Iridium Satellite System Poses Threat to Radio Astronomy

As telecommunications technology burgeons, radio astronomers are fighting to prevent electromagnetic pollution from obscuring their observations of the cosmos. Motorola's global satellite system, Iridium, is a timely example of such a turf battle: The commercial satellites' space-to-Earth signals are expected to cause out-of-band emissions in a nearby radio astronomy frequency band that exceed the internationally agreed upon protection level. With the launching of the first few of Iridium's 66 satellites imminent, radio astronomers and Iridium representatives are still trying to arrange ways to share the spectrum.

The frequency band in question is 1610.6–1613.8 MHz, which includes the 1612 MHz spectral line of the astrophysically abundant hydroxyl (OH) radical. When the population states of OH are altered by infrared photons, this transition becomes a maser and background radio energy is amplified by stimulated emission. The OH maser is used by radio astronomers to study comets, star-forming clouds and red giant stars that eject their outer layers; the absolute distance to such a red giant can be determined from interferometric measurements of the diameter of the expanding ejected layer in combination with measurements of the time delay between signals from this layer's near and far sides. "The OH maser is one of the few ways astronomers have for measuring absolute galactic distances," says Brian Robinson, a consultant in space research, radio astronomy and remote sensing in Sydney, Australia, and former chair of the Inter-Union Commission on Frequency Allocations for Radio Astronomy and Space Science (IUCAF), an international body that represents the interests of scientific uses of the electromagnetic spectrum.

"At every turn, we encounter arguments that the few radio-quiet bands remaining in the radio spectrum must be sacrificed for economic gain," says Robinson. "It would be terrible to close this hydroxyl window."

Iridium and spectrum use

The Iridium satellite system will provide worldwide mobile telecommunications services—voice, fax, data transfer and paging (see figures on page 72). A

> Because of growing demands on the frequency spectrum by commercial telecommunications activities, radio astronomers are becoming increasingly vigilant and working together to prevent losing their radio window.

total of 66 satellites will orbit Earth at a height of 780 km, with 11 in each of six orbital planes, digitally serving even the most remote spots on Earth. (Iridium is named for chemical element number 77 because it was originally designed to have 77 satellites; the system was subsequently changed to its present configuration.) Iridium is designed to transmit both Earth-to-space (uplink) and space-to-Earth (downlink) in the frequency range 1616–1626.5 MHz; intersatellite links and links between satellites and ground-based control stations will be in the range of 19–30 GHz. Iridium is scheduled to begin commercial operations in 1998. The cost for construction, launching and one year of operation is expected to come to approximately $4 billion; users will initially pay about $3 per minute.

At a conference in Torremolinos, Spain, in 1992, the International Telecommunication Union (ITU), an independent agency of the United Nations, allocated the frequency band 1610–1626.5 MHz to Mobile Satellite Services (MSS), the service to which Iridium belongs. The uplink was given a primary allocation, and the downlink a secondary one (from 1613.8 MHz). (A secondary allocation permits use of a given frequency band with the proviso that no harmful interference be caused to, and no protection requested of, primary users.) Allocations are to services, rather than to specific systems, which must then obtain licenses to operate from the national bodies that oversee spectrum use, such as the Federal Communications Commission (FCC) in the US.

At the same conference, the status of the radio astronomy allocation for the 1610.6–1613.8 MHz band was upgraded from secondary to primary, to provide protection for radio astronomy. "Radio astronomers have long pushed hard for this allocation, particularly in light of the GLONASS debacle," says Tomas Gergely, who oversees electromagnetic spectrum use for the National Science Foundation. GLONASS, the Russian Global Navigation Satellite System, was launched in 1982, and has interfered strongly with radio astronomy observations in this OH band. James Cohen, of Nuffield Radio Astronomy Laboratories at Jodrell Bank, England, and others recount that, after much lobbying by IUCAF on behalf of radio astronomers worldwide, the Russians agreed in 1993 to shift to lower frequencies. The conversion will be completed in 2005. "It seems that just as GLONASS is clearing the skies, Iridium is stepping in," says Cohen.

