Moonbounce from Arecibo Observatory

Last April hundreds of amateurs who had never had an opportunity to try operating Moonbounce finally got their chance.

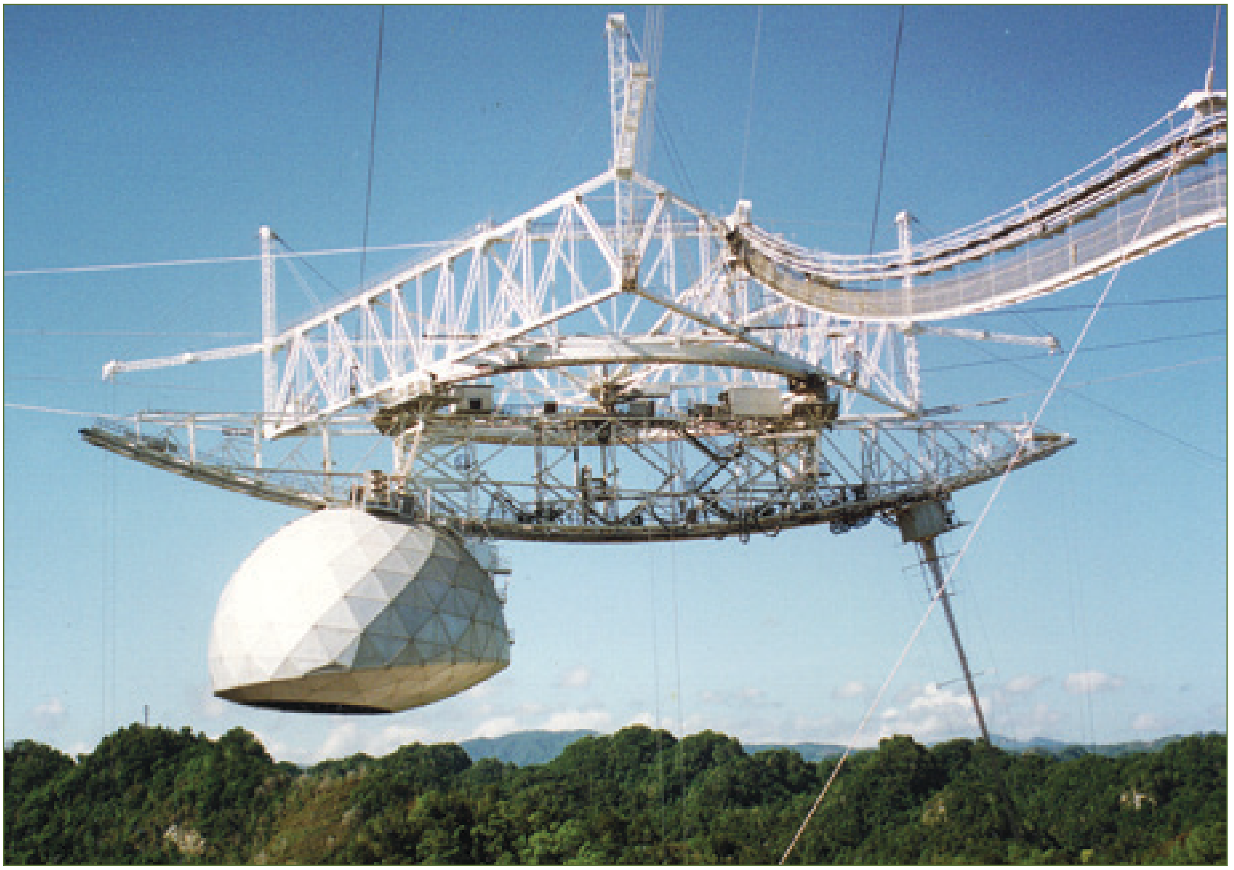
Joe Taylor, K1JT, Angel Vazquez, WP3R, and Jim Breakall, WA3FET

For nearly half a century the world's largest and most sensitive radio telescope has been the 1000-foot reflector of the Arecibo Observatory, in Puerto Rico. Operated by Cornell University under a cooperative agreement with the US National Science Foundation, the big dish is world famous for enabling pioneering studies of the Earth's atmosphere and ionosphere; of many objects in our solar system including planets, moons, asteroids, and comets; and of erupting stars, clouds of gas, pulsars, galaxies and quasars in much more distant parts of the universe.

