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WELCOME ABOARD

Your commute in the age of urban air mobility PAGE 26

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MEO
LEO
GEO

The past few years have been rough for builders of geosynchronous communications satellites as they square off in the marketplace against demands for low Earth and medium Earth orbit constellations. Debra Werner spoke to some of the leaders in the satellite industry about the future of GEOs and came away with some surprising revelations.

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MATCH OF THE CENTURY

With World War II grinding to its conclusion, Arthur C. Clarke, then a radar instructor in the British Royal Air Force, turned his mind to outer space. He sent a letter and then a paper to the British trade magazine Wireless World in which he explained the possibility of sending an "artificial satellite" high over the equator at a precise speed and altitude so that "it would remain fixed in the sky of a whole hemisphere and unlike all other heavenly bodies would neither rise nor set."

Clarke called his satellites extra-terrestrial relays, but today we know them as geosynchronous satellites. For some government agencies and those in the satellite communications business, these truck-size GEO satellites are no longer where the future lies. They can cost upward of $1 billion, presenting enormous liabilities in the event of a launch accident or technical issue, and to at least one Air Force general, they are at best "juicy targets." Stock traders live in fear that prices will drop precipitously in the quarter of a second it can take for a "sell" command to bounce 36,000 kilometers into space and back on its way to a stock market half a world away.

For these and other reasons, much of the entrepreneurial action today in the satellite world centers on erecting constellations of small, often mass-produced spacecraft in low or medium Earth orbit for voice communications, broadband internet and Earth imaging.

Given all the hubbub about nongeosynchronous satellites, as they are known in the industry, no one could be blamed for wondering if the sun is about to set on Clarke's great vision. Many experts I spoke with don't think so, and the reasons often come down to dollars and cents and memories of the 1990s, when LEO satellites also seemed destined to rule the skies.

First, the money question. Satellite customers typically push their needs and budgets through "the affordability equation," says Harris Corp.'s Bill Gattle, president of the company's Space and Intelligence Systems segment.

Does the business plan dictate global or regional coverage? If only regional coverage is needed, that could argue for a single GEO satellite. Are advances in materials, power and computing coming so quickly that it makes sense to launch new satellites every five years instead of 15? If so, that would suggest smaller, less-expensive satellites in low Earth orbit. How much latency can be accepted? If, like a stock trader, the answer is not much, then lower latency of nonGEO satellites might be a necessity.

AIAA fellow Daniel Hastings, who leads the aeronautics and astronautics department at MIT, summarizes the tradeoffs like this: "The GEOs will continue to be good for applications which do not require low latency. The obvious example is DirecTV. It would be hard to deliver the quality signals from a moving set of LEOS which are only overhead for 10-20 minutes," he said in an email. "On the other hand, the low latency with cross links that the LEOS give enable voice and internet communications in a way that the GEOS have a hard time doing."

The budget aspects of the affordability equation can be trickier to assess. Customers must anticipate the cost of building, launching and operating a constellation of small satellites, including ground equipment, and compare that cost to the price of building and launching just one or a few GEO satellites.

"The costs required for a LEO system are a big unknown right now, and the devil is in the details," says engineering consultant and AIAA fellow Chris Hoeber, a former senior vice president at SSL, a longtime manufacturer of truck-size GEO satellites that now also produces minifridge-size satellites for

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EXTRA-TERRESTRIAL RELAYS

Can Rocket Stations Give World-wide Radio Coverage?

By ARTHUR C. CLARKE

ALTHOUGH it is possible, by a suitable choice of frequencies and routes, to provide telephony circuits between any two points or regions of the earth for a large part of the time, long-distance communication is greatly hampered by the peculiarities of the ionosphere, and there are even occasions when it may be impossible. A true broadcast service, giving constant field strength at all times over the whole globe would be invaluable, not to say indispensable, in a world society.

Unsatisfactory though the telephony and telegraph position is, that of television is far worse, since ionospheric transmission cannot be employed at all. The service area of a television station, even on a very good site, is only about a hundred miles across. To cover a small country such as Great Britain would require a network of transmitters, connected by coaxial lines, waveguides or VHF relay links. A recent theoretical study[1] has shown that such a system would require repeaters at intervals of fifty miles or less. A system of this kind could provide television coverage, at a very considerable cost, over the whole of a small country. It would be out of the question to provide a large continent with such a service, and only the main centres of population could be included in the network.

