

# Code Generation Scheme and Property Analysis of Broadcast Galileo L1 and E6 Signals

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## BIOGRAPHY

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James J. Spilker, Jr. received the B.S., M.S., and Ph.D. degrees from Stanford University in 1955, 1956, 1958, respectively in Electrical Engineering. He was co-founder and Chairman of Stanford Telecommunications Inc. At present, he is a Professor (Consulting) in the Electrical Engineering and Aero-Astronautics Departments at Stanford University. He is also co-founder and Chairman of AOSense Corporation, and co-founder and Chairman of Rosum Corporation. Dr. Spilker was one of the principal architects for the GPS Global Positioning System, and is also noted for originating the delay lock loop. Dr. Spilker has been elected a Member of the National Academy of Engineering, a Life Fellow of the IEEE and a Fellow of the Institute of Navigation.

Todd Walter is a Senior Research Engineer in the Department of Aeronautics and Astronautics at Stanford University. Dr. Walter received his Ph.D. in 1993 from Stanford and is currently developing WAAS integrity algorithms and analyzing the availability of the WAAS signal. He is a fellow of the ION.

Per Enge is a Professor of Aeronautics and Astronautics at Stanford University, where he is the Kleiner-Perkins, Mayfield, Sequoia Capital Professor in the School of Engineering. He directs the GPS Research Laboratory, which develops satellite navigation systems based on the Global Positioning System (GPS). He has been involved in the development of WAAS and LAAS for the FAA. Per has received the Kepler, Thurlow and Burka Awards from the ION for his work. He is also a Fellow of the ION

and the Institute of Electrical and Electronics Engineers (IEEE). He received his PhD from the University of Illinois in 1983.

Dr Tony Pratt graduated with a B.Sc. and Ph.D. in Electrical and Electronic Engineering from Birmingham University, UK. He was on the teaching staff at Loughborough University, UK from 1967 to 1980. He held visiting professorships at Yale University; IIT, New Delhi and University of Copenhagen. In 1980, he joined Navstar Ltd, as Technical Director. In 1995, with Peek plc, he was involved in the formation of Tollstar Ltd, a 5 company consortium developing Electronic Road Tolling. He left Peek in 1997, starting OrbStar Consultants and joining Navstar Systems Ltd as Technical Consultant. He was, until recently, Technical Director (GPS) of ParthusCeva Ltd. He is a Special Professor at the IESSG, University of Nottingham, UK. He is a Consultant to the UK Government in the development of Galileo Satellite System and it is in this role that the present work has been conducted.

## ABSTRACT

In this paper, we decode the PRN codes of the L1 and E6 signals broadcast by the Galileo GIOVE-A test satellite. We apply the 45.7 m Stanford SRI Dish and the 1.8m dish of the Stanford GNSS Monitor System to receive the satellite signal. The received data are processed in a chain of wiping off carrier, Doppler offset, Binary Offset Carrier (BOC) and navigation bits.

Two code sequences are revealed in each frequency band, L1-B, L1-C, E6-B and E6-C. The L1 signals have the chip rate of 1.023 Mbps. The L1-B primary code has a period of 4 msec with 4092 bits. The L1-C primary code lasts 8 msec, and has 8184 bits. L1-B has navigation data modulated on its primary code, while L1-C has 25 bits of secondary code, which extends the whole L1-C code period to 200 msec. The E6 signals' chipping rate is 5.115 Mbps. The E6-B code is 5115 bits long and carries

navigation data. The E6-C code contains a 10230-bit primary code and 50-bit secondary code. It lasts 100 msec in total.

In addition to obtaining the code sequences, we also deduce the code generators. This reduces the required receiver memory size from thousands of bits to around 50 bits. As a result, the receiver cost can be dramatically decreased. All L1 and E6 broadcast codes are proven to be truncated Gold Codes. Among them, E6-C is a 14-order Gold Code, and the others are 13-order. They can be generated by Linear Feedback Shift Registers (LFSR), which are completely specified by tap weights and initial states.

We then analyze the code properties such as balancing, run-length distribution and correlation to evaluate the pseudorandomness. These properties determine the code processing gain, the robustness to noise or interference, and the lowest tolerable signal to noise ratio (SNR). We calculate the correlation performance at different frequency offsets to take account of the Doppler residual in the current satellite signal and Doppler frequency shifting in other potential satellite signals.

By investigating this code we make it possible to track the GIOVE-A signal with our own software receiver and evaluate the performance of the selected code. We intend to use this technique to further evaluate the GIOVE-B and other Galileo signals as they become available.