Hardly surprisingly, a number of permanent staff members and visiting scientific users of Arecibo are licensed radio amateurs. The three of us are among this fortunate group, each enjoying an association with the Observatory spanning more than 30 years. In 1972 Joe, K1JT, brought specialized equipment to Arecibo that enabled detection of the first known binary pulsar. He has continued to make frequent trips to Arecibo, usually accompanied by a small group of research students, throughout his professional career. Jim, WA3FET, first arrived as a summer student in 1974. He later conducted research for his PhD at Arecibo, providing new results on absolute calibration of the telescope and its high power radar transmitter, and finishing his doctorate in 1983. He has been involved since then with designing antennas for the Observatory. Angel, WP3R, joined the technical staff as a telescope operator in 1977. Since then he has served as PC systems specialist and network administrator in the computer department, and most recently also as spectrum manager. Additional operators included our good friends Pedro, NP4A, and Angel, WP4G, who brought important operating and technical skills and EME experience to the group, and visitor Pat, AA6EG, who rounded out the team.

Needless to say, it was great fun for us and other members of the Arecibo Observatory Amateur Radio Club (AOARC) to put KP4AO on the air for 432 MHz EME (Earth-Moon-Earth, better known as *moonbounce*) over the long weekend April 16-18, 2010, using our all-time-favorite radio antenna. What a great QSO party it was! The telescope's huge forward gain, about 61 dBi at 432 MHz, guaranteed that even small stations could get into the game. Many hundreds of stations copied the KP4AO signal after its half-million mile round trip to the Moon and back — some using small handheld Yagis or even a dipole, and in at least one case a rubber flex antenna. The wall of stations responding to our CQs sounded like 20 meters during a

The 1000 foot antenna of the Arecibo Observatory.



The Arecibo feed-support system. The azimuth arm rotates about a central bearing; the "carriage house" (at right) and secondary reflector (inside radome, at left) move along the azimuth arm under computer control. In this way the telescope can be pointed to any direction within 20 degrees of the local zenith.

DX contest! Even with skillful, well-behaved operators spread out over 15 kHz and more, we had to work hard to pick call signs out of the din. Wideband real-time recordings have enabled us to copy hundreds of additional call signs, after the fact. A total of 242 lucky ones made it into the log with completed two-way QSOs, in about 8 hours of actual operation.

The Arecibo Antenna

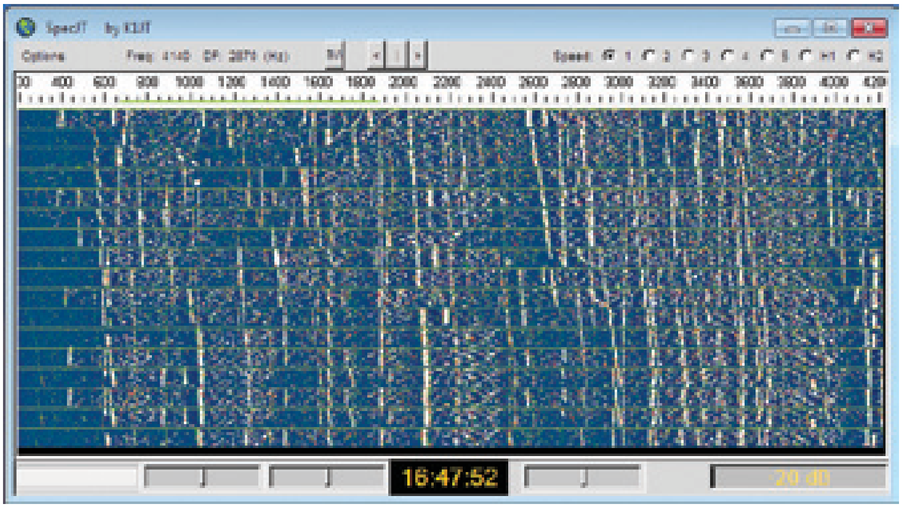
Imagine a conducting sphere 1740 feet in diameter, resting in a hole in the ground some 157 feet deep. Cut the sphere with a horizontal plane at ground level, and remove the top portion. What's left is a bowl-shaped reflector with the original radius of curvature, 870 feet, and a diameter of 1000 ft — just the shape and size of the Arecibo antenna. When construction began in 1962, most of the necessary hole in the ground was there already, thanks to the rugged "karst" geology of the region. The antenna's reflecting surface is made of some 39,000 perforated aluminum panels, each one individually adjustable, suspended from catenary cables and tied to concrete anchors in the ground. The measured surface of the dish conforms to the desired spherical shape with a root-mean-square accuracy of 2.2 mm.

