Before the
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LIBRARY OF CONGRESS
Washington, D.C.

In the Matter of	)	
	)	
	)	**Docket No. 2006-1 CRB DSTRA**
Adjustment of Rates and Terms for Preexisting Subscription and Satellite Digital Audio Radio Services	)	

WRITTEN DIRECT TESTIMONY OF TERRENCE SMITH

(On behalf of Sirius)

Background and Experience

1. I am Senior Vice President, Engineering of Sirius Satellite Radio Inc. ("Sirius"). I joined Sirius in February 2002, just as we were commencing broadcast operations. I submit this statement in support of Sirius' direct case in this matter to describe the extraordinary innovation and continuing technological effort needed to make the Sirius service a reality.

2. I have been involved in digital technology for approximately 27 years. Prior to joining Sirius, I was employed at RCA Labs and at Sarnoff Labs, where I was involved in pioneering work with High Definition Television and the development of digital satellite television service launched by DIRECTV. I hold a Bachelor of Science in Electrical Engineering degree from the University of Notre Dame and a Master of Science in Electrical Engineering degree from Drexel University. I am a named inventor or co-inventor on 18 United States Patents.

3. At Sirius, I direct all of our engineering activities and technology developments. These include our system design and development; our broadcast studios; our satellite uplink; our satellite design, development and operations; our ground repeater design, development and operations; our digital compression technologies, our chipset and antenna design and development; our product design and development; and testing and quality control. I am also personally involved in securing the necessary licenses for our devices and operations from the Federal Communications Commission ("FCC") and other governmental entities. I have a team of 200 employees that reports to me, including dozens of engineers with advanced degrees in systems engineering, communication systems, orbital dynamics, and digital compression systems. As Senior Vice President, Engineering, I am familiar with the engineering challenges that have confronted Sirius since its inception and the solutions that have been developed and implemented. I base this testimony on my experience and information I have learned through my work at Sirius.

Sirius' Technical Contributions

4. The difficulty of the technical challenge that faced Sirius at its inception can hardly be overstated. Sirius took on the enormous task of designing and building from scratch a reliable, practical and affordable satellite digital audio radio service. At the time that Sirius (then operating under the name Satellite CD Radio, Inc.) was founded, the technology existed to send a basic stream of audio data to a fixed point on the earth via satellite, but no one had ever succeeded in developing – or to my knowledge, had even attempted to develop – a satellite system for distribution of audio content on a seamless nationwide basis to moving vehicles. Among other issues, commercial satellite antennae capable of capturing the relatively weak signal from a satellite were generally large and expensive dishes, which are not practical for use

with vehicles. Even DirectTV–type dishes were far too large to mount on a family vehicle. Sirius also had to engineer around issues of blockage so that service to moving vehicles would be seamless even in crowded urban areas. Thus, in addition to dedicated satellites, Sirius simultaneously pioneered the development of highly advanced yet small and affordable antennae, the use of advanced audio compression techniques, and the construction of an advanced chipset and receiver. In 1990, Sirius was the first company to apply to the FCC to construct, launch, and operate a satellite system to provide digital audio radio programming to users across the continental United States. However, the system did not become operational, and even limited service did not begin, until February 2002. This decade-long gestation period reflects the technological and regulatory hurdles that were required to be overcome in order to make Sirius a reality. Moreover, the technical challenges posed by digital satellite audio stand in stark contrast to traditional terrestrial radio, where the underlying technology has been established for many years.

5. It is very important to note that, even with the satellites in orbit and a fully operational system, Sirius has had to continue to invest in intensive technological innovation. We are constantly upgrading our chipset and antenna designs to provide better sound quality with smaller size using less power. We are also constantly improving our compression technology, so we can provide higher fidelity sound and greater diversity from the available bandwidth. Finally, in addition to the constant enhancement updating of our technology on the ground, we will be required in the future to replace our satellites, at significant cost and risk.