## INTRODUCTION

The first test satellite of the Galileo system, GIOVE-A was launched on December 28, 2006. It will secure the Galileo frequencies allocated by the International Telecommunication Union (ITU) and also test certain Galileo satellite components [1]. GIOVE-A started to broadcast Galileo signals on January 12th, 2006. The Galileo signal structure, code sequence, and the code generation have attracted much attention in both industrial and academic fields. We study the Galileo codes for engineering insight. We are considering designs for new signals from GPS and terrestrial ranging sources that could augment GPS. Thus, we are eager to gain a deep understanding of the recent efforts by our European colleagues.

This paper analyzes the broadcast Galileo L1 and E6 signals, extracts their PRN codes, and reverse engineers the Galileo code generators. The first part of the paper describes the Galileo signal collected from the Stanford SRI Dish and another high gain dish of the Stanford GNSS Monitor Station (SGMS) [2]. In the second part, each chip is estimated from the collected I/Q data, and periodic Galileo code sequences are obtained after wiping off carrier, Doppler offset, Binary Offset Carrier (BOC)

[3] and navigation bits. We find two codes in each frequency band; namely, the L1-B, L1-C, E6-B and E6-C codes. (L1-B and L1-C are sometimes known as E1-B and E1-C [4].) The shortest code is 4092 bits, which is already costly to store in receiver memory. Fortunately, we demonstrate that the codes are linear, and it is only necessary to store the code generators. The generators (code polynomials and initial states) are presented in this paper. Finally, we study the pseudorandomness and correlation properties of the Galileo codes to evaluate their processing gain and tolerance to noise and interference.

## DATA COLLECTION

The GIOVE-A signals are collected by the Stanford SRI Dish and SGMS.

The Stanford SRI Dish shown in Figure 1, is a high gain parabolic antenna located in Stanford hills. It is 45.7 m in diameter, and the total structure weighs 1400000 kg. The surface is made of soft aluminum hex pattern mesh with 1.6 cm spacing. The SRI Dish is designed for L-band signals with central frequency 1420 MHz. Its attainable gain can be as high as 52 dB with  $0.25^\circ$  beamwidth and 35% efficiency. The gain is high enough to boost the received Galileo signal above the noise floor, and thus makes it possible to further decode the Galileo code sequences.



Figure 1. Stanford SRI Dish

The other facility is SGMS, shown in Figure 2. SGMS has a 1.8 m steerable parabolic dish antenna with an L-band feed. The antenna has approximately  $7^\circ$  beamwidth, and provides about 25 dB of gain over conventional patch antennas. As the SGMS dish is located on the roof of the GPS Lab building, it is more accessible than the Stanford SRI Dish. In addition, the motor of the antenna can be driven by satellite tracking software, so that the dish can automatically point to and track a specific satellite.



Figure 2. Stanford GNSS Monitor System, 1.8m dish

The signal from the feed of the antenna goes through a low noise amplifier, a band pass filter, and is collected by an Agilent 89600 Vector Signal Analyzer (VSA) as shown in Figure 3.



Figure 3. Agilent 89600 Vector Signal Analyzer (VSA)

“Nova for Windows” is the software used to drive the antenna to track the GIOVE-A satellite. The interface of the software is shown below. It provides the view of satellite paths, azimuth, elevation information, etc.

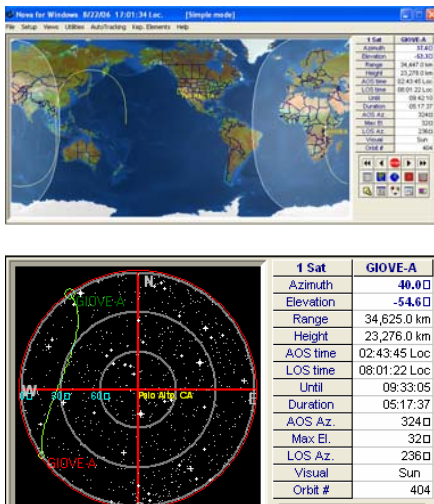


Figure 4. “Nova for Windows” software interface

We first use “Nova for Windows” to determine a good observation time for the GIOVE-A satellite pass over Palo Alto. For the SRI Dish, the azimuth and elevation information of the satellite is read from the software, and manually set for the SRI Dish control unit, so that the SRI Dish is able to point to the satellite. For SGMS, the dish is

automatically driven by the software. Figure 5 shows the received GIOVE-A signal on a Hewlett Packard spectrum analyzer.