Space-to-Earth transmissions present a more serious problem for radio astronomy than do uplinks. Although both can cause unwanted interference, uplink interference is easier to prevent—by assigning mobile telephones to frequencies outside of the shared part of the frequency band in exclusion zones around observatories, for example. Remote locations and mountains also help shield observatories.

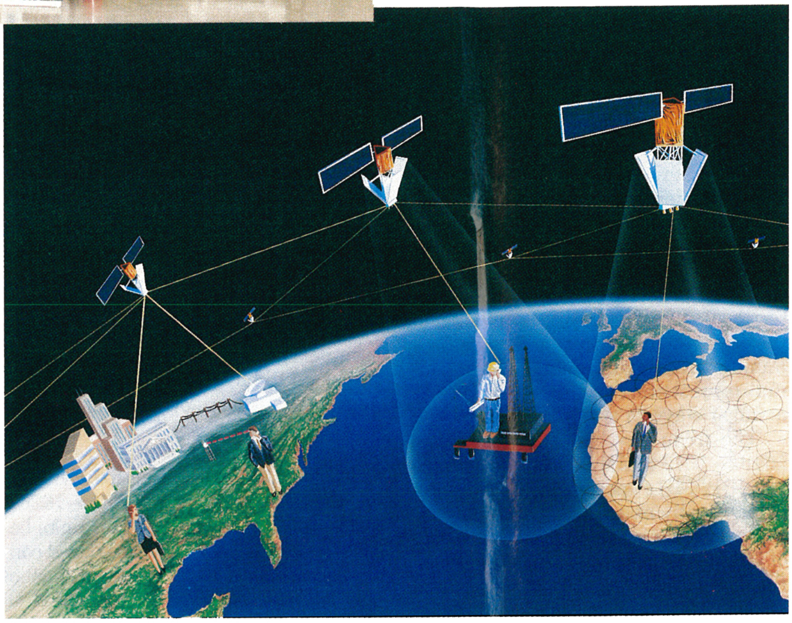
Several companies plan to launch global telecommunications satellite systems, but Iridium is the only one designed to use the 1616–1626.5 MHz frequency band for downlinks. James Ennis, a lawyer for Iridium LLC, the Motorola spin-off that owns the largest share of the satellite system, says that the other option, near 2500 MHz, which other systems, such as GlobalStar, plan to use for downlinks, "has too much interference from microwave ovens and other unlicensed sources." And, he adds, "if the up- and downlink frequencies are too far apart, two antennas would be needed, which would make the hand-held telephones bulkier and more expensive."

What and who decides?

The issue of unwanted, out-of-band emissions has evolved into a standoff between radio astronomers and Iridium LLC. They disagree about both the threshold of harmful interference and whether Iridium is in fact required to protect radio astronomy observations from its out-of-band emissions.

"We were reassured in 1991, when Motorola promised IUCAF, in writing, that Iridium would protect radio astronomy observations in the 1612 MHz hydroxyl band," says Cohen. That was

SATELLITES FOR THE IRIDIUM SYSTEM, at left, in various stages of assembly at Motorola's production factory in Chandler, Arizona. (Courtesy of Motorola's Satellite Communications Group.) Below, a depiction of Iridium's satellite-based global mobile telephone system. (Courtesy of Iridium LLC.)



before the 1992 ITU conference, where, Cohen continues, satellite companies, particularly Motorola, "exerted pressure to be given a downlink in the 1613.8–1626.5 MHz range." On the basis of the 1991 agreement, explains Robinson, "IUCAF did not oppose the US delegation's application for a secondary MSS downlink allocation." Furthermore, says Robinson, "the ITU spectrum allocation includes clauses specifically forbidding MSS from causing harmful interference to users of the adjacent hydroxyl band." Willem Baan, a radio astronomer at Arecibo Observatory in Puerto Rico, and chair of IUCAF, adds, "In retrospect, our acceptance of the MSS allocation was unwise, and it's haunting us now."

