# Initial Observations and Analysis of Compass MEO Satellite Signals

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**Much remains to be learned about Compass, the GNSS being developed by China. Filings with the International Telecommunications Union indicate that Compass will broadcast signals in four frequency bands, some of which overlap other GNSS signals. The first three Beidou-Compass satellites were placed in geostationary orbits. Recently, a satellite was placed on an inclined geosynchronous orbit (IGSO) orbit. On April 13, however, the first Compass middle earth orbit (MEO) satellite was launched and soon began broadcasting signals. Engineers at CNES, the French Space Agency, are monitoring Compass broadcasts and provide an initial analysis of the system's signal design.**

On April 13, the People's Republic of China launched the first middle earth orbiting (MEO) satellite in its Compass GNSS system, 21,550 kilometers (or about 13,200) miles above the Earth. The spacecraft began transmitting signals on three frequencies within a few days, much more quickly than operational satellites in other GNSSes.

Engineers at the Centre National d'Études Spatiales (CNES, the French Space Agency) have been monitoring the newest Compass (Beidou) satellite. On April 23, they made a series of observations to characterize the signals, all of which will overlay GPS and Galileo signals' spectra. This article presents the results of those observations and a subsequent demodulation analysis of the Compass pseudorandom noise (PRN) codes.

## Compass Signals

According to Chinese filings with the International Telecommunications Union (ITU), Compass satellites will broadcast signals in four frequency bands: 1561 MHz (E2), 1589 MHz (E1), 1268 MHz (E6), and 1207 MHz (E5b). Expected Compass modulations are described in Table 1.

Figure 1 shows the frequency plan for GPS, Galileo, and Compass in three separate panels. The top panel shows the GPS signals as they will appear after launch of GPS III satellites with the third civil signal at L5; the middle panel shows the Galileo frequency plan; and the bottom, the three Compass signals monitored by CNES.

In the top two panels, the Galileo and GPS signals are shown, respectively, in gray. In the bottom panel, the GPS and Galileo signals are shown as a gray background for the Compass spectra

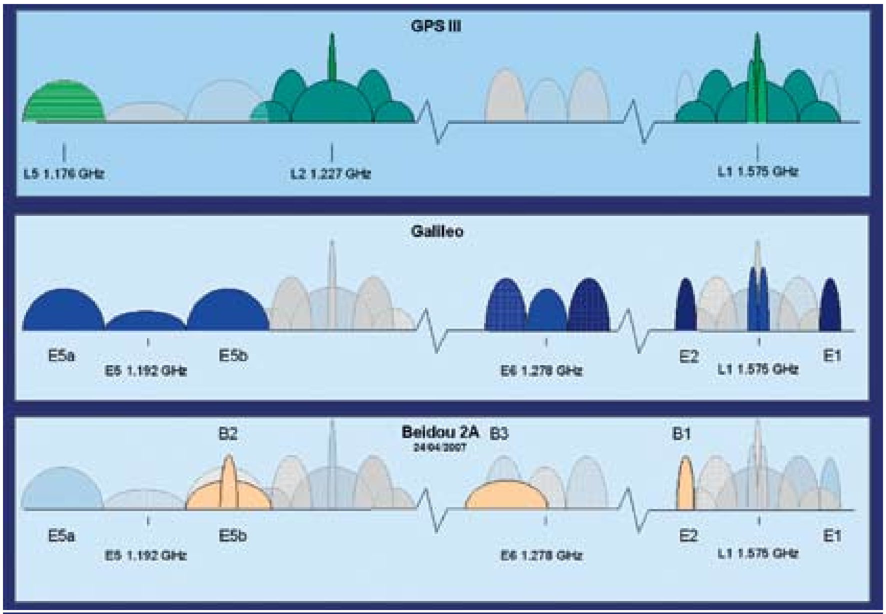



FIGURE 1 GPS, Galileo, and Compass/Beidou frequency plan

shown in beige. Compass spectra are those measured at CNES on April 23. It does not include the Compass E1 signal, which could not be observed.

| Frequency (MHz) | Modulation |
|---|---|
| 1561.10 | QPSK(2) |
| 1589.74 | QPSK(2) |
| 1268.52 | QPSK(10) |
| 1207.14 | BPSK(10) + BPSK(2) |

TABLE 1. Compass frequencies and modulations

## Compass Spectra

Compass signals were recorded on April 23 using the CNES tracking and recording system, which was developed in collaboration with the European Space Agency (ESA). This system has already been successfully used to collect signals broadcast by the Galileo in-orbit validation experiment (GIOVE-A) satellite as well as modernized GPS satellites.