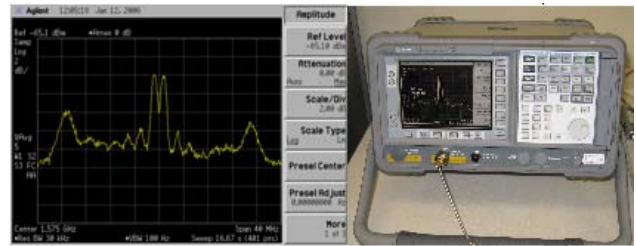


Figure 5. Received signal on a HP spectrum analyzer

The VSA data are then uploaded to Matlab. Figure 6 shows both the frequency spectrum and time-domain phase.

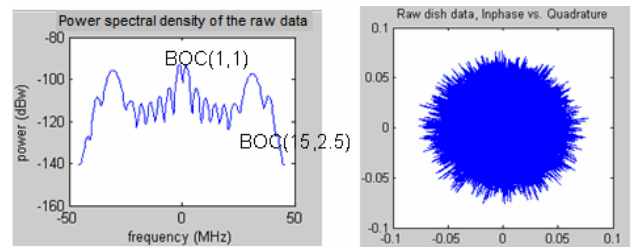


Figure 6. Received signal uploaded into Matlab

Due to the high antenna gain, the spectrum is clean and far above the noise floor. The two bumps in the middle are lobes of the BOC(1, 1) commercial service signal, while the other two lobes on the sides are due to the BOC(15, 2.5) signal of public regulated service. In the time-domain, the signal is not phase locked because of the residual Doppler offset, which will be discussed in the next section.

### CODE SEQUENCE DEMODULATION

The received satellite signal is the product of a carrier, a BOC code, a pseudo random (PRN) code and navigation data. We now describe each of these components in the following paragraphs.

The carrier frequency is 1575.42 MHz for the L1 signal and 1278.75 MHz for the E6 signal. The relative movement of the satellite with the respect to the Earth causes a Doppler frequency offset associated with the carrier frequency. The Doppler offset results in constant phase variation. Since the phase is not locked, the inphase vs. quadrature plot is smeared, as shown in the right hand plot of Figure 6.

BOC( $a$ ,  $b$ ) represents a digital carrier of frequency of  $a*1.023$  MHz. The parameter  $b$  indicates that the PRN modulation is at  $b*1.023$  MHz. BOC modulation maps the original spectrum into two symmetric spectrum lobes

on either side of the center frequency. This spectral separation reduces the interference to and from other existing signals, such as the GPS C/A signal. Since its Gabor bandwidth [5] is larger than single carrier signals, it also provides a sharper acquisition peak and thus better positioning accuracy.

Each of the L1 and the E6 signals has two channels, a data channel and a pilot channel. The data channel has low rate navigation data modulated on top of the carrier, a BOC and a PRN code. Navigation bits provide information about time stamp, parity check, bit recovery, etc. The pilot channel carries a low rate secondary code instead of navigation bits. Since receivers know the secondary code beforehand, they can integrate for long periods of time for acquisition, and thus obtain a high processing gain.

The PRN code is the spreading code for identifying each satellite. Knowing the PRN code is critical for the receivers to perform acquisition and tracking. However, the broadcast PRN codes are not released publicly.

In order to demodulate the GIOVE-A L1 PRN code, we need to wipe off the carrier and Doppler offset from the received signal, and extract BOC and navigation bits. The processing chain is shown in Figure 7.

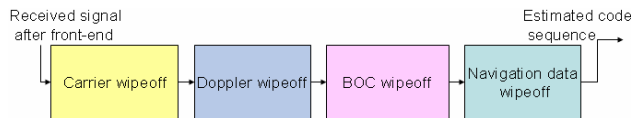
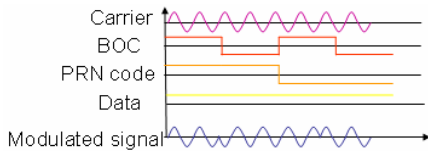


Figure 7. L1 PRN code demodulation diagram

Since we only deal with the BOC(1, 1) open service signal, we first filter out the BOC(15, 2.5) signal with a 4<sup>th</sup> order Chebyshev Type I digital filter.

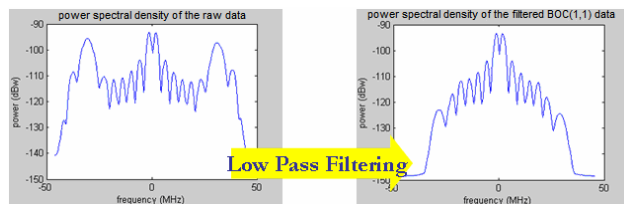


Figure 8. Filtering out BOC(15, 2.5) signal in L1 band

We then search in the whole Doppler offset domain and correct the phase plot until it appears as three vertical groups as shown in Figure 9. The Doppler offset is wiped off.

