GIOVE-B on the Air

Understanding Galileo's New Signals

Following up on their earlier work analyzing and decoding new GNSS signals, researchers from Stanford University and the University of Colorado provide an early analysis of signals being transmitted by the latest Galileo test satellite, GIOVE-B.

GIOVE-B, mounted on its payload adapter, being lowered onto Fregat (upper stage of launcher) – ESA photo, P. Müller

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Europe's second Galileo In-Orbit Validation Element (GIOVE-B) test satellite was launched on April 27, 2008, at 22:16 UTC and began transmissions on May 7.

On the same day, we observed signals in the L1, E5a, and E5b bands, with the L1 spectrum showing multiplexed binary offset carrier (MBOC) modulation. We then identified the generators for the PRN codes in each band, using the approach described in our previous Institute of Navigation (ION) conference papers listed in the Additional Resources section at the end of this article. We revealed these codes to be 13- or 14-stage Gold codes, different from the memory codes in the Galileo Interface Control Document (ICD).

Our results were validated by acquiring the transmitted signals with these codes. In the following discussion, we elaborate on our data collection apparatus, the observed signal spectra, and the revealed PRN code generators of GIOVE-B.

GIOVE-B Transmissions

In order to obtain a positive signal-to-noise ratio to view the individual spread spectrum chips, we used highly directive antennas: the 1.8-meter parabolic Stanford GNSS Monitor Station (SGMS) in California and the 20-meter parabolic antenna at Table Mountain, Colorado.

As in previous observations described in a 2006 article in *Inside GNSS* (see Additional Resources at the conclusion of this article), both antennas were connected to an vector signal analyzer that enabled the capture of extended data records of multiple seconds of 36 MHz bandwidth at the various frequency bands of interest. We used data from the SGMS to determine the codes associated with the GIOVE-B L1 transmission, while data collected with the larger-aperture antenna was used to study the GIOVE-B E5 code generation.

The 20-meter parabolic antenna shown in the photo on page 37 is locat-

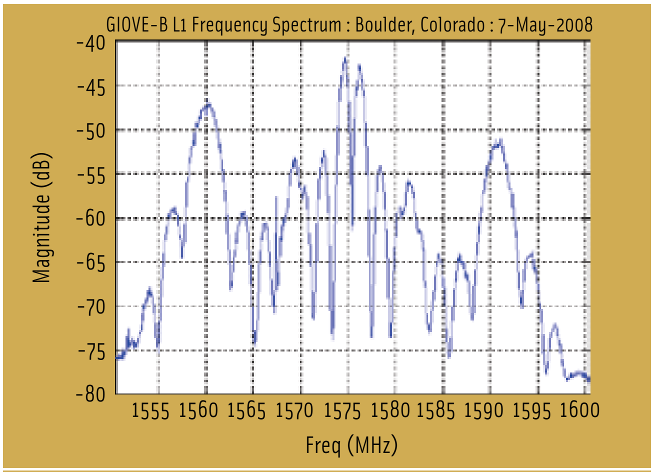


FIGURE 1 **GIOVE-B L1 frequency spectrum**

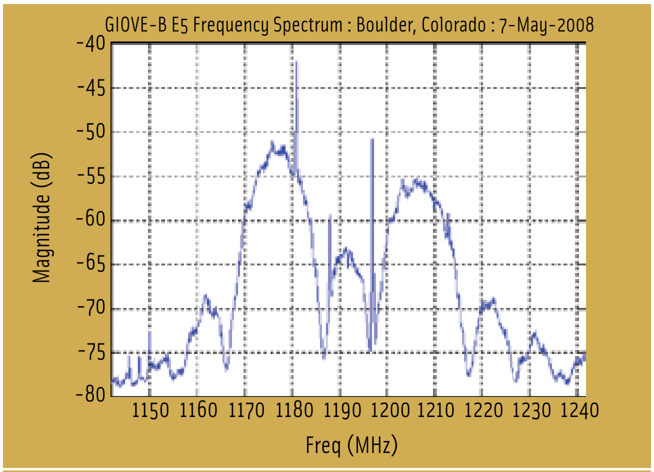


FIGURE 2 **GIOVE-B E5 frequency spectrum**

ed at Table Mountain in Colorado and owned by the Institute for Telecommunication Sciences (ITS). The institute is the research and engineering branch of the National Telecommunications and Information Administration (NTIA). Until recently, the facility had sat dormant but has now undergone a renovation bringing it to operational status, thanks in part to a joint effort involving ITS, the volunteer Deep Space Exploration Society <http://deep-space.org/index.shtml>, and the University of Colorado.

Precise tracking files were generated based on the publicly available Two Line Orbital Elements (TLEs) obtained from Dr. T.S. Kelso's Celestrack webpage <www.celestrak.com/NORAD/elements>, which provided sufficient accuracy to track GIOVE-B.