This system is composed of a tracking station, a broadband digitizer, and a high-capacity recorder (or data logger). It enables the observation of GNSS satellites in the 1.1-1.7 GHz band and the post-processing of recorded signals. The tracking station includes a 2.4-meter steerable parabolic antenna dish and can automatically monitor signals from a specified satellite.

Figures 2, 3, and 4 show Compass signals' spectra in E2/L1 (Galileo/GPS), E6 (Galileo), and E5b (Galileo) bands. No signal was observed at frequency E1. Measured spectra result from 1,000-time averaging. On the measured spectra, we have superimposed the theoretical spectra of the expected Compass signal modulations. We also superimposed the theoretical spectrum resulting from the sum of noise and signal. This latter plot is really helpful for comparing a real spectrum with theory.

Note that the measured spectra are very close to theory. The slight mismatch is probably due to receiving chain equalization errors.

Note also that the power spectral density (PSD) decibel values in the vertical axis are relative. Absolute power levels have not been calibrated; so, only the spectral shapes are significant.

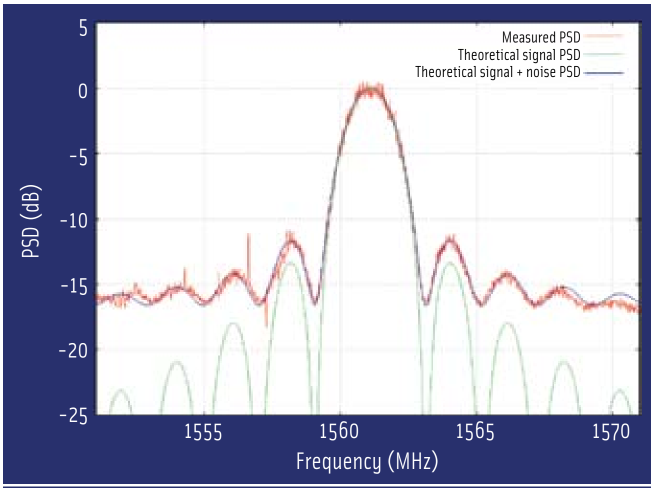



FIGURE 2 Compass spectrum in E2

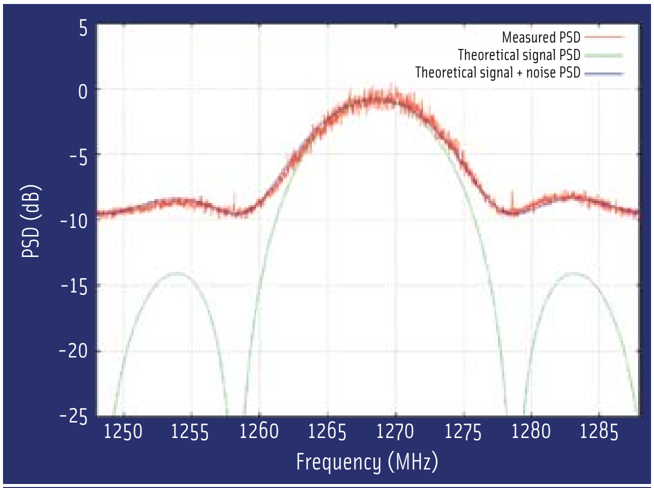



FIGURE 3 Compass spectrum in E6

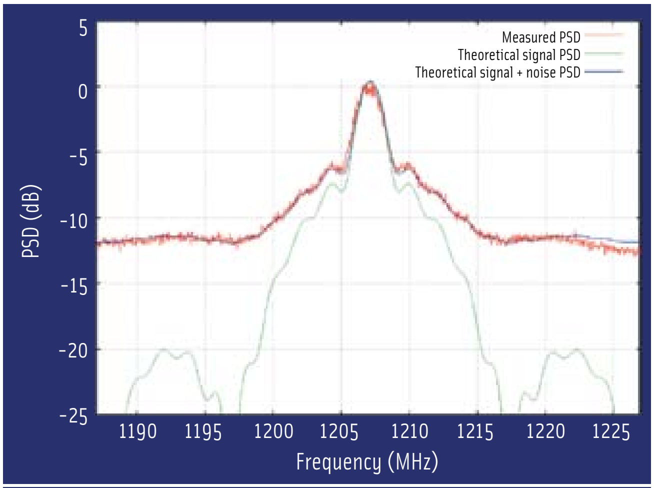



FIGURE 4 Compass spectrum in E5b

## Compass PRN Code Demodulation

CNES analyzed the Compass transmissions further in an effort to determine the modulation, code period, and secondary code of the new signals.

**Baseband signal modulation.** The first processing step consists of removing the Doppler frequency offset and the residual carrier phase so as to obtain baseband signals. Compass signals are acquired using codeless acquisition techniques. After removal of the Doppler and carrier phase residual, the signal is decomposed in its two components: in-phase (I) and quadrature (Q).

We then performed accumulations over chip duration in order to reduce noise and estimate chip values. Chip duration is the inverse of the chip rate and depends on the processed signal (either 2.046 or 10.23 MHz). We then plotted I-Q diagrams to determine signal modulation.

The three Compass signals appear to have balanced quadrature phase-shift keying (QPSK) structure: QPSK(2) in E2, QPSK(10) in E6, and binary phase-shift keying (BPSK(10)+BPSK(2)) in E5b. Figure 5 shows an I-Q diagram for E2. The 4 spots of a QPSK constellation clearly appear. The same kind of diagram is obtained for E6 and E5b.

**Code period determination.** The second step consists in determining the period of PRN codes. Thanks to the high gain of