The problem is equally serious when an attempt is made to link television services in different parts of the globe. A relay chain several thousand miles long would cost millions, and transoceanic services would still be impossible. Similar considerations apply to the provision of wide-band frequency modulation and other services, such as high-speed facsimile which are by their nature restricted to the ultra-high-frequencies.

Many may consider the solution proposed in this discussion too far-fetched to be taken very seriously. Such an attitude is unreasonable, as everything envisaged here is a logical extension of developments in the last ten years—in particular the perfection of the long-range rocket of which V2 was the prototype. While this article was being written, it was announced that the Germans were considering a similar project, which they believed possible within fifty to a hundred years.

Before proceeding further, it is necessary to discuss briefly certain fundamental laws of rocket propulsion and "astronautics." A rocket which achieved a sufficiently great speed in flight outside the earh's atmosphere would never return. This "orbital" velocity is 8 km per sec. (5 miles per sec), and a rocket which attained it would become an artificial satellite, circling the world for ever with no expenditure of power—a second moon, in fact.

The German transatlantic rocket A10 would have reached more than half this velocity.

It will be possible in a few more years to build radio controlled rockets which can be steered into such orbits beyond the limits of the atmosphere and left to broadcast scientific information back to the earth. A little later, manned rockets will be able to make similar flights with sufficient excess power to break the orbit and return to earth.

There are an infinite number of possible stable orbits, circular and elliptical, in which a rocket would remain if the initial conditions were correct. The velocity of 8 km/sec. applies only to the closest possible orbit, one just outside the atmosphere, and the period of revolution would be about 90 minutes. As the radius of the orbit increases the velocity decreases, since gravity is diminishing and less centrifugal force is needed to balance it. Fig. 1 shows this graphically. The moon, of course, is a particular case and would lie on the curves of Fig. 1 if they were produced. The proposed German space-stations would have a period of about four and a half hours.

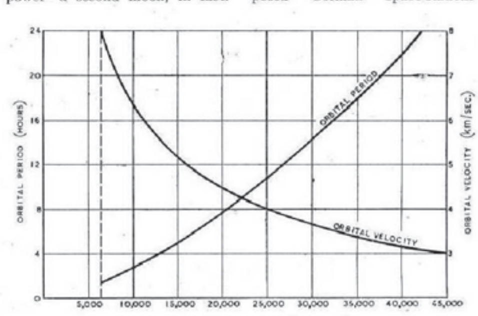
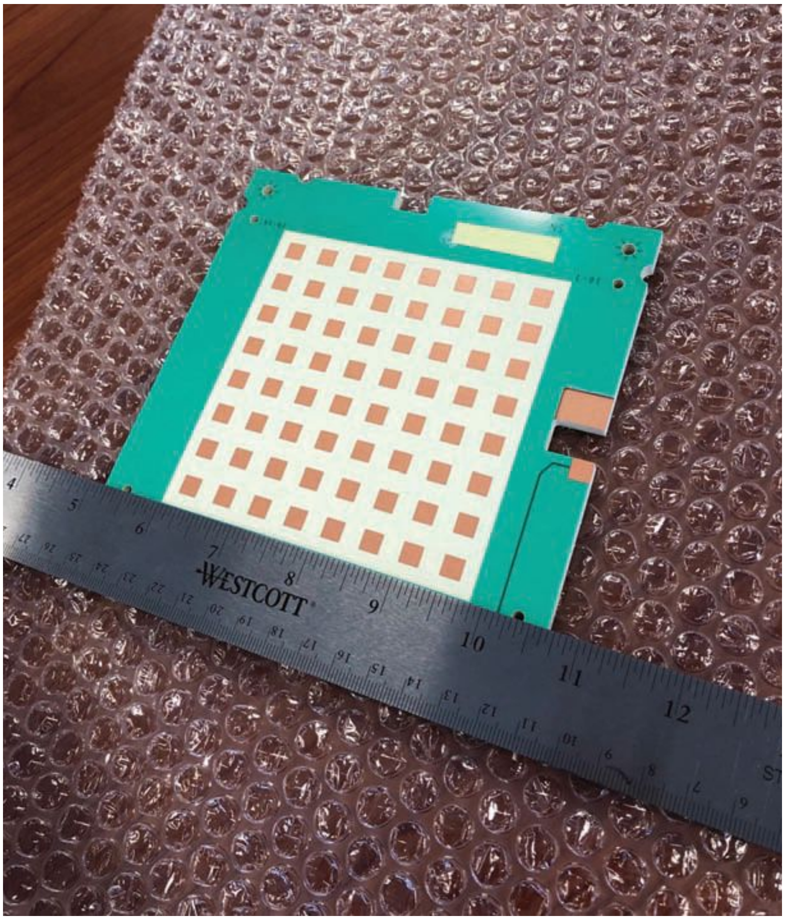


