipment manufacturers would have been hard pressed to meet the smaller sizes and manufacturing tolerances required for the higher frequency bands. And if they had tooled up to deliver those finer tolerances, the equipment would have been unaffordable in the commercial market.

As it was, once C-band satellites became established, 5-m-diam. satellite dishes sprouted on apartment buildings and in motel parking lots across the U.S. like mushrooms, because wherever you were, all you needed was a satellite dish and a power supply. There was no need to dig up the roads to lay miles of cable.

Virtual real estate

C-band was sufficient for everyone's need for satellite channels in the early days, but as satellite services increased in popularity the frequency spectrum available at C-band began to fill up. Once frequency spectrum is fully utilized, all you can do is make 'tweaks,' such as developing ways to use the same bit of spectrum more than once—so-called frequency reuse, which is done by transmitting on opposite polarizations.

The same frequency band can also be reused by transmitting from satellites spaced widely apart on the geostationary arc, so that ground station antennas are pointing at completely different parts of the sky, and thus do not suffer interference. But this works well only when your nation is spread across a wide range of longitude, as is the U.S. In Europe, angular separation is extremely limited, so engineers began to develop the alternative real estate of Ku-band (which offered an extra 6 GHz of frequency space between 12 and 18 GHz).



Small TV antennas were the legacy of Ku-band. Credit: Mark Williamson.

The move to Ku-band, pioneered by ESA in the late 1970s, resulted in development of the first-generation Eutelsat and Inmarsat satellites, known respectively as ECS and Marecs (for Maritime ECS).

The technical advantages included the ability to provide the narrower coverage areas, or footprints, required by the smaller nations. This follows from the physics of antenna design that prescribes a narrower beamwidth at higher frequencies for the same physical antenna size. Moreover, narrower footprints meant that frequencies could be reused many times across a region without interference. This led ultimately to the development of multiple spot beams for frequency reuse within individual nations, akin to the now-familiar cell-phone network pattern.

But it was satellite-delivered direct-to-home (DTH) television that proved to be the ‘killer app’ for Ku-band. According to Roger Dewell, managing director of U.K.-based High Q Systems, it was Ku-band developments that engendered the small, wall-mounted receive dishes and made the DTH market viable in the first place, “because you need a smaller physical area at higher frequency bands to achieve the same amount of gain.” Imagine, by contrast, having to mount a 5-m C-band antenna on your apartment wall!

Indeed, before long, Ku-band had become the de facto frequency space for broadcast TV and other advanced telecommunications applications in the developed world, leaving C-band for legacy cable distribution in the U.S. and for entry-level satellites in emerging nations. Meanwhile, lower frequency bands had been adopted for other applications: broadly speaking, L-band for mobiles, S-band for satellite telemetry, tracking and command, and X-band for military applications.

Push to Ka-band

But even Ku-band was not enough. As early as the 1980s, there was a general realization that the technical advantages would be accentuated by an ordered progression from Ku- to K- and Ka-band (the designations Ku and Ka reflect their positions ‘under’ and ‘above’ K-band). Indeed, the 22-GHz of frequency space encompassed by K- and Ka-band speaks for itself.

In a push to provide the technologies required for the higher frequencies, ESA began developing Ka-band systems in the late 1970s. This culminated in 1989 with the launch of its Olympus technology demonstration satellite. Olympus carried a 20/30-GHz communications payload and a Ka-band beacon payload to quantify atmospheric attenuation at those frequencies. Its successful operation proved the potential of Ka-band and led to the development, by Italy, of the Italsat 1A and 1B satellites, designed to demonstrate the operational capabilities of an advanced Ka-band payload and provide a preoperational service within the Italian telecommunications network.

The Italsat spacecraft were launched in 1991 and 1996, respectively. Research into Ka-band was further advanced by NASA’s ACTS (Advanced Communications Technology Satellite), launched in 1993, and Japan’s COMETS (Communications Engineering Test Satellite), launched in 1997.