6. A pictorial representation of the Sirius system is included as SIR Ex. 10. From our broadcast studios in New York the more than 130 channels of content are aggregated, individually compressed, and multiplexed into a single, encrypted digital signal that is

transmitted via fiber optic cable to our satellite uplink facility in Vernon, New Jersey. There the signal is uplinked to the two satellites that are then above the equator ("live" over the United States as described below) and then retransmitted back down to Earth. For subscribers in certain urban areas where a signal from the satellite might be difficult to receive directly due to blockages from building clutter, there are terrestrial repeaters that also broadcast the same signal. Each subscriber's radio includes a very small, specially designed antenna to receive the signal from the satellite, a proprietary chipset that permits the signal to be processed, service to be provisioned for each subscriber, and typical control and amplification functions. Through our satellite signal, entitlement messages are also sent that enable (or disable) individual receivers' ability to decrypt the subscribed services. This system is described in greater detail below.

The Satellites

7. Sirius uses a constellation of three dedicated satellites owned and controlled exclusively by Sirius to provide a very high quality of service throughout the continental United States. The satellites are deployed in inclined, elliptical, geosynchronous orbits, on three different planes, as illustrated by SIR Ex. 11. Each satellite's orbit has a period equal to the earth's rotational period. This unique configuration ensures that there is always at least one satellite at a high elevation relative to any given point in the continental United States at any given time. This helps to provide continuous coverage and minimize blockage, which significantly reduces Sirius' reliance on terrestrial repeaters. Sirius is the world's first commercial satellite broadcast system using non-geostationary orbits. The initial decision to use inclined, elliptical orbits rather than geostationary orbits (fixed in orbit over the equator) drove many of the engineering decisions.

8. The three-satellite geosynchronous approach required that the satellites be launched on three different planes, 120° apart. This allows each satellite to spend 16 hours north of the equator transmitting to the continental United States, and 8 hours south of the equator at "rest." At any given moment, two of the satellites are above the equator, providing signal throughout the continental United States. The two active satellites transmit the same signal at slightly different frequencies with a 4 second delay between them. A matching four second delay in the receiver allows the streams to be matched up in time. This architecture permits receivers to find the best signal at any given moment and create a seamless listening experience. So, for example, if a driver goes through a tunnel, the four second delay helps ensure that once the obstruction of the tunnel is removed, the receiver still has a complete and seamless programming stream for the listener.

9. The development of this three-satellite system was more than ten years in the making. The designs needed to be constantly updated to accommodate changing payload requirements, as well as other technological advances, all while maintaining the integrity of the overall system quality. Our engineers had to take into account dozens of orbit-specific requirements, as well as operational requirements. Each decision was critical to the creation of a functional and affordable commercial service. While Sirius' geosynchronous orbits ensure broad signal coverage on the ground, they created many engineering challenges to the design of the satellites themselves.

10. For example, by choosing a geosynchronous orbit rather than a geostationary orbit, Sirius had to engineer around the problem of orbital disturbance caused by its satellites' relative location to the sun, moon, and earth. In a geostationary orbit scenario, the satellite is in relatively the same plane as the sun and moon, so most tidal disturbances cancel each other out.

Sirius' orbits, however, are prone to much greater orbital disturbances, resulting in notable differences in fuel requirements amongst the three satellites. Having an elliptical geosynchronous orbit also means that the satellites have a variable orbital rate, rather than the fixed orbital rate of a geostationary satellite. The satellites therefore had to be designed to include an on-board system to provide constant reference information to allow the satellites to compensate for their varying orbital rates and apparent variations in earth size.

11. Similarly, the satellites had to be designed to constantly correct for sun-moon intrusions. For geostationary orbits, sun-moon intrusions occur at regular, predictable points in a satellite's orbit, and can be programmed to regularly inhibit earth sensor scans during intrusion periods to prevent the satellite from losing its lock on the earth. Satellites in geosynchronous orbits experience a much larger number of intrusions, often in rapid succession. The Sirius satellites are therefore programmed to constantly calculate sun and moon intrusions and automatically disable and re-enable earth sensor scans as necessary to ensure that the satellite does not lose communications with the Earth.

12. Moreover, although the high elevation of the chosen orbits ensures the fullest possible ground coverage, such high elevation can block the satellites' access to solar power, resulting in an unacceptable near total loss of array power generation. Sirius solved this problem by employing "yaw steering" for its satellites. The satellite body rotates about its yaw (earth-pointing) axis, which helps keep the body of the satellite properly perpendicular to the sun at all times, maximizing the efficiency of the solar panels. This is done only during certain months out of the year; at other times, the satellite follows a normal orbit path to maximize solar exposure. The flexibility of yaw steering allows Sirius' satellites to best take advantage of solar power

without affecting signal quality. This steering choice also helped ensure that the satellites do not experience too great of a fluctuation in temperature.