Fig. 1. Variation of orbital period and velocity with distance from the centre of the earth.

It will be observed that one orbit, with a radius of 42,000 km, has a period of exactly 24 hours. A body in such an orbit, if its plane coincided with that of the



▲ OneWeb founder Greg Wyler tweeted that this antenna prototype can transmit data at 20 megabits per second. Analysts say that antennas tracking low Earth satellites need to become cheaper before consumers will buy them.
@greg_wyler/Twitter

low Earth orbit. By contrast, the costs of GEO satellites for commercial communications are well understood, because a commodity market has developed over several decades, he explains.

Consider OneWeb, a startup based in Arlington, Virginia, that's starting to launch satellites to LEO for global internet access. The company used to say that its entire planned constellation of 648 satellites would cost $2.5 billion to $3.5 billion. Now, the company does not provide a figure, although industry observers suspect the cost could be twice that.

"The costs required for a LEO system are a big unknown right now, and the devil is in the details."

— **Chris Hoeber**, an engineering consultant

Hype vs. reality

It's impossible to ignore the buzz around the megaconstellations announced by OneWeb, SpaceX and about a dozen others. Even the term for these constellations comes with a bit of hype: Sticklers for metric prefixes like to note that mega means million and that no one anticipates launching that many satellites. They prefer to say "proliferated" constellations. Regardless, the new constellations have attracted lots of media attention, including here in Aerospace America, but more importantly, billion-dollar investments. Although just beginning to launch, they've already hurt GEO satellite sales by disrupting the market. Orders for GEO satellites have fallen precipitously in recent years, as the world's top satellite customers watched the new constellations begin to take shape and wondered what impact the upstarts would have on the market for satellite services.

"During this period of transition, everyone has a wait-and-see attitude," says Lluc Palerm-Serra, a senior analyst at Northern Sky Research, a consulting firm based in Cambridge, Massachusetts.

Analysts suspect it will be years before we know which of the budding satellite internet constellations will survive, since companies have barely begun to launch their spacecraft. SpaceX of California and Telesat of Ottawa launched the first prototypes for competing proliferated satellite internet constellations in 2018. OneWeb sent its first six operational satellites into orbit in February.

The GEO-focused service providers are taking the megaconstellations seriously. One of the GEO providers is Hughes Communications, which links 1.3 million residential and business customers in North America with internet access through 24 GEO satellites operated by its parent company, EchoStar Corp. Hughes chose to be an early investor in OneWeb and is building gateways, modems and power amplifiers for the constellation. Hughes sees OneWeb as complementary to its GEO business for this reason: GEO satellites tend to focus on regions, like North America, Europe or Africa. They're good at moving a lot of data, such as beaming video, to customers in their region, says Paul Gaske, executive vice president and general manager of Hughes Network Systems North America Division. "The beauty of LEO is coverage of the entire planet" and low latency, which means quicker responses for games and web pages, he says.

Stock traders or business customers who can't wait for signals to travel 36,000 kilometers to satellites in GEO and back, could access the internet through OneWeb's satellites, which at 150 kilograms are 30 to 40 times lighter than GEO communications satellites.