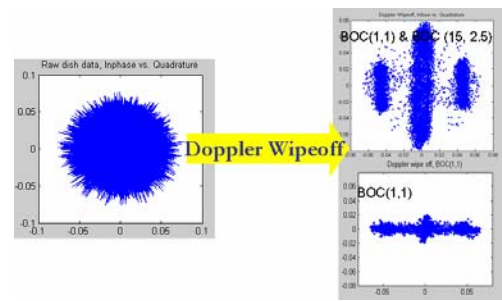
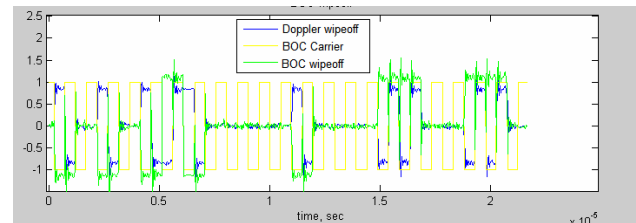


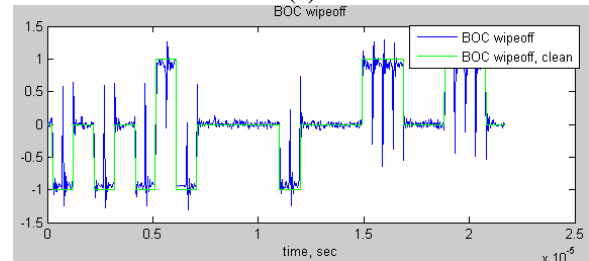
Figure 9. Doppler wipeoff of L1 signal

The inphase channel has BOC(1, 1) modulation, and the quadrature channel is BOC(15, 2.5). When the signal is projected on the inphase axis, we see three values: -2, 0, 2. This is because two  $\pm 1$  codes (L1-B and L1-C) are added together in this channel. The three levels can be seen in Figure 10(a), in which the inphase signal is plotted with respect to time.

The next step is to wipe off the BOC modulation. This is done by aligning the BOC(1, 1) carrier with the Doppler wipeoff signal, and then multiplying them together, as in Figure 10(a). The resulting BOC wipeoff signal is noisy. A threshold is applied to obtain the clean signal, as shown in Figure 10(b).



(a)



(b)

Figure 10. BOC wipeoff

With carrier, Doppler and BOC wiped off, only PRN codes and navigation bits remain. To compute the navigation bits, we first correlate the whole code sequence with a small slice of itself. The correlation plot is shown in Figure 11. The intervals between pairs of peaks are used to compute the code length. Because two codes are used, the peaks are of varying height. We see full peaks and half peaks separated by intervals of 4092 chips, and we deduce the existence of null peaks. The varying peak heights also indicate that the codes have different periods. We now assume the small slice of code used for correlation contains (B+C) in order to extract the



navigation bits; we discuss this assumption later. Then the full peaks represent (B+C), half peaks represent B only, while zeros at the multiples of 4092 chips are (B-C). Moreover, code B has 4092 bits and code C is twice as long at 8184 bits. The extracted data of L1-B and L1-C in the snippet of Figure 11 are listed in Table 1.

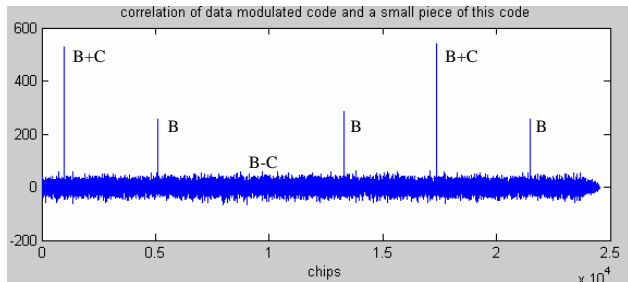


Figure 11. Extract navigation data and secondary code

	Period	Data
Code B	4092	[1, 1, 1, 1, 1, 1]
Code C	8184	[1, 0, 1]

Table 1. Extracted data of L1-B and L1-C

Once navigation data and the secondary code are known, we unmix the PRN codes for L1-B and L1-C, as illustrated in Figure 12.

