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Permanent Link to Innovation: Where Is GIOVE-A Exactly?

2021/03/12

Using Microwaves and Laser Ranging for Precise Orbit Determination By Erik Schönemann, Tim A. Springer, Michiel Otten, and Matthias Becker Though Galileo's GIOVE-A is a test satellite not necessarily ready for scientific use, orbit analyses with a reduced accuracy can help to identify weaknesses and suggest improvements. This month, the authors share work being carried out to precisely determine the orbit of GIOVE-A using SLR and microwave observations. This preliminary investigation will benefit the procedures to be implemented for the future Galileo constellation.

INNOVATION INSIGHTS by Richard Langley WE USE THEM FOR LISTENING TO MUSIC, for routine surgeries, for making a point in a presentation, and even for hanging pictures straight. Of course, I'm talking about lasers. Invented in 1960, the laser (an acronym for light amplification by the stimulated emission of radiation) has become ubiquitous in modern society. Every CD and DVD player has one. Many printers use them. But lasers are also used in a wide range of industrial and scientific applications including determining the orbits of satellites through satellite laser ranging (SLR). In the SLR technique, pulses of laser light from a ground reference station are directed at satellites equipped with an array of corner-cube retroreflectors, which direct the pulses back towards a collocated receiving telescope. By accurately measuring the two-way travel times of the pulses and knowing the location of the station and other operating parameters, the positions of the satellites can be determined. A network of SLR reference stations around the globe is used to monitor the orbits of satellites over time and their variations have been used by scientists to improve our knowledge of the Earth's gravity field; to study the long term dynamics of the solid Earth, oceans, and atmosphere; and even to verify predictions of the General Theory of Relativity. The first SLR measurements were obtained from the Beacon Explorer-B satellite, which was launched in October 1964. Since then, dozens of satellites equipped with corner-cube retroreflectors have been launched including a number of radio-navigation satellites. Every GLONASS

satellite is equipped with retroreflectors and two GPS satellites have been equipped—SVN35/PRN05 and SVN36/PRN06. The COMPASS-M1 satellite in medium Earth orbit carries retroreflectors, as do both GIOVE-A and -B, the Galileo test satellites. Precise orbit determination of radio-navigation satellites using SLR has the advantage of being unaffected by any onboard satellite electronics and associated signal biases. Radiometric observations of a satellite's microwave signals, on the other hand, are influenced by the satellite's clock, for example, and its effect must be estimated to obtain precise (and accurate) satellite orbits for navigation and positioning. Therefore, a comparison of SLR- and microwave-derived orbits can be very useful for studying the performance of the data measurement and orbit-determination processes of both techniques. In this month's column, we take a look at some work being carried out to precisely determine the orbit of the GIOVE-A test satellite using SLR and microwave observations. This preliminary investigation will benefit the procedures to be implemented for the future Galileo constellation.

"Innovation" is a regular column that features discussions about recent advances in GPS technology and its applications as well as the fundamentals of GPS positioning. The column is coordinated by Richard Langley of the Department of Geodesy and Geomatics Engineering at the University of New Brunswick, who welcomes your comments and topic ideas. To contact him, see the "Contributing Editors" section on page 6. The navigation office of the European Space Operations Centre (ESOC) is engaged in various activities using observations of the Galileo test satellite, GIOVE-A (Galileo In-Orbit Validation Element-A), recorded at the Galileo Experimental Sensor Stations (GESS). The work includes the assessment of the quality and performance of GIOVE satellite observables and the testing and improvement of orbit-determination software. These activities support the long-term goal of advancing the scientific applications of the future Galileo constellation. Since the launch of GIOVE-A on December 28, 2005, various tests have been carried out to analyze the quality of the new code (pseudorange) and carrier-phase observables derived from tracking the satellite's microwave signals. All of these tests demonstrate the advantages of the new signal structure compared to that of legacy GPS signals. In general, the reduction of the noise by factor of 4-5 as well as a reduction of the code multipath by approximately a factor of 1.2 (GPS C1C versus GIOVE-A C1B/C1C) could be seen. As the comparison of observations is done indirectly (GPS and GIOVE-A have different orbits) and the databases used for most analyses published up to now is sparse, a deeper analysis of the signal quality parameters seems appropriate, especially as data quality has a direct impact on the precision of orbit determination. Our analyses, presented in the first half of this article, are based on a broad base of data from most of the stations in the GESS network. Because of the difficulty in accessing the phase multipath directly, we first evaluated the signal strength and the code multipath, which gave the first hint of the multipath behavior. In order to compare GPS and GIOVE-A data directly, only data received from the same elevation angles and azimuths were used. Subsequently, we present an analysis of the phase residuals derived by precise point positioning. The second part of this article focuses on the precise orbit determination or POD of the GIOVE-A spacecraft. The Navigation Package for Earth Observation Satellites (NAPEOS) software used at the ESOC Navigation Support Office allows microwave (radiometric) and satellite laser ranging (SLR) observations to be used either separately or together. The two methods are