A major reason for the investment by space agencies in Ka-band research was the trend toward greater attenuation at higher frequencies. Typically, a signal transmitted through the atmosphere at Ka-band will

THE MAIN SATELLITE FREQUENCY BANDS *(as defined by ITU)*

Frequency band	Frequency range, GHz
L-band	1-2
S-band	2-4
C-band	4-8
X-band	8-12 (in U.S., 8-12.5)
Ku-band	12-18 (in U.S., 12.5-18)
K-band	18-27 (in U.S., 18-26.5)
Ka-band	27-40 (in U.S., 26.5-40)
O-band (not yet developed)	40-50 (Q-band in U.S.)
V-band (not yet developed)	50-75

suffer between five and 10 times the attenuation of a C-band signal. Thus, if nothing is done to increase the transmission power, the receiver will have to be that much more sensitive (and expensive), or the antenna will have to be larger.

In addition, the absorption of radiated energy by rain drops (so-called rain attenuation) can easily be more than 10 times as bad at Ka-band as at C-band. As Joseph Pelton, director emeritus of the Space and Advanced Communications Research Institute at George Washington University, notes: "This makes Ka-band much harder to implement in places with particularly heavy and seasonally intense rainfall, such as Southeast Asia and tropical Africa, where it can persist for months."

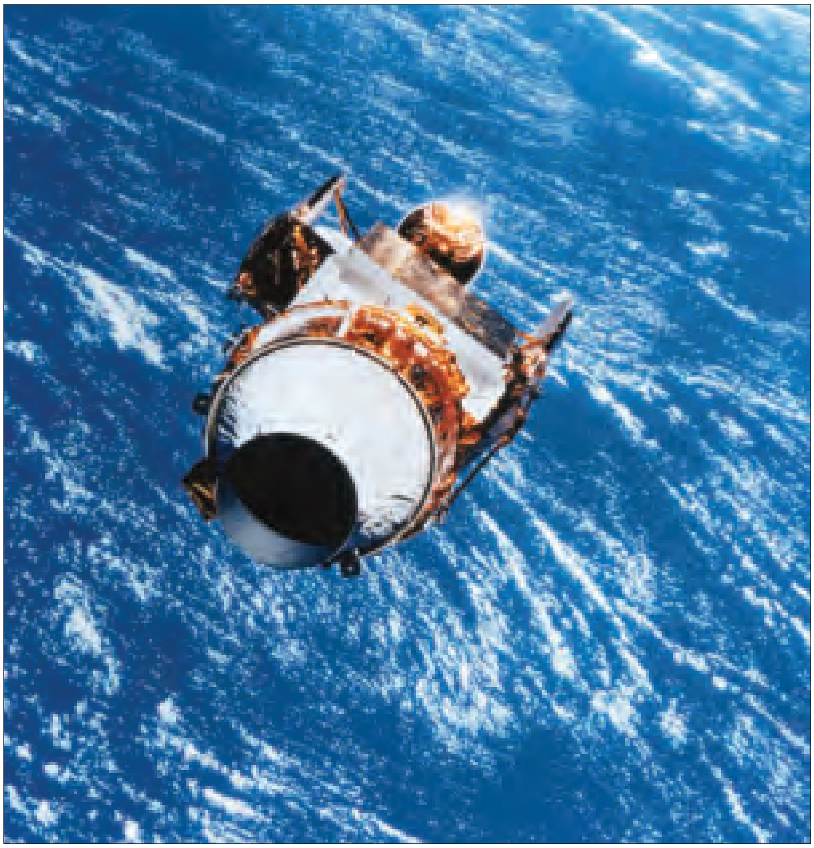
Luckily, Pelton explains, there are several solutions, including "highly concentrated antenna beams (0.5 degrees or smaller)" to provide higher radiated power to offset the attenuation, and adaptive systems that can target areas experiencing high rain rates "on demand." Although onboard processing can "correct the signal and restore its integrity on board the satellite," he continues, more R&D is needed "to develop cost-effective and reliable onboard processing capabilities."