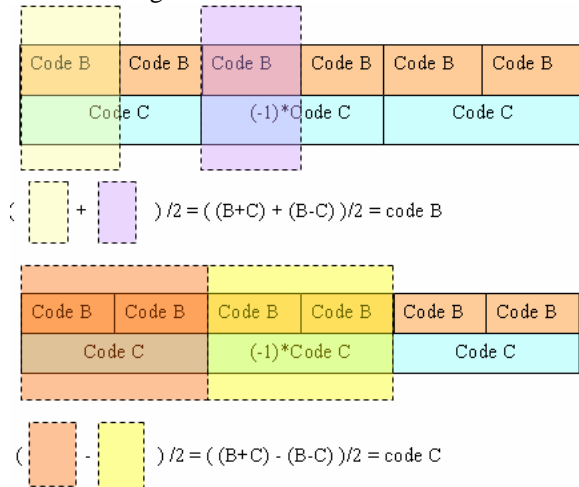
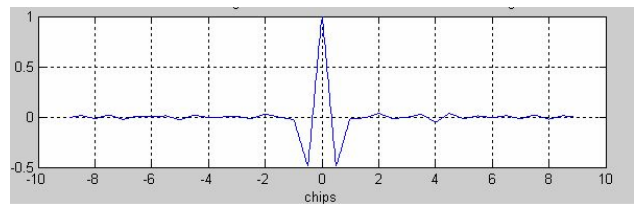
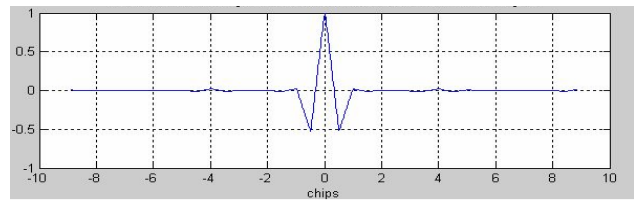


Figure 12. Navigation bits and secondary code wipeoff

To verify the demodulated sequences, the generated code B and code C are correlated with the broadcast L1 signal. The clear main peak and two negative side peaks in the correlation plots in Figure 13 match the BOC correlation function, supporting the correctness of the demodulated code sequences.



(a) Generated code B vs. broadcast L1 signal



(b) Generated code C vs. broadcast L1 signal

Figure 13. Correlation between generated code sequence and broadcast Galileo L1 signals

GIOVE-A satellite is capable of transmitting on two frequencies at the same time. In addition to the L1 signal, it was broadcasting on the E6 band at the time of data collection.

The E6 signal contains Commercial Service (CS) codes and a Public Regulated Service (PRS) code. There are two CS codes (E6-B and E6-C) added together and they are BPSK modulated. Since there is no BOC modulation, demodulating the code sequences only requires wiping off carrier, Doppler and navigation data, as shown in Figure 14.



Figure 14. E5 code sequence demodulation diagram

Similar to the L1 signal, the inphase vs. quadrature, plot of the E6 signal also appears as three columns. This confirms the existence of two codes adding together.

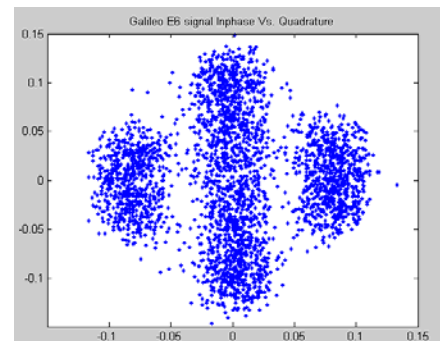


Figure 15. E6 signal after Doppler wipeoff

The E6-B code is 5115 bits long, and the E6-C code is 10230 bits. The chip rate for both codes is 5.115 MHz,

and this makes the E6-B code last 1 msec and the E6-C code 2 msec.

## DERIVING CODE GENERATORS

With the code sequences for L1-B and L1-C obtained, we can implement these PRN sequences in Galileo receivers for acquisition and tracking. However, storing thousands of bits in the receiver is expensive for flash memory. For DSP units, the memory cost is even greater. This drives the desire to minimize the code representation.

We consider linear codes as likely candidates for the Galileo code design, because they have good correlation performance, and can be generated by linear feedback shift registers (LFSR), which require only tens of bits.

The schematic of a LFSR is shown in Figure 16. Its outputs are linear combinations of the previous bits. In other words, the output sequence is completely determined by its tap weights ( $a_1 \cdots a_N$ ) and initial state ( $u_1 \cdots u_N$ ). The LFSR arithmetic is modulo 2.