different due to different tracking networks and the different sensitivity of the observables to atmospheric effects and in their noise levels. We will present the orbit results focusing on internal orbit consistency checks and SLR validation of the microwave-based orbits. Data Analysis We first describe the procedures used for analyzing the microwave data followed by those used for the SLR data. Microwave Analysis. For the GIOVE-A signal analysis and precise orbit determination we used the RINEX data from all of the GESS stations available from the GIOVE archiving facility (see TABLE 1). All stations are equipped with GPS/Galileo antennas, built by Space Engineering S.p.A. and Galileo Experimental Test Receivers (GETRs), built by Septentrio. The data, containing tracking data of all GPS satellites and the GIOVE-A satellite, is given in the RINEX 3.00 data format with a sampling interval of 1 second. To save on storage space for the long-term analyses, such as orbit determination, the RINEX data is decimated to 30-second samples and Hatanaka-compressed, using a test version of the Hatanaka software for the RINEX 3.00 format. The signal analyses shown here were carried out using GNU Octave, an open-source program for performing numerical computations similar to Matlab, and different scripts developed by the Institut für Physikalische Geodäsie at the Technische Universität Darmstadt. These analyses cover a selection of the designated Galileo signals recorded by the GESS within the time span from December 16 to 27, 2006. Within this time period, the current GPS signals, as well as the GIOVE-A signals E1 and E5, shown in TABLE 2, were recorded. The table also shows the signal components as well as the RINEX observation-type identifiers, which we use in this article. The stations used for the analyses show a quite similar level of performance in general. There are stations with different behaviors for single signals, as for example GIEN with a stronger code multipath behavior on C1B and C1A, but no station with a considerably different performance level could be identified. The averaging over the data from all sites reduces the station-dependent effects such as multipath and the atmosphere to a large extent, and gives a good indication of the mean signal performance. The analyzed phase residuals were taken from the processing carried out for the second part of this article. Hence, they include observation data over an extended period of 149 days and were limited to the GIOVE-A C1C/L1C and C7Q/L7Q signals. This extended data period is from December 12, 2006 (day of year 346), until May 26, 2007 (day of year 146). During this interval, there is a period where no GIOVE-A data was available due to maintenance of the spacecraft. This gap occurred from February 12 to 28, 2007. So in total we have analyzed 149 days of microwave data. Because there are some differences between the results before and after this gap in February, many of the statistics are given for the first and second part separately. The first part covers December 12, 2006, until February 11, 2007; the second part covers March 1, 2007, until May 26, 2007. We performed the precise orbit determination using the NAPEOS software, a general-purpose software package for orbit determination, prediction, and control, supporting all phases of an Earth-observation mission in terms of mission preparation and operations. For the GIOVE-A analysis, the three main NAPEOS programs we used are GnssObs, Bahn, and Multiarc. GnssObs reads, cleans, and decimates the RINEX data and converts the data into the NAPEOS internal tracking-data format. The NAPEOS tracking-data format contains the ionosphere-free linear combination, for both code and phase, of the RINEX observations. For GPS, the ionosphere-free linear combination is based on