Unlike most other radio telescopes and large antennas built for space communication, the Arecibo reflector does not move. However, its beam can be steered by moving the feed antennas. The feed support system is comprised of a circular azimuth track and banana-shaped, 328 foot long azimuth arm, which rotates about a central pivot. Steering in zenith angle is accomplished by moving the feed antennas along a track on the underside of the azimuth arm. The large geodesic radome encloses secondary and tertiary reflectors and switchable feed horns to cover the frequency range 1-10 GHz, plus a number of lower frequencies ranging down to 327 MHz. At the opposite end of the azimuth arm there is a rectangular "carriage house" supporting the 96 foot line feed for 430 MHz. This feed is essentially a leaky waveguide; the rings are spaced so as to provide optimum illumination of the primary reflector. Other low-frequency feeds, for 47 MHz, for example, can also be mounted on the carriage house. We used the 430 MHz line feed for our EME sessions.

The 430 MHz line feed.

Equipment Setup for 432 MHz EME

For operating convenience and to prevent disruption to scientific programs scheduled in other parts of each day, we installed all amateur equipment at ground level, near the control room in the main electronics build-



A screen shot showing signals in a 4 kHz passband during JT65B operation. Many dozens of signals are present and easily copied.

ing. For the necessary feed line, some 1500 feet long, we used the permanently installed WR2100 waveguide (0.04 dB loss per hundred feet) normally used for the 2.5 MW 430 MHz radar transmitter. Amateurs who use waveguide for their microwave stations will be amused by the sheer size of WR2100, with cross-section dimensions 21 × 10.5 inches.

To obviate potential problems of mismatched linear polarization angles, we elected to transmit and receive using right-hand circular polarization. A signal's sense of circularity is reversed upon reflection, so the most efficient reception would use left-hand circular polarization. However, the 3 dB loss for stations using linear polarization would be of minor importance, and there would be no problems with mismatched angles. Since we received only the cross-polarized signal in our own self-echoes, they were attenuated by some 15–20 dB; however, they were still S9+ in our receiver.

For extra flexibility we used two Kenwood TS-2000 transceivers — one for transmitting and one for receiving. The receive side included a GaAsFET preamplifier with noise figure 0.5 dB and equivalent noise temperature 35 K. The telescope beamwidth is only 0.15° at this frequency, less than ⅓ the size of the Moon's disk. Consequently, our system noise temperature was dominated by the Moon's surface temperature, about 210 K. Total system noise temperature including receiver noise, feed line, waveguide and rotary-joint losses, and antenna "spillover" was around 350 K.

We had two power amplifiers available — one using a 3CX800, and the other a solid-state unit built by F1JRD and donated by Freescale Semiconductor to the AOARC for scientific and educational purposes. As things worked out, we had problems with the tube amplifier and were not ready with the SSPA on the first day, so we ran the TS-2000 barefoot at about 35 W. On April 17 we started with 350 W from the 3CX800 amplifier, but after an arc-over we switched to the SSPA at 500 W. On the final day we used the 3CX800 again because a problem had developed in the 50 V power supply for the SSPA. Murphy tried his best, but we were well supplied with spares and servicing skills.

On the Air!

Notice of our scheduled operation had been publicized for only a few weeks, but the grapevine was so efficient that hundreds of stations were listening for us on 432.045 MHz at the time of our first Moon acquisition, 1645 UTC on Friday. A brief "Hellooo… Moon!" on SSB to check our echo was followed by a "CQ CQ from KP4AO, Arecibo Puerto Rico…," and a huge pile-up erupted. Fifteen SSB QSOs were made in the next few minutes; we then switched to CW and worked another 74 stations before our Moon window closed. It was disappointing not to have an amplifier ready for service on the first day, but for most of the calling stations it hardly mattered. We were delighted with the total of 89 QSOs made with 35 watts.