13. Taking into account commercial considerations, the satellites lower their signals while in the southern hemisphere, so as to avoid interference with services licensed to operate below the equator. To ensure signal accuracy while minimizing disruptions to service, the satellites thrusters and antennae are reoriented daily while the satellites are below the equator. The satellites are steered using antennae beam steering, which allows control of both the yaw steering and normal orbit modes of operation. To keep the elliptical orbit pattern aligned with the continental U.S. while in yaw steering mode, the antenna subreflector mechanically rotates in the opposite direction of the rest of the satellite. The satellites also employ compensation heaters to ensure that the communications panels maintain stable temperatures during their cold trip through the southern hemisphere.

14. The satellites receive signals from our satellite uplink facility in New Jersey at the 7.1 GHz frequency, then send the signals to subscribers throughout the continental United States at the 2.3 GHz frequency. The satellite antenna that receives the signal from the ground is a mere .75 meters in diameter, and is steered on two axes to ensure that it always receives the signal. The main reflector of the sending antenna is 2.4 meters in diameter. The subreflector is continuously rotated to maintain the elliptical coverage pattern even when the satellite's body is rotated in yaw. In order to amplify the signal sufficiently, Sirius uses a unique single transponder design which combines 32 Traveling Wave Tube Amplifiers to feed our single digital stream to the antenna. The satellites also carry redundant control electronics, receivers for tracking, telemetry and command (TT&C), a propulsion subsystem, an attitude control system, a thermal subsystem, a power subsystem, and a mechanism subsystem. All of these systems must

work flawlessly together to ensure that the satellites remain in orbit and properly send and receive the programming data.

15. The antennae used for ground tracking, telemetry, and command (TT&C) of the satellites are more complex for Sirius' inclined elliptical orbits than those that would be required to run geostationary satellites. Sirius' ground antennae are full-motion, continuously tracking antennae, located near the equator in Quito, Ecuador and Utive, Panama. These tracking stations are required to ensure communication with the satellites while they traverse both the northern and southern hemispheres.

Launching the Satellites

16. Even after Sirius completed the satellite designs, Sirius still faced an enormous hurdle in launching the satellites successfully. The selection of the vehicles to launch the satellites also reflect the enormous risks, costs, and capital investments Sirius has taken on in order to provide its service. The highly inclined elliptical orbits of the Sirius satellites required a heavy lift launch vehicle capable of injecting the 3800 kg separated mass satellites into the chosen orbit. Only two commercially available launch vehicles could possibly have met these requirements. Sirius chose to launch its satellites using the Proton K/Block DM launcher. The first of Sirius' satellites, dubbed Sirius-1, was launched in June 2000 from the Baikonur Cosmodrome in Kazakhstan. The remaining two satellites, Sirius-2 and Sirius-3, were launched in September 2000 and November 2000, respectively, also from Kazakhstan.

17. Designing, building and launching a satellite is an enormously lengthy, costly, and risky proposition. Launch vehicles are extremely complex and fail on a regular basis. Moreover, even when a satellite is in orbit, it is required to function in extremely difficult

conditions and is subject to complete or partial failure at any time. If a serious failure occurs, commercial satellites are for all practical purposes unrepairable once in orbit. For this reason, Sirius designed and built Sirius-4, a backup satellite that has never been launched and that remains in storage in Palo Alto, California.

18. In the near future, Sirius will be required to update the existing satellite constellations. Although it is impossible to predict with any degree of certainty how long the existing satellites will continue to function, all three are showing various signs of aging. Accordingly, beginning in 2008, Sirius will begin replacing them. Sirius has commissioned Space Systems/Loral to construct a new, powerful satellite that is intended to be launched in 2008. This new satellite will be placed into a geostationary position to augment the existing satellites in their highly inclined elliptical orbits. Subsequently, Sirius will launch additional satellites to replace those currently in the inclined elliptical orbits by 2012.