the combination of C1P and C2P code and L1P and L2P phase measurements. GIOVE-A offers several different observables allowing for many different ionosphere-free observations. For most of the work presented in this article, we have used the ionosphere-free linear combination of the C1C and C7Q and L1C and L7Q observations for code and phase respectively. The next module, Bahn, performs the parameter estimation. In this step, we use the ionosphere-free code and phase observations at a sampling interval of 5 minutes, and we have applied an elevation angle cut-off of 5 degrees. The data is processed in batches of 24 hours, thus resulting in 1-day-arc solutions. The estimated parameters in these daily solutions are the GIOVE-A state vector (position and velocity), five dynamical orbit parameters from the extended Center for Orbit Determination in Europe (CODE) orbit model, a GIOVE-A clock offset for each epoch, all receiver clock offsets for each epoch, one GPS-GIOVE-A "intersystem bias" parameter per day for each station except for a selected reference station, and the carrier-phase ambiguities (integers not resolved). The station coordinates are estimated but tightly constrained (1 millimeter) to their a priori value. We obtained the a priori station coordinates by combining the full set of daily solutions. Despite the fact that the 13 GESS stations provide very good global coverage, it is expected that 24-hour solutions will not give the most precise GIOVE-A orbit estimates. To generate longer arc solutions, we have used the Multiarc program. This is a tool that has recently been added to the NAPEOS software package. It allows for a rigorous combination of normal equations, also referred to as normal equation stacking, which are generated by Bahn. During the normal equation combination, the satellite orbit parameters may also be rigorously combined, thus effectively leading to multi-day orbital arcs. For the work presented in this article, we have used Multiarc to generate solutions with arc lengths of 1, 2, 3, 4, and 5 days. We also used Multiarc to compute accurate a priori station coordinates by stacking all available 1-day normal equations. Satellite Laser Ranging Besides the 13 GESS stations, GIOVE-A is also tracked by more than 17 different SLR stations around the world. For most periods of the mission, the tracking has been consistent enough to allow for GIOVE-A POD using only the SLR data. As the SLR data is completely independent of the microwave data, the resulting orbit solutions will be to a large extent independent as well and thus can be used to give an indication of the achieved precision of the different microwave solutions. The orbit determination strategy used for the SLR solutions is very similar to the one used for the microwave orbits with the main difference being the increased arc-length of 7 days. The same satellite parameters are estimated as with the microwave solutions: the GIOVE-A state vector and five dynamical orbit parameters from the extended CODE orbit model. No further parameters need to be estimated and all corrections applied to the SLR data are according to the International Earth Rotation and Reference Systems Service 2003 standards and, for station coordinates, we used those from the rescaled International Terrestrial Reference Frame 2005 solution. As the noise level of the SLR data is very low, the measurements can also be directly used to give an indication of the precision of the radial position components of the different microwave solutions by computing the SLR residuals without using them in the estimation process itself. Combined Microwave and SLR Analysis. In this step, the SLR data was added to the microwave data in the 24-hour solutions. For the data weighting, we used 100 millimeters for SLR and 1000 millimeters and 10 millimeters for GIOVE-A and GPS code and phase

observables respectively. The only change in the analysis strategy in this case was that we now processed the SLR data in 24-hour solutions and not in 7-day batches. All the processing options remained as described in the two previous sections. The resulting 1-day solutions, or rather the associated normal equations, were used in Multiarc to generate combined solutions of different arc lengths.

Microwave Data Quality

We now take a detailed look at the quality of the microwave data in terms of signal-to-noise ratio (SNR), code-tracking noise and multipath, carrier-phase-tracking noise, and carrier-phase residuals.

Signal-to-Noise Ratio

The SNR (or equivalently carrier-to-noise-density ratio, C/N0) is strongly dependent on the satellite transmitter, the signal path through the atmosphere, and the receiver configuration (ground station, antenna, receiver, cable, etc.). Hence the SNR cannot be seen as an absolute value. The SNR is specific to the position, the equipment, and the time. Furthermore, the determination of the SNR values depends on the receiver and the firmware used. As a result, SNR values from different receivers cannot be readily compared. Nevertheless, using only one type of receiver, assuming similar effects on all the different signals at the same epoch, and taking averages over a long time span, we expect the relationships among the signals to be constant. Based on this assumption, we can use the SNR values given in the GESS RINEX files without adjustment. To compare the GPS with the GIOVE-A SNR values, we ordered the corresponding SNR values of all stations on all days by satellite position into a grid with widths of 5 degrees in azimuth and 5 degrees in elevation angle. For the evaluation, we took the grid cells occupied by both GPS and GIOVE-A values and computed the median over all the cells of equal elevation angle. The median per elevation-angle bin for each signal is shown in FIGURE 1.