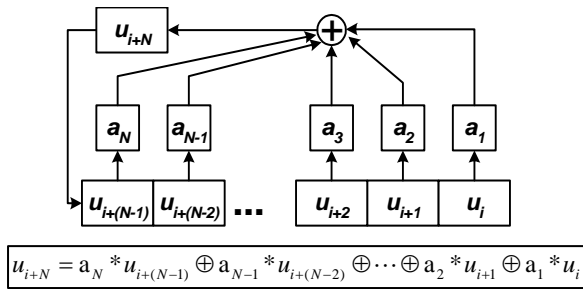


Figure 16. Linear Feedback Shift Register (LSR)

The algorithm in Figure 17 is developed for searching for a linear code representation.

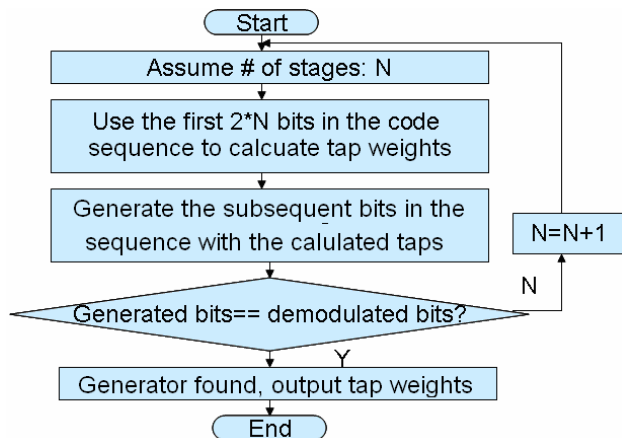


Figure 17. Searching for linear code representation

Take the L1-B code as an example. Since the code has period 4092 bits, if it was a linear code, the number of stages must exceed  $\log_2(4092)$ . We initialize  $N=12$ . We can form the following equation set with 12 equations, and 12 unknown tap weights,  $a_1 \cdots a_{12}$ .

$$\begin{cases} u_{13} = a_{12} \cdot u_{12} \oplus a_{11} \cdot u_{11} \oplus \cdots \oplus a_1 \cdot u_1 \\ u_{14} = a_{13} \cdot u_{13} \oplus a_{12} \cdot u_{12} \oplus \cdots \oplus a_2 \cdot u_2 \\ \dots \\ u_{24} = a_{23} \cdot u_{23} \oplus a_{22} \cdot u_{22} \oplus \cdots \oplus a_{12} \cdot u_{12} \end{cases}$$

The above equation set is solved modulo 2 to obtain the tap weights. The following bits in the sequence can then be generated.

If the generated bits and the demodulated bits match, the code generator is then found. If not, we increment  $N$  and repeat.

With this algorithm, both L1-B code and L1-C code are proved to be linear codes, and they can both be generated by 26-order LFSRs.

L1-B:  $X^{26} + X^{25} + X^{23} + X^{18} + X^{16} + X^{15} + X^{10} + X^8 + X^6 + X^4 + 1$

L1-C:  $X^{26} + X^{23} + X^{22} + X^{20} + X^{18} + X^{16} + X^{12} + X^{10} + X^8 + X^6 + X^3 + X + 1$

The above 26-order polynomials can be further factorized into two 13-order polynomials. This indicates that the L1-B and L1-C code sequences can be generated by module 2 summing the outputs of two 13 stage LFSRs. In fact, the two 13-order polynomials form the preferred pair of a Gold Code. [6]

Recall that in the previous section, we used a small slice of code to correlate with the whole code sequence. We made the assumption that the small slice of the code contains (B+C). This assumption may not be true. In fact, the small slice of code can be any linear combination of B code and C code. Since we assume it is (B+C), all the navigation data are possibly flipped. As a result, after wiping off navigation bits, the whole code B or code C sequence can be flipped. This ambiguity can be solved after deriving the PRN code polynomials. If the PRN code polynomial can be factorized by '1+X', then the code is flipped. Otherwise, it's not. This is because polynomial '1+X' generates a sequence of all '1's that is added modulo 2 to the code sequence, flipping all code bits.

L1-B and L1-C are concluded to be 13-stage Gold codes. The polynomials and initial states are listed below.

L1-B code (4092 bits, 4msec, 13-stage Gold code)	
Polynomial_1	$X^{13} + X^{10} + X^9 + X^7 + X^5 + X^4 + 1$
Initial State_1	111111111111
Polynomial_2	$X^{13} + X^{12} + X^8 + X^7 + X^6 + X^5 + 1$
Initial State_2	110111000011

L1-C code (8184 bits, 8msec, 13-stage Gold code)	
Polynomial_1	$X^{13} + X^4 + X^3 + X + 1$
Initial State_1	111111111111
Polynomial_2	$X^{13} + X^{10} + X^9 + X^7 + X^5 + X^4 + 1$
Initial State_2	110011000011

Table 2. Galileo L1 code generators

Code B is a dataless pilot code, and has a secondary code modulated on the top of the PRN code. The secondary code is also found. It has 25 bits as follows:

[1 0 1 1 0 1 1 0 0 1 0 0 0 1 1 1 0 0 0 0 0 0 0 1 0]

The E6-B and E6-C code generators are also obtained by the algorithm in Figure 17. They are shown to be Gold Codes as well. The polynomials and initial states are shown in Table 3.