Reasons for reluctance

But all this development costs money, which goes some way to explain why Ka-band systems are far from prevalent more than two decades after the pioneering technology demonstrations of ESA's Olympus.

Why have commercial operators shown such reluctance to jump on the Ka band wagon? For a start, explains Dewell, "moving to new frequency ranges means that new hardware must be designed and qualified for use in space. This is very costly for the supplier, and then for the purchaser, at a time when manufacturing volumes are low." Moreover, he adds, because "satellite communications is not built on first-mover advantage, hardware tends to be non-leading edge, as heritage and reliability win out over the latest designs." And because the dimensions of Ka-band hardware are smaller, any manufacturing defects will have more of an effect than at lower frequencies.

However, Dewell maintains that technical issues such as rain attenuation are "more of a system constraint than a commercial disincentive." It is more a question of "need vs. ability," he says. "There have to be overriding reasons why operators can no longer live with the older frequency bands, such as congestion of the spectrum." So we are back to real estate.



The 1993 launch of ACTS helped further Ka-band research.

Developments

Despite the challenges, in recent years, several satellite companies have invested in Ka-band systems. According to a July 2011 Euroconsult study of fixed satellite service operators, "17 operators have invested in Ka-band over the last 18 months, with six companies actually having launched Ka-band capacity."

Canada's Telesat was among the first to specify Ka-band on an operational, as opposed to experimental, basis with its Anik F2 satellite, which carried 38 Ka-band transponders to orbit in 2004.

In the U.S., long-time operator Hughes, bought by EchoStar in 2011, has been migrating subscribers to its Spaceway 3 satellite, which has a Ka-band payload. However, the big push will come with Jupiter, its all-Ka-band satellite slated for launch by midyear: According to Hughes, it will have 10 times the throughput of Spaceway and will be able to handle 1.5 million-2 million subscribers. Like-

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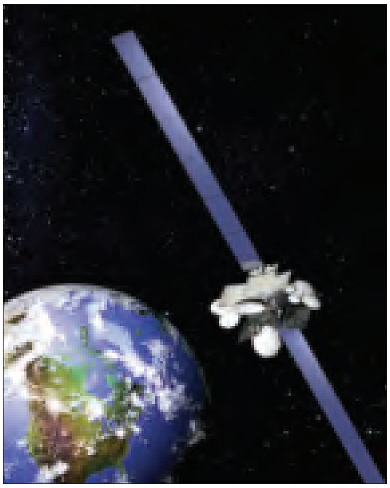


In Europe, Eutelsat has been leading the Ka-band rollout, most notably with its aptly named KA-SAT.

wise, Hughes' competitor ViaSat plans to capitalize on its ViaSat-1 satellite, launched in October, for its WildBlue broadband service.

In Europe, Eutelsat has been leading the Ka-band rollout, most notably with its aptly named KA-SAT: Its payload is based on 82 narrow spotbeams, which allow frequencies to be reused 20 times, and a total throughput of some 70 Gbps. Although Eutelsat's key competitor, SES, has been slower to adopt Ka-band, its Astra2Connect consumer broadband service will migrate from Ku- to Ka-band on future spacecraft. SES has three such satellites on order—Astra 2E, 2F, and 2G—and expects to launch them between this year and 2014.

More unusual is SES's participation as the largest shareholder of O3b networks, a Channel Islands-based company aimed at emerging markets. O3b (an abbreviation for other three billion, referring to people in regions lacking modern satellite services) plans to launch its first eight satellites in the first half of 2013 and has recently ordered four more from Thales Alenia.

