POINT OF VIEW

Radio as a Science Tool

By SAMI ASMAR

Radio technology was one of the defining developments of the 20th century. When Marconi wirelessly received the simple Morse code for the letter "s" across the Atlantic Ocean in 1901, an alternative was born to the use of paper or even the use of a connecting wire to send messages. Over the next three decades, narrowband transmitters replaced spark gaps and enabled President McKinley's inaugural audio to be broadcast to home receivers throughout the country. Video was added within 20 years and home television reception brought news and entertainment to family living rooms. The subsequent trend towards more powerful transmitters and larger antennas allowed coverage to be nearly universal and the invention of the transistor opened the door to a new branch of technology where functionality could be improved with less power consumption. In time, digital techniques gained favor over analog, and small portable radios became common, eventually supplanted by smart mobile phones and computers networked by wireless repeaters; the industry is anticipating data transfers at rates in excess of 300 Tb/s, an enormous leap over Marconi's few dots.

About 30 years after the first wireless demonstration, relatively large antennas looked towards the heavens and, in the early 1940s, Grote Reber discovered that the sky produced its own radiation. Consequently, *radio astronomy* opened a new window to exploring an invisible part of the universe. In addition to the natural radiation, radio signals were transmitted towards the sky and the first radio echoes from the Moon were received in the mid 1940s and from Venus and Mars by the early 1960s. This *planetary radar* technique revealed variations in the surface scattering properties of those worlds.

By then, spacecraft were launched on solar system exploration missions. Large terrestrial steerable antennas, some with a diameter of 70 m, were developed purposely to control the spacecraft as well as receive the valuable scientific data collected during close encounters with their targets. Unlike communications with satellites on Earth or lunar proximities, deep space communication faces the challenge of vast distances sometimes exceeding 100 Astronomical Units (~15 billion km) which, given typical spacecraft transmitter power of under 20 W, makes the signals reaching Earth drop by numerous orders of magnitude, yet still captured and interpreted. This success, one of the most notable technological accomplishments in space exploration, is primarily due to an investment by the National Aeronautics and Space Administration (NASA) in an infrastructure designed to maximize performance and reliability, centered on a national asset called the Deep Space Network (DSN). Europe, Japan, and other nations also developed their large tracking stations as their solar system exploration programs expanded.

With the DSN, the field of *radio science* was born when the communication link signals transmitted by the spacecraft and propagated towards Earth were themselves utilized to probe the planets and their environments. Achieving high precision in "radiometric" observations, such as the Doppler shift and range to the spacecraft, requires great care in

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modeling all perturbations of the radio signals as well as calibrating all known sources of error. To scientists, however, some perturbations contain important scientific information. This user community examines changes in the characteristics of the electromagnetic waves such as the phase/frequency, amplitude, line-width, polarization, as well as round-trip light time to study planetary atmospheres, ionospheres, rings, and surfaces; they also measure planetary masses and gravitational fields, monitor the solar corona, and test theories of relativity.

Fifty years into the space program, these scientific fields built on radio technologies are in transition. They often share resources with radio communication and radio navigation facilities that are increasingly costly to build and maintain. But the fields are also advancing with the utilization of new technologies. The Radio Science community started applying uplink occultations with more sophisticated processors on-board the spacecraft that can also enable spacecraft-to-spacecraft occultations to improve on the received signal-to-noise ratio and achieve global coverage faster. They also moved to higher frequencies (34 GHz) to further lower the propagation noise on gravity measurements and are preparing for the era of possible optical communications with plans for optical science. Recent advances in planetary radar have improved the quality of the imaging and reduced the uncertainty in ranging to 4 m. And radar system enhancements to reduce ranging resolution to 1 m are being considered.

Numerous discoveries were made via these techniques revealing their tremendous value to the science community. Creativity will lead optimization of limited resources and will advance many technologies enabling future scientific breakthroughs. A future special issue of the Proceedings of the IEEE in early 2011 will feature the challenges and opportunities in a series of detailed papers by experts from around the world.

The objective of this upcoming Special Issue is to report on recent research and development efforts in the areas of radio science and radar astronomy/planetology, with a focus on solar system investigations. For planetary distances, both radio science and radar observations have been shown to be very effective in characterization of the media of interest. Radar observations provide simple and cost-effective ways to obtain survey information about planetary surfaces and subsurfaces on scales of interest to landers and rovers, and for understanding planet's past evolutions. Similarly, radio observations of planetary atmospheres and ionospheres provide effective means of investigating the gaseous part of planets, including Saturn's moon Titan, and the sun.

Space science has captivated the imagination of the human race for millennia. With the advent of modern scientific discoveries and technological advances, a wealth of space-related knowledge has unveiled itself, stimulating human curiosity regarding the solar system. Important questions are being asked: What lies in the future for our planet? Is there life in the solar system beyond Earth? Which planets and moons contain water? These questions are addressed via *in situ* exploration as well as remote sensing techniques. Radar astronomy/planetology and radio science are two effective means of searching for answers to these questions. These techniques have been very successful in providing a wealth of information from regions of the solar system that are hard to get to, and continue to move science forward.

Marconi would be proud indeed of where progress in wireless communications has taken us. ■