<u>Sending the Programming to the Satellites</u>

19. In order to deliver a compelling service offering, Sirius also had to pioneer substantial breakthroughs in the area of audio compression. Because the bandwidth available to Sirius is severely constrained, Sirius faces an inherent trade-off between the number of channels it can broadcast and the quality of the sound on those channels. The challenge is to provide acceptable quality for each audio application while using the fewest number of bits. Through the advanced digital compression technologies that Sirius has developed and funded, which reduce the number of bits required to provide equivalent sound quality, Sirius is now able to deliver more channels simultaneously with better sound quality. Sirius continues to invest heavily in basic research into how the human brain and audio system perceive sound, which ultimately will lead to further advances in the quality of the Sirius service.

20. To further enhance the efficiency of our audio compression system, Sirius has also pioneered the use of statistical multiplexing for audio applications. The fundamental basis of statistical multiplexing is the simultaneous analysis of multiple audio channels and reliance on the probability that not all audio passages will be equally difficult to code at high quality. For example, silence is often found in passages of both voice and music channels. Since silence does not represent a very complex audio signal, fewer bits can be assigned to a channel during those moments of silence. The bits that are saved from the temporarily silent channel can be dedicated to another channel that currently represents a complex audio passage. While statistical multiplexing is common in video systems, Sirius is unique in its investments to apply these concepts to audio compression schemes.

Terrestrial Repeaters

21. While Sirius' pioneering geosynchronous inclined, elliptical orbits greatly reduced the need for an extensive network of terrestrial repeaters, even Sirius' advanced system requires terrestrial repeaters in the densest urban areas to ensure continuous coverage. Sirius has drawn from the lessons of AM/FM transmission, cellular telephone transmission, and satellite television services such as DirecTV to design a unique system that provides maximal coverage.

22. At present, Sirius' system employs approximately 140 terrestrial repeaters nationwide. These repeaters receive the Sirius signal not from the main Sirius satellites, but rather through a VSAT service delivered via a geostationary satellite on which a transponder is leased by Sirius. This leasing arrangement provides significant cost savings to Sirius as compared to launching a fourth satellite specifically to feed the repeaters. Because the signal is relayed by this third-party satellite, however, the repeaters receive the signal at a frequency that is not within the range at which Sirius is licensed to transmit its signals to subscribers. Sirius'

repeaters must therefore first translate the signals they receive into the correct frequency to be transmitted to the receivers. The repeaters send the signal out at a modulation that allows for better transmission in dense urban areas. At the same time, the repeaters had to be designed with sophisticated filtering to ensure that they did not interfere with the signals from our own satellites, or with our rival XM's service.

23. In the future, Sirius will likely employ even more repeaters, to help fill in coverage gaps. However, each additional repeater imposes a significant financial and legal burden on Sirius. For each repeater Sirius places, it must first determine, from an engineering standpoint, the best possible location that will allow for maximal ground coverage while still receiving the signal from the VSAT satellite. When possible, Sirius prefers to place the repeaters on top of tall buildings in order to maximize the coverage of each transmitter. Once the optimal location is identified, Sirius must obtain placement permission from the landowner, as well as obtaining the required state and local building permits, state communications permits, and FCC approval. Often, Sirius is forced to settle for a less-than-optimal location for a given repeater because of permitting issues. Navigating this bureaucracy can take a year or more for each additional repeater, and requires the steady attention of a team of lawyers and engineers.

<u>The Sirius Chipset and Receivers</u>

24. To complete the delivery of the Sirius service to subscribers and turn the signal sent out by Sirius' satellites and terrestrial repeaters into an enjoyable consumer listening experience, Sirius also had to develop a system to receive, decode, and decompress the satellite signals. Working intensively with Lucent and their microelectronics division (now Agere Systems), Sirius created the proprietary set of application specific integrated circuits, or chipset.

The chipset is the core technology in every Sirius radio, no matter what the interface looks like. In creating such a system, Sirius was ever mindful of two primary factors: size and pricing.

25. Sirius' first generation chipset technology was pioneering in many respects. Sirius developed technology to allow the radio to choose the strongest signal from any of the two currently transmitting satellites or a terrestrial repeater at any given time. The radios also buffer the signals so that, even if the signals of all of the satellites are momentarily blocked, the user hears only seamless programming.