Observations were taken on May 7 during a pass over Boulder, Colorado. During this time, we observed the expected spectral signatures on the L1 and E5 frequencies; however, no signal was observed on the allocated E6 frequency. **Figures 1** and **2** present the observed spectra for L1 and E5.

The middle part of the L1 spectrum displays the MBOC modulation for the Galileo Open Service (OS) signals, while the two side lobes 15 MHz from the center frequency show BOC(15, 2.5) modulation for Galileo's Public Regulated Service (PRS) signals. The E5 spectrum indicates AltBOC(15, 10) modulation.

We assume the asymmetry of the L1 or E5 spectrum is due to early stage components (filters and amplifiers) in the RF chain and not directly representative of the satellite signal. The issue probably arises from the filter connected to the antenna, not the filter in the software receiver. In other words, the asymmetry is from capturing the data, not processing the data.

Time domain data was collected independently at E5a and E5b for PRN code determination at those frequencies. The data were also used for L1 PRN code validation.

Revealed PRN Codes

We decoded the GIOVE-B civilian codes in all available frequency bands, namely L1, E5a, and E5b, with two codes in each band. All six codes are Gold codes, which are different from the memory codes published in the Galileo ICD.

Interestingly, the GIOVE-B codes have the same lengths and code generator polynomials as GIOVE-A broadcast codes, but different initial states. The decoding process is similar to that of the GIOVE-A codes. For details, please refer

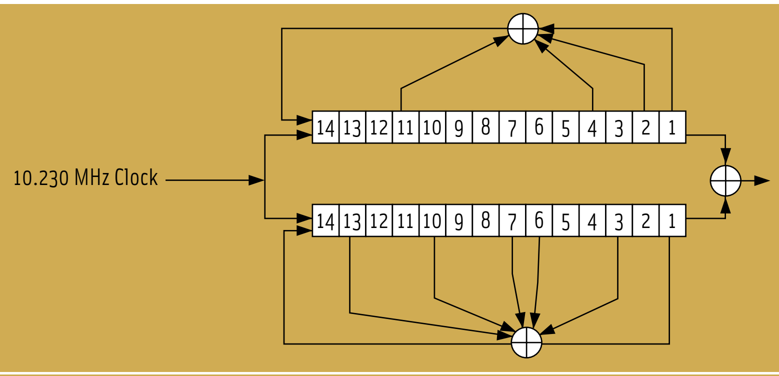


FIGURE 3 E5b code generator

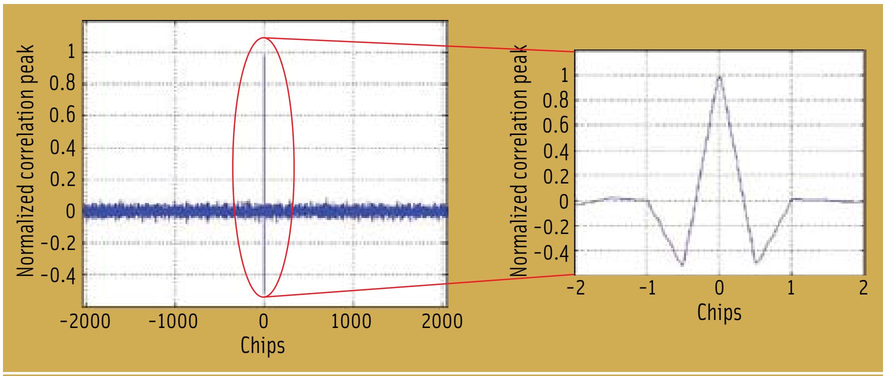


FIGURE 4 GIOVE-B L1 correlation peak using BOC(1, 1)

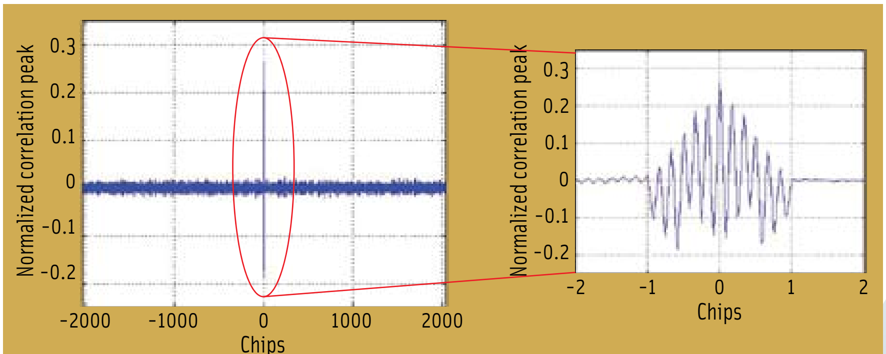


FIGURE 5 GIOVE-B L1 Correlation peak using BOC(6, 1). The peak is normalized regarding BOC(1, 1) peak.