Arguably the most surprising investor in Ka-band real estate is Inmarsat, which until now has used mainly the L-band spectrum. Its next-generation Inmarsat-5s will, according to the company, "form the backbone of our new Inmarsat Global Xpress network, offering broadband [download] speeds of 50 Mbps around the world" to mobile user terminals as small as 60 cm, and upload speeds of 5 Mbps.

Planned for launch in 2013-2014, the three Boeing 702 satellites are part of a new $1.2-billion worldwide wireless broadband network designed to make Inmarsat "future proof" in the face of increasing competition. As the company puts it, "Each Inmarsat-5 will carry a payload of 89 Ka-band beams, capable of flexing capacity across the globe and enabling Inmarsat to adapt to shifting subscriber usage patterns over their projected lifetime of 15 years."

Perhaps most significant—although Boeing is also prime contractor for the USAF's Wideband Global Satcom system, which uses Ka- as well as X-band—Global Xpress will mark the first use of Ka-band by a commercial operator of a global satellite system.

Supply issues?

A potentially show-stopping issue brought to light by the news media is an alleged 'supply bottleneck' of key satellite payload components that threatens to delay satellite manufacturing programs and launches in the coming years. The most critical item appears to be the Ka-band traveling wave tubes (TWTs) that form the heart of the satellites' high-power amplifiers.

The problem is one familiar to all markets of high-technology components, especially in the early development phase. R&D is expensive and often fraught with technical problems that can delay deliveries. Initial demand for products is low, because the market is wary of moving to new technology, but can ramp up quickly once early adopters have broken the ice (which is

Radio spectrum: Managing the resource

Every spacecraft needs a radio link with Earth. These communications links are made using specially designated parts of the radio frequency (RF) spectrum, a portion of the electromagnetic spectrum in the range 3 kHz-300 GHz. For convenience, the spectrum has been divided into bands by the ITU (International Telecommunication Union), the Geneva-based body responsible for planning and regulating international telecommunications services:

• VLF	*3-30 kHz*	*• UHF*	*300-3,000 MHz*
• LF	*30-300 kHz*	*• SHF*	*3-30 GHz*
• MF	*300-3,000 kHz*	*• EHF (lower)*	*30-300 GHz*
• HF	*3-30 MHz*	*• EHF (upper)*	*300-3,000 GHz*
• VHF	*30-300 MHz*		

Satellite communications frequencies are mainly in the SHF band, but UHF and EHF are also used.

The ITU allocates and coordinates radio frequencies for communications satellites, imaging satellites, science spacecraft, and any other space-based or terrestrial system that communicates using radio frequencies. It also allocates and coordinates geostationary orbital positions and nongeostationary orbital elements for a variety of spacecraft.

For frequency allocation, the ITU has divided the world into three regions: Region 1 is Europe, Africa, the CIS, and Mongolia; Region 2 is the Americas and Greenland; and Region 3 is Asia, Australasia, and the Pacific.

Satellite operators apply for the frequencies and orbits they intend to use to the ITU, which publishes the details for comment. In the U.S., the FCC performs a similar function. If no conflicts with existing or planned systems are identified, the resources are allocated to the operator (usually for exclusive use, but in some cases on a shared basis).

The process of frequency coordination ensures that satellite and terrestrial communications systems can operate without mutual interference. It entails the submission of details of channel frequencies, satellite orbital position, geographical location of the intended Earth station, a polar diagram of the antenna radiation pattern, and other parameters such as transmitter power and data format. An interference analysis is performed to determine whether the proposed service will interfere with existing communications links

The ITU defines a number of different satellite services, depending on how the satellite will be used. The most important are the FSS (fixed-satellite service), BSS (broadcasting-satellite service) and MSS (mobile-satellite service).

Of growing interest is the issue of resource management and control, the problem being that the ITU has no powers to police the applications or punish spectrum-hoarders, interferers, or other rule-breakers; it is simply a service organization tasked with the administration of frequency allocation and coordination. The process has operated smoothly in the past only because of the mutual understanding among users that breaking the 'rules' will eventually result in chaos for all.