A harbinger of demand for nonGEO constellations is O3b Networks, the medium Earth orbit constellation purchased in 2016 by SES of Luxembourg, one of the world's largest satellite fleet operators. Like the new constellations, O3b satellites in 8,000-kilometer orbits offer lower latency than GEO satellites. As a result, web pages load and transactions conclude more quickly. Each O3b satellite has 12 steerable Ka-band spot beams supplying broadband to remote towns, companies, schools and ships. For Royal Caribbean Cruise Lines, for instance, O3b spot beams follow ships, supplying passengers and crew with continuous Wi-Fi.

OneWeb and O3b captured global attention with promises of extending internet access to underserved communities around the world. But faced with the enormous cost of building nonGEO constellations,

each has redirected their initial focus to first bringing in revenue from wealthier customers.

The ultimate goal of the LEO constellations is to ensure people rich and poor can remain connected to high-speed networks in remote regions and aboard trains, ships and airplanes. For that to happen, the new networks will need more bandwidth and new user terminals.

▼ Geosynchronous satellites like the GOES weather series are still necessary because they collect simultaneous readings that low Earth orbit satellites cannot.

Lockheed Martin

Communications satellite developers are looking beyond Ka-band to Q- and V-bands, a treasure trove of available bandwidth. They also are working with antenna developers because LEO constellations will never serve mass markets until the terminals to access them become more affordable.

Today, terminals sophisticated enough to track one satellite darting across the sky for a few minutes and then acquire the next satellite in the series are installed on some aircraft, yachts and emergency response vehicles, but they cost anywhere from a couple of thousand to a couple of hundred thousand dollars. Government agencies and corporations can afford them, but terminal prices, including the tracking antennas, need to fall to the $200 to $300 range before consumers embrace them, says Tom Butash, an AIAA fellow who leads Innovative Aerospace Information Systems, a consulting firm in Virginia.

Greg Wyler, who founded O3b before starting OneWeb, announced in January that his company has prototyped an inexpensive electronically steered antenna it hopes to begin selling in 2020. Antenna experts are dubious. These billion-dollar constellations are betting on technology that remains to be fully demonstrated, Butash says.

Rough patch for GEOS

Communicating with GEO satellites is much easier. Antennas selling for less than $100 can bring TV and internet access into homes and schools. From their positions over the equator, they can't cover the poles but can reach latitudes between 70 degrees north and 70 degrees south. Manufacturers are quick to point out that's where the vast majority of human activity and communications traffic occurs.

Demand for GEO service remains strong because consumers want perpetual access to high-speed broadband, says Dave Ryan, president of GEO satellite operator Viasat Space and Commercial Networks of Carlsbad, California, which delivers internet access and secure networks for commercial and government customers.

To keep up, Viasat plans to add three Viasat-3 satellites to its constellation. Each will deliver about a terabit per second of network capacity for high-speed, high-quality internet surfing and video streaming by customers throughout the Americas, Europe, the Middle East, Africa and Asia. Slated to launch between 2021 and 2022 and designed to last at least 15 years, the 6,400-kilogram satellites demonstrate the company's conviction in the long-term future of its GEO satellite business, Ryan says.

Despite rising demand for bandwidth, sales of GEO satellites have slowed. From 2005 to 2010, companies around the world annually bought a total of 20 to 25 large geosynchronous satellites. In recent years, they've announced roughly half that

> **"I can move a [GEO] satellite that's been sitting over one region to another region for a short period of time, for something like the Olympics or the World Cup, and then move it to a different market. This is the place where GEO has a dramatic advantage over LEO."**
>
> — **Erik Daehler,** Lockheed Martin Space Systems

number, as high-throughput satellites produced a surge in available bandwidth, lowering the price of leased capacity. That trend made some customers hesitant to commit hundreds of millions of dollars for new satellites.

Even with weak sales, satellite manufacturers are spending heavily on high-power solar arrays, solid state power amplifiers and digital signal processors. In the past, satellite service providers spent hundreds of millions of dollars to customize satellites to serve specific markets over their lifespans of 15 years or more. While that still occurs in some markets, flexibility is becoming increasingly important.