As shown in the following table, in Saturday's Moon window we increased the QSO rate to about 40 per hour. Altogether our log shows 242 QSOs with stations in 36 DXCC entities. The accompanying waterfall image made from our recordings of our JT65B operation gives a good impression of the number of stations calling.

	SSB	*CW*	*JT65*	*Total*
Friday	15	74	0	89
Saturday	75	31	0	106
Sunday	16	17	14	47
Totals	**106**	**122**	**14**	**242**

As had been planned and announced in advance, an hour of Sunday's window was allocated to the slower but extremely sensitive digital mode, JT65B. It was impossible to work more than a tiny fraction of the stations that were calling. We tried to pick out some of the weaker decodable signals, making a total of 14 QSOs in our final hour of Moon time.

Even with reasonably good signals in both directions, it is not possible in any mode to run an EME pileup at the QSO rates sometimes achieved by top contesters or DXpeditioners. An inevitable 5 second delay (twice the round-trip travel time to the Moon, at the speed of light) occurs between each station's standby and the first echoes heard from a QSO partner. Moreover, we wanted to respect the minimal-QSO standards generally used in the EME world, which include full exchange of both call signs, a signal report, and acknowledgments. We provided live video and audio streaming of the whole operation, and many viewers were amused by the screeches from tropical birds inadvertently sharing our transmitter room, as well as plenty of human noises from lookers-on. We hope these distractions have not caused a significant number of errors in logging the stations worked.

Angel, WP3R, connects LMR-900 feed line to a waveguide-to-coax transition, just outside the transmitter room.

Soapbox Comments

We could tell many more stories about the goings-on at Arecibo, but in many ways the most interesting ones will be told by operators at the other ends of our EME paths. Here are some selected (and lightly edited) comments that we received after the event…

Persistence paid off...25 elements and a 100 W brick amplifier was enough for a QSO. — **WB2SIH**. Nice to listen to the KP4AO SSB signal with a simple station: 12-element Yagi, 0.5 dB LNA, homebrew converter and SDR receiver. Honest 55 to 57 signals. An awesome experience! — **PY3FF**. Very impressive on JT65B! Was sending every period, but my flea power of 50 W and a 16-element Yagi didn't cut it. — **E51WL**. Tried for hours on SSB and CW without success; was very surprised to make it with the tremendous pile up when you went to JT65! Huge signals here on my single 28-element Yagi. I suspect after this weekend more stations will be encouraged to have a go at 70 cm EME. — **G4ZFJ**. I called for a few minutes soon after your Moonrise, not really expecting to be heard through the pile. After about ten minutes — lo and behold! — the operator came back with "W4RBO 59." I almost fell out of my chair. — **W4RBO**. A 21-element Tonna with az/el pointed manually, SWR 2.5:1, 20 meters of coax, FT-817, no preamp. Signal was fantastic, peaking up to S3. — **HB9DRI**. Set up on the New Jersey shore with a single 12 element Yagi on a photo tripod, 15 feet of RG-8 into an FT-847. You were Q5 throughout on CW. — **W2KV**. Fifteen students built 4- and 8-element Yagis, all 1 meter or less in length. With the help of an 18 K preamp, copied your 35 W CW signal on every one! Then worked you easily using our 16×10-element array. — **WD5AGO**. Very strong signals! Made contact in SSB and also my daughter, SW8NAC (12 years old) made an SSB QSO. — **SV8CS**. FT736R and Mirage 100 W brick, KLM 432C18 circularly polarized satellite antenna. All modes copied here, but we couldn't bust the pileups. — **K7IP**. OSCAR 13 station, IC-7000, and home-design cross Yagi with 13+13 elements, 15 meters of 9913 coax. RST 419 in CW mode, JT65B tones clearly audible in speaker. — **LU8YD**. Too bad you didn't have a month of Moon time to work all the stations calling! — **NY2NY**. FT-857 and 100 W brick, single 11-element WA5VJB cheap Yagi on tripod, no preamp. Solid copy all day on Sunday at –11db on JT65B. — **W6OUU**. I'm sure that thanks to this event EME will see a big increase of activity in the future on CW and JT65. Many new stations have tasted blood! — **CT1HZE**. FT736R barefoot, no preamp, Cushcraft 719B on a 6 foot stepladder, 50 feet of LMR400. Copied on SSB, CW, and JT65B. — **NJØU**. Thanks for my first EME QSO in over 30 years! — **KØTV**. Feeling proud of being a ham! Using a 10-element Yagi and an FT-817, I desperately tried to contact KP4AO in JT65B, but didn't succeed. Nevertheless I felt like Jodie Foster in the movie *Contact!* — **LY2SS**. Used a 3-element Yagi on wooden picnic bench in back garden, pointed roughly towards the Moon, with preamp and about 20 meters of good quality coax to an ICOM R9000. Good copy in JT65B mode on Sunday! — **Chris (SWL in UK)**. Great fun listening to the fantastic signal and the pileup of stations calling. — **SM2CEW**. KP4AO peaked 57 on sideband; perfect copy, hardly a word missed. Used an 8-element Yagi, boom length 0.8 meters, with one of my own LNAs, 0.3 dB NF and 27 dB gain — **G4DDK**. OSCAR 10-class station with 436CP30 antenna, 150 W through 110 feet of Andrew FSJ4-50B. Solid copy on CW and JT65B. My first EME QSO on 70 cm, and hopefully not the last. — **W1ICW**. Nice to still find a thrill after 30 years of ham radio! — **9H1GB**.