E6-B code (5115 bits, 1msec, 13-stage Gold code)	
Polynomial_1	$X^{13} + X^{10} + X^8 + X^5 + 1$
Initial State_1	111111111111
Polynomial_2	$X^{13} + X^{12} + X^{11} + X + 1$
Initial State_2	010101110000
E6-C code (5115 bits, 1msec, 14-stage Gold code)	
Polynomial_1	$X^{14} + X^{11} + X^6 + X + 1$
Initial State_1	111111111111
Polynomial_2	$X^{14} + X^8 + X^7 + X^4 + X^3 + X^2 + 1$
Initial State_2	01101000011101

Table 3. Galileo E6 code generators

The E6-C code has a secondary code of 50 bits as follows:

[0 1 0 1 1 1 1 1 1 0 0 1 0 1 1 1 0 1 0 1 1 0 0 0 0 1 0 0 1 0 1 0 0 0 0 1 1 1 0 1 1 0 0 1 1 0 0 0 1 0]

## CODE PROPERTY ANALYSIS

With the codes and generators available, Galileo receivers that are capable of positioning can be designed. Beyond the positioning capability, we care about the accuracy, integrity and robustness to interference. These concerns are affected by the Galileo PRN codes' balancing and run properties and their auto- and cross-correlations at different frequency offsets.

The balancing and double-balancing properties of a code characterize its first and second order randomness, respectively. A code is balanced if it contains the same number of '1's as '-1's. An unbalanced code creates a power-inefficient direct circuit (DC) component in both the carrier-removed satellite signal and the local replica. The DC is measured by the offset, the number of '1's minus the number of '-1's.

A code is double-balanced if, among the bits following '1's, there are an equal number of '1's and '-1's, and among the bits following '-1's, there are an equal number of '1's and '-1's. In this case, the offset has format 'a/b', where 'a' and 'b' are the offsets among bits following '1's and '-1's, respectively.

The balancing and double-balancing properties of L1-B, L1-C, E5-B and E5-C codes are listed in Table 4. None of the PRN codes are balanced or double balanced. The lack of balance is a consequence of the linearity and truncation of the codes.

Galileo PRN codes	L1-B	L1-C	E6-B	E6-C
Balanced?	No	No	No	No
Offset	-22	-4	-21	12
Double-balanced?	No	No	No	No
Offset	-43/21	60/-64	1/-22	127/115

Table 4. Balancing and double-balancing performance of Galileo broadcast codes

Another characteristic of randomness is a code's run-length distribution. A run is a string of consecutive '1's or '-1's and its run-length is the length of the string. For example, the sequence [1 1 1 1 -1 -1 1 -1] has one run of length 4, one run of length 2 and two runs of length 1. For a truly random sequence, 1/4 of the bits should have run-length of 1, 1/4 of the bits should have run-length of 2, and  $n/2^{n+1}$  of the code should have run-length of  $n$ .

The run-length distribution of the Galileo codes is listed in Table 5 below. The run performance of the broadcast codes is close to that of a pure random sequence.

Run-length	L1-B	L1-C	E6-B	E6-C	Random
Average run-length	1.97	2.03	2.01	1.95	2
run					
1	26.52%	24.24%	24.36%	26.53%	25.00%
2	24.29%	25.05%	26.20%	25.10%	25.00%
3	18.26%	17.85%	18.42%	17.77%	18.75%
4	11.05%	12.51%	12.43%	12.94%	12.50%
5	8.55%	9.53%	7.23%	7.18%	7.81%
6	4.40%	3.67%	4.81%	4.75%	4.69%
7	2.91%	3.16%	3.15%	2.81%	2.73%
8	1.96%	1.66%	1.56%	1.49%	1.56%
9	.66%	.99%	.35%	.53%	.88%
10	.24%	.61%	.78%	.20%	.49%

Table 5. Run-length property of Galileo broadcast codes

The auto- and cross-correlation functions of the code determine the system's robustness to noise and interference. The lower the side lobes are, the lower signal to noise ratio (SNR) the system can tolerate. Table 6 shows the maximum correlation side lobes. L1-C and

E6-C codes have lower maximum side lobes than their B counterparts, because they are twice as long, and thus have longer integration time. When computing cross-correlation, two periods of B codes are used to accommodate the C code length.