Iridium LLC representatives acknowledge that out-of-band emissions from the satellites' downlinks into the 1612 MHz hydroxyl band will exceed the threshold protection spectral power flux density of (expressed in decibels) -238 dBW/m^2 Hz recommended by the ITU. But Bary Bertiger, head of the satellite communications group and a vice president at Motorola, maintains that "we are protecting radio astronomy, and we are not breaking our promise to do that. But we never agreed to remain below '–238.'" This point is contested by Robinson and others, who say Motorola's 1991 agreement specified it would protect radio astronomy and respect the ITU harmful interference level; "IUCAF would not have signed a less specific agreement," says Robinson. According to Bertiger and Ennis, out-of-band emissions from Iridium in the hydroxyl band will be about 20 dB above the ITU recommended threshold. (The amount of unwanted emissions will depend on the amount of satellite traffic; this estimate is for peak traffic.) "Radio astronomers won't be able to hear us," claims Bertiger.

Ennis and Bertiger call the ITU threshold recommendation, which carries no legal weight, "arbitrary," and Bertiger says that, as a spectrum user, Motorola has "as much right [as the radio astronomers] to help determine what the protection level should be." But radio astronomers counter that the ITU threshold value is based on physical principles. Michael Davis, a radio astronomer at Arecibo Observatory, explains that it is calculated from the sensitivity of an antenna at its side lobes, accounting for background noise and the intrinsic noise of the antenna and receiver. "Things would be clearer if the FCC defined 'harmful interference' quantitatively, by a measurable value," says Davis.

As for the issue of out-of-band protection, Gergely points out that, in its interpretations of the ITU recommendation on this matter, the FCC states explicitly that protection applies for both in-band and out-of-band emissions. Ennis, however, says this last point is "legally unclear," and maintains that "Iridium has no obligation to protect radio astronomers using 1610–1613.8 MHz, since it's a different band."

Despite the sometimes contentious and conflicting statements, "by and large the discussions have been friendly," says Bertiger. "We do not want to cause harm to radio astronomy." He attributes radio astronomers' distrust of Iridium LLC "to what happened with GLONASS. They are worried that once we are in operation, we will blow them off."

Sharing the spectrum

Both sides are trying to resolve their frequency interference problems, as required by ITU procedures. Iridium must have a license from each country it serves; in the US, FCC approval is conditional on Iridium LLC coordinating with other spectrum users. And, while radio astronomers remain defensive about sharing their protected band, as Davis observes, "We have to negotiate—Iridium is an exciting new application at the cutting edge of technology." Baan expresses a view echoed by many radio astronomers: "We consider Iridium to be a test case, because things like this will continue to happen."

Because of the nature of the signals radio astronomers observe, compromise is difficult: Cosmic signals can be neither scheduled nor turned up in power nor tuned to different frequencies. "It is more of a strain for other spectrum users to protect radio astronomy than for them to protect one another," says Richard Thompson, of the National Radio Astronomy Observatory (NRAO) in Charlottesville, Virginia. "We have little recourse other than the moral argument," notes Cohen.

The avenues of compromise under discussion mainly involve time-sharing arrangements; other tacks, such as changing the satellite design or limiting Iridium telephone usage, would be too costly, says Ennis. For example, fitting the amplifiers on the satellites with better filters to reduce the intermodulation effects responsible for the unwanted, out-of-band emissions, would make the satellites heavier, and therefore costlier to launch.