The eventual solution—though there is little sign of it—may be to extend the ITU's remit by international negotiation, to let it police the spectrum for the good of all users. If the world is to maintain the communication links it now takes for granted, a solution must be found—sooner rather than later.

Clean room standards are extremely high for fabrication of devices such as traveling wave tubes, or TWTs, built at this Thales manufacturing facility. Credit: Thales Electron Devices.

now happening with Ka-band satellites).

But the overall market, by its nature, is relatively small and can support only a few key component suppliers (especially considering the high costs of entry), meaning buyers have a limited choice of supplier. For these and other reasons, there are arguably only three Ka-band TWT suppliers in the world considered 'up to the job': Thales Electron Devices of France, Tesat-Spacecom of Germany (formerly AEG-Telefunken), and L3 Communications of the U.S. (formerly Hughes Electron Dynamics).

Despite the news reports, Paul Maisonnier, vice president for microwave and imaging subsystems activities at Thales, says "To date, we have no production issues. We are in line with our contractual commitments." However, he finds it difficult to estimate his company's market share and cannot comment on any production issues at L3. "We have two factories producing space TWTs," he says. "Our competitor has one, so we estimate that global needs are spread similarly over these three factories." Although Maisonnier appears not to recognize Tesat as a significant competitor (despite its being the supplier of Ka-band tubes for the Inmarsat-5 system), he knows that "other companies are developing products, mainly in Asia," a market western suppliers ignore at their peril.

Building reliable space-qualified amplifiers is not like making iPods—when demand increases, you can't just turn up the speed dial on the production line. TWTs and other RF components usually are hand crafted by experienced technicians, while any technical problems are addressed by teams of expert engineers with resumés as long as their arms. Moreover, manufacturers, mindful of the telecommunications downturn of the early 2000s, are wary of expanding production too fast.

Despite this being a quality business, quantity too is an issue. Twenty years ago, a satellite equipped with 20 or 30 travelling wave tube amplifiers (TWTAs) would be fairly standard; today, it is not unusual to find 90 or 100 TWTAs on board. If it were simply a matter of multiplication, tube manufacturers might be able to cope; but quality control is so strict that many of these components have to be rejected before they get anywhere near a satellite. As Maisonnier puts it, "the constraints lead to lower manufacturing yield and longer manufacturing cycles." Some industry commentators suggest that rejection rates are over 50%. This simply adds to the pressure on tube manufacturers.

Given the problems with TWTAs, is there an alternative? Yes…and no. For decades, solid-state power amplifiers (SSPAs) have been replacing tubes as the high-

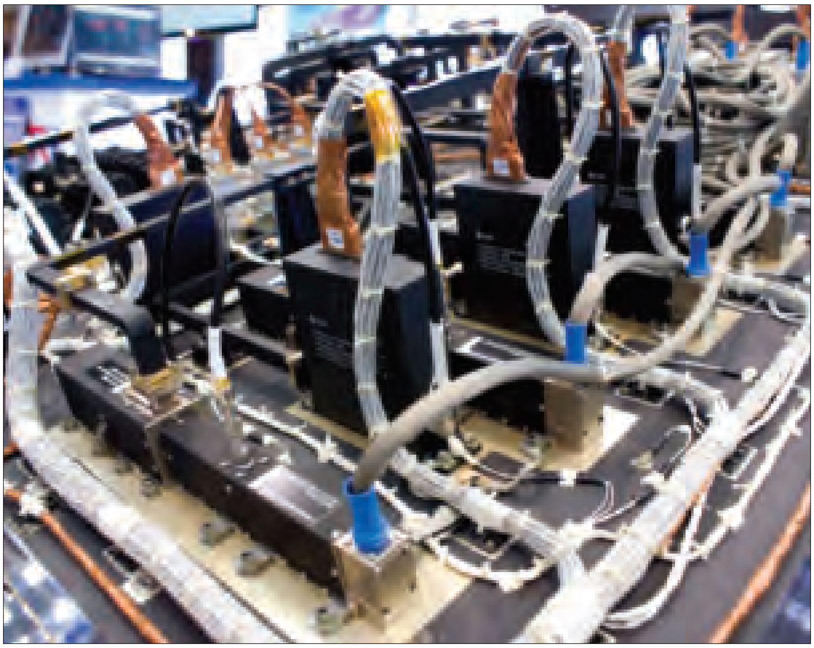
There are two main types of traveling wave tube, one cooled by conduction through a baseplate, the other by direct radiation to space (the bell-shaped cover has been removed to show the radiator fins). Credit: Thales Electron Devices.