The tired but happy operators are (left to right) WA3FET, K1JT, WP4G in front of WP3R, and NP4A. AA6EG was behind the camera.

Acknowledgments

Many people at the Arecibo Observatory worked hard to make this event successful. We especially wish to thank Israel Cabrera, KP4LCL, who loaned his TS-2000; Alfredo Santoni, who gave generously of his time and engineering skills; Dana Whitlow, K8YUM, who made the wideband recordings; Mike Nolan, Observatory Site Director, who granted us the necessary telescope time, and Pat Barthelow, AA6EG, who made the initial inquiry and suggested possible dates of operation.

Joe Taylor is an ARRL member first licensed as KN2ITP in 1954, and has since held call signs K2ITP, WA1LXQ, W1HFV, VK2BJX and K1JT. He was Professor of Astronomy at the University of Massachusetts from 1969 to 1981 and since then Professor of Physics at Princeton University. He was awarded the Nobel Prize in Physics in 1993 for discovery of the first orbiting pulsar. He chases DX from 160 meters through the microwave bands. Joe can be reached at 272 Hartley Ave, Princeton, NJ 08540, or **k1jt@arrl.net**.

Angel M. Vazquez, WP3R, is an ARRL member who was born in Arecibo, PR, but raised in Brooklyn, NY from the age of 2 until he graduated from CUNY with an Associate degree in Electrical Engineering. He achieved a First Class Radiotelephone FCC license and worked one year for WNYC as a Radio Engineer; in 1977 he moved to Puerto Rico and took a position at the Arecibo Observatory. Positions there have included Telescope Operator, Senior Telescope Operator, Spectrum Manager, PC Systems Admin, RFI Manager and Head of Operations. You can reach Angel at HC 3 Box 53995, Arecibo, PR 00612, or **angel@naic.edu**.

ARRL member Jim Breakall, WA3FET, was first licensed as WN3FET in 1965. He received BS and MS degrees from Penn State University and a PhD in Electrical Engineering and Applied Physics from Case Western Reserve. He worked at the Lawrence Livermore National Laboratory, mainly on development of the Numerical Electromagnetics Code (NEC) used to this day for antenna modeling, and taught at the Naval Postgraduate School in Monterey, CA. Presently he is Professor of Electrical Engineering at Penn State and works mainly on antennas, notably feed designs for the 1000 foot Arecibo dish. He is a frequent speaker at the Antenna Forum at the Dayton Hamvention, and has built two major contest superstations, K3CR and KC3R, near Penn State, and WP3R, on his farm in Puerto Rico near the big dish. His son is Jimmy Breakall, W3FET, who got his license at the age of 9. You can reach him at 225 Electrical Engineering East, Penn State University, University Park, PA 16802 or at **jimb@psu.edu**.

Photos of the Arecibo antenna and the feed-support system are courtesy of the NAIC — Arecibo Observatory, a facility of the National Science Foundation. Remaining photos are by WP3R, K8YUM and WP4G.