In June 1994, NRAO signed a memorandum of understanding with Motorola. In it, Motorola guarantees radio-quiet periods, during which out-of-band emissions from Iridium's downlink signals in the 1610.6–1613.8 MHz band will be limited: For Green Bank Observatory in West Virginia, for example, unwanted signal may not exceed -238 dBW/m^2 Hz for four continuous hours late each night; for the Very Large Array in Socorro, New Mexico, and the ten scattered Very Long Baseline Array sites, the agreement specifies higher thresholds that apply 24 hours a day. (These two telescope arrays use interferometry, and can therefore distinguish better than single-dish telescopes between wanted and unwanted signals.) "We have lost some flexibility," acknowledges Thompson. "But we use the hydroxyl band less than 4 hours a day, so we did not have a strong case for objecting to this arrangement." He adds that the agreement "guarantees some unpolluted time, which may become an important precedent as commercial uses of the spectrum continue to grow."

Negotiations between Motorola and Arecibo Observatory—the other major US site for radio astronomy—have yet to be resolved. The Arecibo telescope is a 300 m single-dish telescope—the largest, and therefore the most sensitive, in the world. The Arecibo group sent a proposal to Motorola in August that, like the NRAO/Motorola memorandum, involves time sharing. "But it should be at least a fifty-fifty split," says Baan, who would not reveal more details since the negotiations were still in progress at press time. He is "optimistic that the proposal will lead to an agreement with Motorola."

Outside the US, where Motorola has also been negotiating with radio astronomers for several years, the satellite company is meeting more vocal opposition. In the UK, for example, "Motorola proposes to operate the downlink as if our radio telescopes did not exist," says Cohen. "We could not sign a memorandum of understanding on that basis." Cohen adds that member countries of the European Science Foundation's Committee on Radioastronomy Frequencies, which he chairs, voted unanimously last year not to sign any memorandum of understanding.

Radio astronomers in Australia, too, declined this year to sign an agreement similar to the one Motorola made with NRAO. "Motorola has gone to the trouble of talking to radio astronomers, and I think that they have genuinely attempted to provide protection," says John Whiteoak, deputy director of the Australia Telescope National Facility in Narrabri, New South Wales. "But I was disappointed that they seem to view the NRAO agreement as an indication that radio astronomers are willing to accept harmful interference."

US radio astronomers feel pressure to compromise, in part because, as Thompson observes, "Iridium is the kind of project that is good for the government, good for foreign trade." Some suggest that such economic pressures may soon find their way to Europe and elsewhere: Iridium LLC is an international company, with about 70% of its stock held by non-US interests. (Motorola owns about 25%, according to Bertiger.) Govind Swarup, a radio astronomer who recently retired from the Tata Institute of Fundamental Research in Bombay, India (see the article below), notes that the Indian telecommunications agency is a partner in Iridium LLC, "so we will soon discuss this issue with our government." Emphatically, Swarup adds that "radio astronomers must work together to protect access to the electromagnetic spectrum."

Toni Feder

India Gets New Radio Telescope

When it becomes fully operable by the end of this year, India's Giant Metrewave Radio Telescope (GMRT) will be the most sensitive telescope in the world in the 38–1430 MHz frequency range.

Located about 80 km north of Pune, at about 19° north latitude, GMRT will be used to observe all of the northern sky and a major part of the southern sky. It consists of 30 fully steerable 45 m antennas: 12 are positioned in a central area that covers about 1 km^2, and the rest form a Y-shaped array around this area that could be circumscribed by a circle approximately 25 km in diameter. GMRT's interferometry design and data collection electronics are modeled partly on those of the Very Large Array (VLA) in Socorro, New Mexico.

GMRT was built for about \$17 million awarded to the Tata Institute of Fundamental Research in Bombay by the Indian government. By contrast, the VLA, which was completed in 1981, cost \$78.6 million (in 1972 dollars).

Govind Swarup, the project's creator and its director until he retired from the Tata Institute last April, recounts some of the strategies he and his team used to meet the challenge of completing the telescope—including roads and buildings—on this relatively small budget. The antennas in the GMRT array are made of thin stainless

PREM KUMAR

TWO OF THE THIRTY 45 M ANTENNAS that make up the Giant Metrewave Radio Telescope near Pune, India. The angular resolution at 21 cm (1420 MHz), the shortest wavelength at which the array operates, is about 2 arcseconds, equivalent to a single 25 km diameter dish.