▼ A U.S. soldier works on a portable satellite terminal during an exercise. The military and intelligence agencies are expected to continue to need geosynchronous satellites.

Lockheed Martin, Boeing and SSL are designing satellites that can change the shape of communications beams to adapt to new markets and hop frequencies if they encounter interference or jamming.

"I can move a satellite that's been sitting over one region to another region for a short period of time, for something like the Olympics or the World Cup, and then move it to a different market," says Erik Daehler, who leads business development for commercial communications and remote sensing for Lockheed Martin Space Systems. "This is the place where GEO has a dramatic advantage over LEO. You can't really move a satellite in LEO from

U.S. Army

NOAA

▲ Weather satellite controllers at NOAA's Satellite Operations Control Center.

one market to another because the orbital dynamics don't let you do that. In GEO, you can very easily walk around the globe and change the position of your satellite over the life of the vehicle."

In the next decade, GEO satellites could complement service provided by the LEO constellations. "LEO constellations spread the capacity evenly around the world. But maybe you would like to have an extra layer of capacity in Africa, Latin America or North Atlantic airplane routes," says Palerm-Serra, the Northern Sky Research analyst. If so, GEO satellites could point spot beams toward the region to offer additional coverage.

In spite of turbulence in commercial satellite markets, government customers in the U.S. are likely to keep buying GEO satellites. "The Air Force and intelligence agencies are not abandoning that orbit," says Brett Loubert, a former Lockheed Martin program manager who leads information technology strategy for Deloitte.

NOAA also will need GEO sentinels for the foreseeable future. Numerical weather models benefit from simultaneous global observation of winds and other atmospheric conditions. "That's something you're never going to get from LEO unless you have 1,000 satellites," says Stephen Volz, who leads NOAA's Satellite and Information Services branch. "People say they can fly that many. But the cross-calibration of 1,000 satellites is a lot harder than it is with five. GEO is going to be around for a while."

Déjà vu?

For some people, the new LEO constellations trigger memories of the LEO constellations of the 1990s. Globalstar, Iridium and Teledesic promised to bring communications to the masses equipped with satellite phones. What they didn't anticipate was the rapid spread of terrestrial cellular networks offering customers inexpensive alternatives to satellite links. All three constellations declared bankruptcy, although Iridium and Globalstar emerged from bankruptcy to build successful businesses.

Will terrestrial networks once again overtake satellites? Network providers are spending tens of billions of dollars on 5G, the fifth-generation standard for cellular mobile communications. Satellites are part of 5G, which promises higher-speed communications and additional capacity. Networks will send traffic over satellites to reach places fiber and sea-floor cables do not. In fact, some call 5G a network of networks.

Experts agree 5G networks will boost satellite communications traffic. They disagree about whether fiber and sea-floor cables will ultimately spread to the point where satellites play a minor role in communications networks.

Mobile terrestrial network operators rely on optical fiber or satellites for backhaul and trunking, connecting remote sites to the core communications network. If 5G boosts network traffic, that means more work for satellites.

"We believe GEO satellites will be part of the solution as will constellations in low Earth orbit and medium Earth orbit and even high-altitude platforms," says Paul Estey, chief operating officer for satellite manufacturer SSL, a Maxar Technologies company.

Linking all the satellites, airships and unpiloted aerial vehicles into a series of seamless nodes won't be easy, but it's necessary for 5G. "When you go to the mountains away from all the cellphone towers, your 5G service will go seamlessly from cell towers to some sort of airborne or spaceborne delivery system," Estey says.

As fiber and undersea cables continue spreading in a global communications web, some think they eventually will diminish the role for satellites of any kind.

"The explosive, exponential growth of fixed and mobile fifth-generation solutions over the next few years will decimate the satellite broadband markets, which have been pretty healthy in developed countries like [those in] North America, Europe and developed parts of Asia," says consultant Butash. That would mean trouble for both GEO satellite manufacturers and the new nonGEO orbit constellations.

Even if that scenario plays out, satellites in GEO and nonGEO orbits will continue to serve customers on the move and in remote communities.

"It will be nearly impossible for the landlines to reach everybody," Gattle says. "It's such a huge infrastructure cost." ★