power amplifier of choice in the lower frequency bands, but, as with tubes, it is more difficult to build them for higher frequencies. Perhaps more important is the SSPA's limitation on output power, mainly because of the difficulty of removing excess heat.

As satellite systems have evolved, the requirement for higher powers (coupled with narrower spot beams and smaller ground antennas) has driven the development of communications payloads, securing a role for the TWTA. Indeed, the recent move to Ka-band appears to have guaranteed the market for TWTAs for the foreseeable future.

Looking forward

The drive to develop the new real estate of Ka-band is rooted in the challenges of technology development, but is not a new phenomenon; nor is the leisurely pace of adoption. We are simply seeing a repeat of the 1970s' transition from C-band to Ku-band, which meant change for both satellite buyers and satellite users.



A satellite communications payload shows traveling wave tubes and electronic power conditioners. Credit: Mark Williamson.

Pelton is sanguine about the need for users to upgrade their ground segment hardware to handle the higher frequencies: "Today the costs of Ka-band ground systems are still much higher than C-band and Ku-band, but in 10 years Ka-band technology development and mass production volumes will bring the costs down," he says. In a forecast he conducted for NASA, Pelton concluded that, for comparable throughputs, the cost of Ka-band VSATs (very small aperture terminals) will be "about the same as Ku-band VSATs in 2015."

However, Dewell adds a warning that applies to any field of technology experiencing an upgrade: "There is a vast quantity of legacy home-receive equipment at C- and Ku-band that is effectively left behind by going to Ka-band," he says. How much of this equipment ends up in the recycling bins remains to be seen.

Pelton sets the prospects for Ka-band satellite services in the broader landscape of telecommunications: "The future in my view will be shaped as much as anything by the economics of not only fiber optic networking technology, but also the cost-efficiency of broadband terrestrial Wi-Fi and Wi-Max systems," he says. "One of the key things to watch is the O3b satellite system, which is optimized to support Internet protocol-based services and to interface with Wi-Fi and Wi-Max systems."

Pelton envisages a future in which "terrestrial fiber, coax, satellite, high-altitude platforms, and terrestrial wireless have largely seamless air interface standards that allow the consumer to get broadband services anywhere and at any time." This would make the Ka-band satellite just one of many options and, he says, would even "obviate the need for a large migration to Ka-band and certainly forestall a further migration to Q/V-band frequencies."

Despite the uncertainties, Dewell's overall view is positive. "I think there is a great deal of interest in Ka-band for commercial satellite services," he says, "and the pace of implementation will grow now that space-qualified hardware has become available."

However, while recognizing the benefits of smaller receive terminals and "the ability to operate for a while in a reduced-interference environment," he believes the rush toward Ka-band will "plateau once there is a reasonable community of users around the world and potentially very different systems have to coexist." Much of the initial effort will amount to "land-grabbing…claiming an early stake in a new operating region of the spectrum."

Developing the real estate of space, even the virtual resources of frequency space, has never been easy. But those hard-to-predict applications—DTH television, in-car satellite radio, real-time telemedicine, UAV operations, satellite navigation—are testament to the return on investment and effort. If Ka-band opens the door to more of the same, then bring it on! Ā