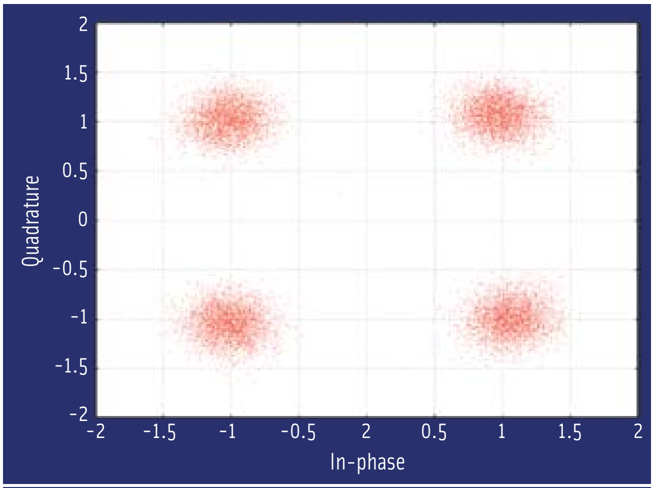



FIGURE 5 I-Q diagram of E2 signal

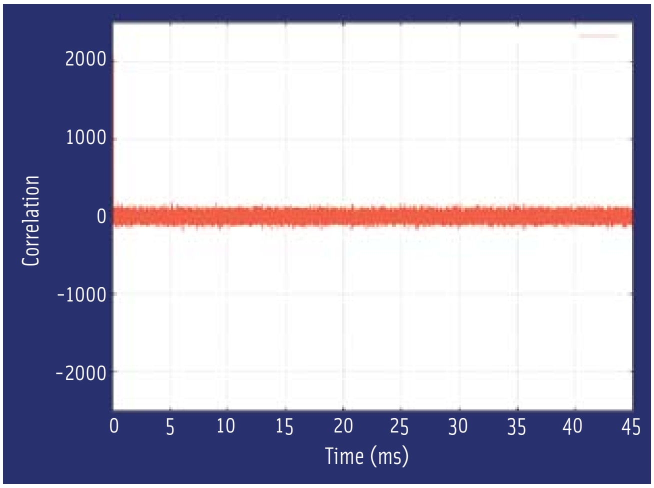



FIGURE 6 Correlation of the E2-I bit sequence with a slice of itself

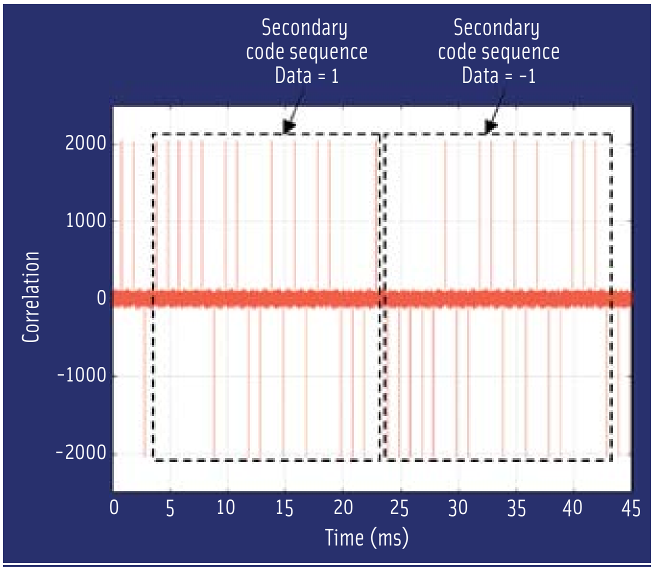



FIGURE 7 Correlation of the E2-Q bit sequence with a slice of itself

the CNES antenna dish, bits can be estimated easily. The bit sequence is correlated with a small slice of itself (1,000 bits).

The correlation plots for E2 in-phase and quadrature components are represented on **Figure 6** and **Figure 7**. The time separation between peaks is the code period. For E2-Q, correlation peaks appear every millisecond (ms); therefore, PRN code period is 1 ms (2,046 chips).

No second correlation peak appears on the E2-I plot. From this we can deduce that the code period is greater than the bit sequence duration. The longest sequence that was processed is 400 ms for E2 and 160 ms for E6 and E5b.

**Secondary code.** We notice that quadrature correlation peaks are either positive or negative and that the binary sequence repeats itself every 20 ms. This means that a 20-ms periodic secondary code is present. The 20-chip sequence is sometimes inverted, which suggests that a 50-Hz data stream modulates the chips.

The same process was repeated for E6 and E5b signals and leads to estimations of PRN codes. **Table 2** summarizes results of this analysis.