L1-B code (4092 bits, 4msec, 13-stage Gold code)	
Polynomial_1	X13+X10+X9+X7+X5+X4+1
Initial State_1	[1 1 1 1 1 1 1 1 1 1 1 1 1]
Polynomial_2	X13+X12+X8+X7+X6+X5+1
Initial State_2	[1 0 0 1 1 1 1 1 1 1 1 0 0]
L1-C code (8184 bits, 8msec, 13-stage Gold code)	
Polynomial_1	X13+X4+X3+X+1
Initial State_1	[1 1 1 1 1 1 1 1 1 1 1 1 1]
Polynomial_2	X13+X10+X9+X7+X5+X4+1
Initial State_2	[0 1 0 0 0 1 0 1 1 1 1 1 1]
E5a-I code (10230 bits, 1msec, 14-stage Gold code)	
Polynomial_1	X14+X8+X6+X+1
Initial State_1	[1 1 1 1 1 1 1 1 1 1 1 1 1 1]
Polynomial_2	X14+X12+X8+X7+X5+X4+1
Initial State_2	[1 0 0 1 1 0 0 1 0 0 0 0 0 0]
E5a-Q code (10230 bits, 1msec, 14-stage Gold code)	
Polynomial_1	X14+X8+X6+X+1
Initial State_1	[1 1 1 1 1 1 1 1 1 1 1 1 1 1]
Polynomial_2	X14+X12+X8+X7+X5+X4+1
Initial State_2	[1 0 0 0 1 1 1 0 1 0 1 1 0 0]
E5b-I code (10230 bits, 1msec, 14-stage Gold code)	
Polynomial_1	X14+X13+X11+X4+1
Initial State_1	[1 1 1 1 1 1 1 1 1 1 1 1 1 1]
Polynomial_2	X14+X12+X9+X8+X5+X2+1
Initial State_2	[0 0 0 0 1 0 1 0 1 1 0 0 1 0]
E5b-Q code (10230 bits, 1msec, 14-stage Gold code)	
Polynomial_1	X14+X13+X11+X4+1
Initial State_1	[1 1 1 1 1 1 1 1 1 1 1 1 1 1]
Polynomial_2	X14+X12+X9+X8+X5+X2+1
Initial State_2	[0 1 0 1 0 0 0 0 0 1 0 1 1 1]

TABLE 1. Generator polynomials and initial states for Galileo L1 and E5 codes

to our previous Institute of Navigation (ION) conference papers. We list the generator polynomials and initial states for all the codes in **Table 1**. For brevity, we show only the schematic for the E5b code generator (**Figure 3**).

For validation, we acquired all the GIOVE-B broadcast signals successfully. When validating L1 codes, we are able to acquire the GIOVE-B broadcast L1 signal by a local replica with either BOC(1, 1) modulation only or BOC(6, 1) modulation only as shown in **Figures 4** and **5**. Thus, it seems that the GIOVE-B L1 MBOC modulation is composed of BOC(1, 1) and BOC(6, 1).

Conclusion

Our early analysis of GIOVE-B produces two observations. We confirm that it transmits on L1, E5a, and E5b bands with MBOC modulation in L1, and we find the PRN generators in all bands to be 13- or 14-stage Gold codes, not the memory codes specified in the Galileo ICD.

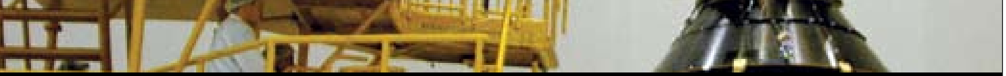
Manufacturers

In our analysis, we used the 89600 Vector Signal Analyzer from **Agilent Technologies**, Palo Alto, California, USA.

Additional Resources

[1] *Galileo Open Service Signal In Space Interface Control Document (OS SIS ICD), Draft 1*, European Space Agency/European GNSS Supervisory Authority, February 2008

[2] Gao, G. X., et alia, Galileo/Compass decoding results, http://waas.stanford.edu/index.html



[3] Gao, G. X., and J. Spilker Jr., T. Walter, P. Enge ,and A. Pratt, "Code Generation Scheme and Property Analysis of Broadcast Galileo L1 and E6 Signals," *ION Global Navigation Satellite Systems Conference 2006*, Fort Worth, Texas, September 2006.

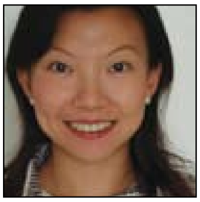
[4] Gao, G. X., and D. De Lorenzo, A. Chen, S. Lo, D. Akos, T. Walter, and P. Enge, "Galileo GIOVE-A Broadcast E5 Codes and their Application to Acquisition and Tracking," *ION National Technical Meeting 2007*, San Diego, California, January 2007

[5] http://www.esa.int/SPECIALS/GIOVE-B_launch/index.html

[6] Lo, S., and A. Chen, P. Enge, G. X. Gao, D. Akos, J-L. Issler, L. Ries, T. Grelier, and Joel Dantepal, "GNSS Album: Images and Spectral Signatures of the New GNSS Signals," *Inside GNSS,* May-June 2006

ITS 20-meter parabolic antenna, Table Mountain, Colorado

Authors



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