Code	Max auto-correlation side lobes
L1-B	-25.39 dB
L1-C	-29.19 dB
E6-B	-26.32 dB
E6-C	-28.11 dB
Code	Max cross-correlation lobes
L1-B with L1-C	-27.94 dB
E6-B with E6-C	-29.27 dB

Table 6. Max side lobes of auto- and cross-correlation

Doppler residual always exists in satellite signals. This causes frequency offset between the incoming signal and the local replica. In addition, when acquiring a certain PRN code, the PRN codes from other satellites behave as interference. Those PRN codes are shifted in frequency due to the relative movement of the satellites. For these two reasons, we need to investigate the correlation performance not only at zero frequency, but also at all frequencies ranging from -10 kHz to 10 kHz. The correlation performance of L1 codes and E6 codes are shown in Figure 17 and Figure 18 respectively. In general, the C codes have 3 dB better performance than the B codes, since the C codes are twice as long as the B codes.

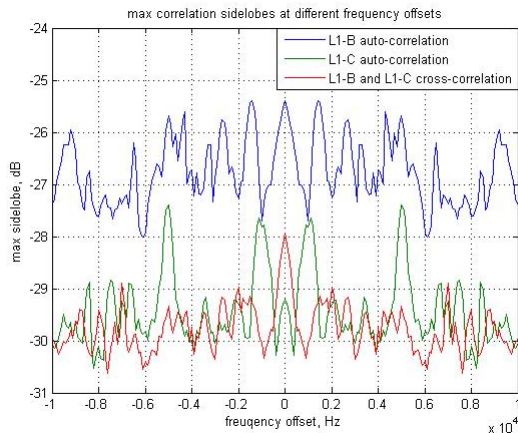


Figure 17. max correlation side lobes of L1 codes

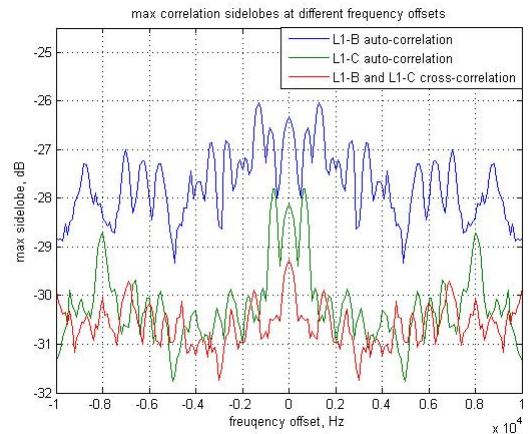


Figure 18. max correlation side lobes of E6 codes

## CONCLUSION

This paper decodes the Galileo L1 and E6 PRN sequences that are broadcast by the GIOVE-A satellite. Not only are the code bits obtained, but also the code generators are derived. All codes, L1-B, L1-C, E5-B and E5-C, are proven to be truncated Gold Codes, and can be generated by linear feedback shift registers. The B codes are further modulated with navigation data, while the C codes carry secondary codes instead. A summary of the codes is listed below.

GIOVE-A broadcast codes		Type	Length	Period	Generated by	With data?	
L1 BOC (1,1) codes	L1-B	Truncated Gold code	4092	4 msec	Two 13-stage LFSRs	Yes	
	L1-C	Primary	Truncated Gold code	8184	8 msec	Two 13-stage LFSRs	No
		Secondary		25	200 msec (With Primary)		
E6 BPSK codes	E6-B	Truncated Gold code	5115	1 msec	Two 13-stage LFSRs	Yes	
	E6-C	Primary	Truncated Gold code	10230	2 msec	Two 14-stage LFSRs	No
		Secondary		50	100 msec (With Primary)		

Table 7. Summary of Galileo broadcast L1 and E6 codes

The code properties are analyzed with respect to balancing, run-length distribution and correlation. The broadcast codes are not balanced, which indicates a margin for improvement. The run properties are close to random codes. Correlation performance is evaluated at different frequency offsets. On average, the C codes are



better than the B codes by 3 dB because they are twice as long.

## ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of the Federal Aviation Administration under Cooperative Agreement 95-G-005. This paper contains the personal comments and beliefs of the authors, and does not necessarily represent the opinion of any other person or organization.

We would also like to thank Sherman Lo, Dennis Akos, Alan Chen, David Lorenzo, and Gary Lennen for their help in data collection and signal processing.

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