Note that E2 and E5b primary codes are identical. The determination of the Compass primary code generation architecture is currently under way at CNES. Note also that the secondary code is identical for the three frequencies. The code is the following (the sign of the sequence being ambiguous the initial chip was set positive): 1 1 1 1 1 -1 1 1 -1 -1 1 -1 1 -1 1 1 -1 -1 -1 1

## Conclusion

Collection of signals from the recently launched, first Compass MEO satellite has enabled us to determine Compass signal structure in E2, E6, and E5b bands. All three frequencies are QPSK modulated. The in-quadrature codes were characterized: primary codes are 1-ms long and are modulated by a 20-ms secondary code.

The E1 signal structure could not be determined as this signal has not yet been observed at CNES. However, the CNES dish is frequently pointed at Compass satellites so as to detect any broadcast. Observing both E2 and E1 signals simultaneously would be very instructive as it would allow us to determine if signals are generated independently or if a specific modulation is used to generate both signals.

## Manufacturers

The digitizing equipment used by CNES was developed by **SMP (Systèmes Midi-Pyrénées)** of Toulouse, France. It allows the sampling of two to four GNSS bands simultaneously. The datalogger used to store the samples was developed by **M3Systems,** also of Toulouse. It offers a recording rate of 250 MB/s and a total capacity of several hundred gigabytes.

