WILLIAM H. GUIER and GEORGE C. WEIFFENBACH

THE EARLY DAYS OF SPUTNIK

When Sputnik I was launched on Friday, October 4, 1957, we followed the news of the orbiting Sputnik with high interest but with little thought of personal involvement. The following Monday, at APL, former staff member Bob Bogle reminded us that APL was a laboratory with the capability of receiving the satellite signals and understanding the telemetry code to obtain useful information. He also pointed out that, surprisingly, there seemed to have been no serious effort at APL involving Sputnik over the weekend. Presumably everyone, like us, assumed somebody else would be "at it."

That first Monday evening there was hardly a receiver/antenna combination at the Laboratory that did not have a group trying to receive the Sputnik signals. We had one distinct advantage over other groups: one of us was completing a Ph.D. dissertation in microwave spectroscopy and had a high-quality communication receiver and the necessary understanding of how to make precision frequency measurements. Because of the fortunate happenstance that the Beltsville, Md. WWV 20-MHz-standard broadcast was at nearly the Sputnik frequency, the output from the receiver could be made to be the audible difference between the WWV standard and the Sputnik signal. Superimposed was the WWV timing signal.

That first evening was fun! Hams were listening and talking "all over the bands" about the launch and exchanging information about when it would be over various locations. At one point our search picked up a broadcast by the Russians (in English on one of the ham bands) that listed times of passage over major cities around the world, including Washington, D.C. We now knew when to listen! Also, during that period we had sufficiently refreshed our memories on the subject of orbital mechanics to have a good idea of what the satellite's period (95 minutes) and inclination ($\approx 64°$) must be and to estimate the number and grouping of successive passes available at our latitude.

Our first reception of the Sputnik seemed only a momentary triumph when we realized that there was no telemetry on the 20 MHz signal, just a pure tone that at first appeared to wander in frequency by a surprisingly large amount. After about 5 minutes, it was unmistakably clear that the wandering was the moving Sputnik's Doppler shift, which we were by then recording with precise frequency and time information. Without a telemetry signal to play with, we turned to considering the Doppler shift and the information that might be gained from it.

We "borrowed" a General Radio wave analyzer from Ed Cochran's laboratory, and by playing the recorded signals back at different frequency settings (≈ 2 Hz bandwidth), we obtained accurate (digital) frequency versus time data. Using those data, it was a natural step to refine the estimates of time of closest approach of the satellite to our antenna. After some laborious hand calculations on a Frieden mechanical calculator, we refined the period of the satellite orbit. Within a few days we were making the most accurate predictions of the next times of signal appearance and were phoning such "alert times" to Vanguard Headquarters in Washington, which had set up an information clearing house for Sputnik fact and folklore.

To our disappointment, the signals stopped after a few days because of the limited storage battery capacity in the Sputnik I, and we were left with only the data we had taken and the typical post-adventure letdown one feels after an intensive effort. Now we could use our professional thinking, the outstanding Laboratory resources, and the support of the Director and Management to place our "stunt" on an accurate quantitative basis. Without yet having a clear idea of an application for such a capability, we joined with the Laboratory's new Digital Computing Center, in particular with Charley Bitterli and his colleagues who helped greatly in computer processing the Doppler data to obtain better orbital parameters and to generate alert times. Laboratory specialists in receivers and antennas (Harry Zink in particular) helped to improve the accuracy and reduce the labor of Doppler data reduction.

To our great joy, the Russians launched Sputnik II on November 3, 1957, so we had a renewed interest in tracking "live" satellites. With the processing power available with the digital computer, we were able to try relatively complex experiments with the Doppler data, including determinations of the Sputnik transmitter frequency, a correction for ionospheric refraction (Sputnik II broadcast on both 20 and 40 MHz), and several different methods for parameterizing the satellite's motion that were more suitable for near-earth satellites than for planetary motion.

The following step was the giant one: Dr. Frank T. McClure conceived both the inverse process of using Doppler information for navigation and the major components of an operational navigation system. Together, he and Dr. R. B. Kershner completed the conceptual design of the Transit Navigation Satellite System, which remains basically unchanged today.

In addition to our pride in being an integral part of the development of the Transit System, we carry cherished memories of those earliest days when we and our colleagues were presented with such an exciting and tidy challenge—when we were in exactly the right place at the right time. The challenge was exciting because it instantly opened a new scientific frontier with fascinating aspects; even the most obvious ones, such as the short time span between passages over opposite parts of the earth, took some time to fully comprehend. It was tidy because even at the low orbits of Sputnik, physical laws remained basic and simple because complications of aerodynamic forces were negligible (at the existing data accuracy) and there were no signal countermeasures to contend with.

We were exactly at the right place because of the unique resources at hand: instrumentation resources nearby and made available; bosses who were tolerant of people spending time on unauthorized projects and who supported progress when there was not yet a well-defined application; and, most of all, our bright colleagues who shot down the bad ideas, who made things work, and who also enjoyed sharing such adventures.

REFERENCE

W. H. Guier and G. C. Weiffenbach, "Theoretical Analysis of Doppler Radio Signals from Earth Satellites," *Nature* **181**, pp. 1525-1526 (1958).