26. Perhaps one of the greatest achievements of Sirius' technology is the small, extraordinarily sensitive antennae used by the system. Whereas the Digital Satellite Services (DSS) such as DirecTV to this day require a relatively large antennae between 18 and 24 inches in diameter with a fixed aim to receive the service signal, the original Sirius antenna was a mere four inches by two inches by one inch and could operate in any direction. With further development, the antenna has now been reduced in size to 47mm x 40mm x 12mm. The tear drop-shaped antenna is installed on the roof of a vehicle. Despite its small size, the Sirius antenna is able to discern the very low-power signal that Sirius transmits, which is just a few decibels above the cosmic background radiation. Before Sirius developed this small antenna, only the military used such low-powered signals. By creating this small antenna, Sirius pioneered the commercial use of low power signals.

27. Sirius has continued to innovate with respect to chipset development as well. In February 2003, Sirius announced that it would begin shipping a second-generation chipset technology. The newer chipset utilized Agere's COM2H process technology to integrate all digital portions of the receiver circuitry, excluding memory, into a single chip. This reduced the

receiver design dimensions to the size of a credit card, from that of a videocassette in the first generation commercial products. In addition to a dramatic reduction in size, the second generation chipset reduced required power by 50 percent and provided improved thermal performance. In 2004, we introduced a Generation 2.5 chipset that further reduced the size, cost and electrical requirements of the chipset. Most recently, in 2005, we rolled out our Generation 3 chipset from ST Microelectronics, representing a significant further advance in all major design parameters. A pictorial representation of our chipset advances is shown in SIR Ex. 12. As with our other technologies, chipset development is an area that requires constant, substantial investment in order to remain competitive.

28. Consumer electronics companies, with the aid of Sirius engineers and substantial monetary subsidies from Sirius, have developed a wide variety of radios for factory installation into new vehicles, installation into existing vehicles in the after market, and home and mobile use. The user interface of the Sirius system presents many innovations beyond traditional terrestrial radios. Foremost, the interface allows easy transition between the more than 130 channels of programming Sirius provides. In addition to consumer electronics products, Sirius works closely with our automotive partners and their suppliers in order to integrate our service into new automobiles as they roll off the manufacturing line. This effort requires significant investment to ensure the high quality standards of the automotive industry are consistently met.

<u>Public Recognition of Sirius' Technological Contributions</u>

29. The satellite and engineering industries have extensively recognized Sirius' enormous technological contributions. On April 11, 2002, Sirius was inducted into the Space Foundation's Space Technology Hall of Fame. The honor recognizes innovators who transform technology originally developed for space use into commercial products. Inductees are selected

by a team that includes input from NASA, the Departments of Defense, Commerce, and Transportation, and commercial aerospace and technology companies. Sirius joined an elite group of fewer than 40 technologies to be so honored, including DirectTV, the Debakey heart pump and the Global Positioning System (GPS).

30. In December 2001, *Popular Science* magazine honored Sirius as the Grand Prize winner of its "Best of What's New" award in its electronics category. *Popular Science* is the world's largest science and technology magazine, with a circulation of more than half a million. Each year in its Best of What's New issue, *Popular Science* features 100 winners in ten different categories honoring product innovation. Among these 100 winners, the magazine also selects ten Grand Prize award winners that represent a significant step forward in each category. In recognizing the Grand Prize recipients, the magazine's editors look for products that must in some way improve the quality of life.

31. The technologies developed by Sirius have resulted in the granting of twelve United States Patents. Many of these innovative technologies are embodied in the Sirius system as it operates today. Moreover, my team continues to file new patent applications as new technology is developed. In addition to these filed patents, many technological advances are held as trade secrets to preserve our competitive advantages and service security.

Conclusion

32. For more than fifteen years, Sirius has been a major innovator of all aspects of satellite radio. From its pioneering three-satellite geosynchronous orbital system to its audio compression technology, from its terrestrial repeaters to its amazingly small antenna and innovative receiver technology, Sirius has invested more than fifteen years of engineering know-

how and hundreds of millions of dollars to develop a commercially viable subscription service to deliver cutting-edge programming. These innovations allow a broad variety of music to reach listeners who otherwise might not be reached by traditional music distribution channels.

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DECLARATION OF TERRENCE SMITH

I, Terrence Smith, declare under penalty of perjury that the statements contained in my Written Direct Testimony in the above-captioned matter are true and correct to the best of my knowledge, information and belief. Executed this 30th day of October 2006 at New York, New York.

Terrence Smith