## Authors

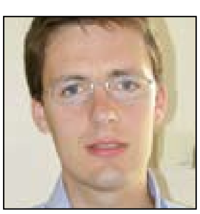
**Thomas Grelier** has been a navigation engineer in the Transmission Techniques and Signal Processing Department at CNES since December 2004. He graduated from the French engineering school Supelec and received an M.S. in electrical and computer engineering from Georgia Tech. Galileo signal processing is one of two main areas of research. He

| Frequency | Modulation | Component | | Rate | Length | Period |
|---|---|---|---|---|---|---|
| E2 | QPSK | In-phase | Code | 2.046 Mcps | - | >400 ms |
| | | Quadrature | Primary code | 2.046 Mcps | 2046 | 1 ms |
| | | | Secondary code | 1 kHz | 20 | 20 ms |
| | | | Data | 50 Hz | - | - |
| E6 | QPSK | In-phase | Code | 10.23 Mcps | - | >160 ms |
| | | Quadrature | Primary code | 10.23 Mcps | 10230 | 1 ms |
| | | | Secondary code | 1 kHz | 20 | 20 ms |
| | | | Data | 50 Hz | - | - |
| E5b | QPSK | In-phase | Code | 10.23 Mcps | - | >160 ms |
| | | Quadrature | Primary code | 2.046 Mcps | 2046 | 1 ms |
| | | | Secondary code | 1 kHz | 20 | 20 ms |
| | | | Data | 50 Hz | - | - |

TABLE 2. Compass signal characteristics

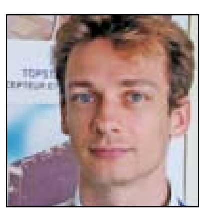
analyzed GIOVE-A, GPS IIR-M, Beidou-1 S-band, and Modernized GLONASS signals. Grelier has also developed various Galileo E5 ALTBOC tracking techniques and analyzed their theoretical performances. His other main activity concerns the signal processing development and testing of RF satellite formation flying hardware, using pulsed GPS C/A codes transmitted in S-band.

**Joel Dantepal** obtained a European Diploma in wireless telecommunication from the University of Limoges, France. He is currently laboratory manager at CNES in the Transmission Techniques and Signal Processing Department and previously in the Radionavigation Department since 1996. He is well experienced in the field of GNSS generators, receivers, L1, L2, L5, E6, and E4 simulators, pseudolites and bitgrabbers, among other RF hardware. He recently performed intensive tests of the CNES GNSS "Juzzle" software receiver, developed by Géraldine Artaud.



**Antoine DeLatour** has been a navigation engineer in the CNES Transmission Techniques and Signal Processing Department since 2003. He is involved in the Galileo program in which he supports the European Space Agency, the European Commission, and the European GNSS Supervisory Authority. DeLatour is involved in the design of the Galileo signals, in the use of GNSS for space applications, in the GPS/Galileo radio frequency compatibility assessment and in the development of a GNSS RF signal simulator. In particular, he studied in depth the CBOC GALILEO signal definition and the PRS signal as well. DeLatour proposed new signal tracking techniques for generic receivers and spaceborne receivers. He was graduated from the Ecole Supérieure d'Electricité ( Sup'Elec) in Paris and obtained a master's degree from the University of Stuttgart.

**Alain Ghion** has worked in the CNES Transmission Techniques and Signal Processing Department since September 2005 as associate manager of the transmission and radionavigation laboratory. He is in charge of most of the ISO-9001 and security management aspects of this laboratory. Ghion is also responsible for some experimental activities involving the parabolic antenna system that tracks and measures GNSS spectra (such as GIOVE-A, GLONASS-M, GPS IIR-M, and Beidou-2/Compass).



**Lionel Ries** has been a navigation engineer in the CNES Transmission Techniques and Signal Processing Department since June 2000. He is responsible for research activities on GNSS2 receivers and signals, including BOC, ALTBOC, and MBOC modulations. Ries is one of the CBOC inventors and participated in developing innovations in the GALILEO CBOC multiplexing technique as well. He is involved in the Galileo program in which he supports the European Space Agency, the European Commission, and the European GNSS Supervisory Authority. He is involved in the predevelopment of several hardware GNSS receivers, for ground or spaceborne applications. Ries also supervised the development of the CNES GNSS "Juzzle" software receiver. He graduated from the Ecole Polytechnique de Bruxelles, at Brussels Free University (Belgium) and received an M.S. degree from the Ecole Nationale Supérieure de l'Aéronautique et de l'Espace (SUPAERO) in Toulouse (France). IG