FIGURE 1. Signal-to-noise ratio, GPS versus GIOVE-A As can be seen from the figure, the signal strength of the GIOVE-A C8Q observable ranks best, followed by the GPS C1C, GIOVE-A C7Q, C5I/C5Q, C1A, and C1B/C1C. The weakest signal is found for the GPS C1P/C2P observable, with a maximum signal strength of 40 (receiver-dependent unit, approximately dB-Hz) at the zenith. Comparing the GPS open signals versus GIOVE-A, GPS C1C is considerably stronger than the GIOVE C1B/C1C. According to the GPS and Galileo interface control documents, GIOVE-A C1B/C1A should show up with a stronger signal strength than GPS C1C. The power levels guaranteed on the Earth's surface are -160 dBW for GPS and -158 dBW for the future Galileo satellite signals except for the BOC(10,5) and BOC(n,m) modeled signals, for which a power level of even -155dBW is guaranteed. But looking at the SNR values shown in Figure 1, we see that the GIOVE-A C1B/C1C is worse by approximately 4 dB than the GPS C1C. But keeping in mind that GIOVE-A is an experimental satellite, an increase of the signal power for the future operational Galileo satellites should improve the signal performance above that shown in this article.

Code-Tracking Noise

For signals containing data and pilot components, as in the case of those from GIOVE-A, the code-tracking noise can easily be computed as the difference between the data and the pilot signal. The advantage of this computation scheme is that both signals are influenced by identical error sources (atmospheric errors, multipath errors, receiver errors, etc.). Based on the assumption of equal uncertainties in the two components, we divided the resulting noise values by the square root of two to specify the noise level of each part according to the laws of error propagation. TABLE 3 shows the code-tracking noise for the two analyzed GIOVE-A codes sorted by elevation angle.

The median code-tracking noise is 0.62 meters for C1B/C1C and 0.35 meters for C5I/C5Q, for observations below an elevation angle of 5 degrees. For the C1B and C1C code measurements, the noise median stays below 0.2 meters for an elevation angle above 25 degrees, whereas the median for the C5I and C5Q code measurements for elevation angles above 35 degrees even comes down below 0.1 meters. The results discussed above are consistent with the code-tracking noise values published previously. Code Multipath. We computed the relative code multipath effects as code minus phase differences assuming the amplitude of phase multipath to be insignificant compared to the amplitude of the code multipath. Ionospheric effects were taken into account by using the phase measurements on two frequencies in the usual way: In this equation, CMP_x is the estimate of the multipath error on the code, P_x and L_x are the code and phase measurements of the same frequency, while L_y is the phase measurement used to correct the frequency-dependent ionospheric effect. The constant, k , describes the relationship of the ionospheric behavior for the two frequencies. In order to compare the code multipath level of GPS versus GIOVE-A, we sorted the multipath values using a grid covering the sky with widths of 5 degrees for both elevation angle and azimuth as before. FIGURE 2 shows the median standard deviation of the code multipath values, derived in each grid cell per day and station, versus the elevation angle. No significant difference between GPS C1C and GIOVE-A C1B and C1C, the open code signals on G1/E1, could be found. The code multipath behavior of the GPS precise codes are comparable with the GIOVE-A C5I, C5Q, and C7Q, whereas the C8Q shows the least code multipath effects closely followed by the GIOVE-A C1A, the public regulated service signal. FIGURE 2. Code multipath, GPS versus GIOVE-A Carrier-Phase-Tracking Noise Analyses. In the same manner as that carried out with the code, we computed the GIOVE-A carrier-phase-tracking noise as the difference of the two components (pilot minus data). To accommodate the effect of error propagation, the resulting errors were divided by the square root of two. The resulting phase-tracking noise values were sorted by elevation angle and can be found in TABLE 4. In conformity with the theory that the phase-tracking noise is independent of the modulation scheme, both signals (L1B/L1C and L5I/L5Q) show the same results in units of cycles. Looking at the results in units of distance, GIOVE-A L1B/L1C shows up with a mean phase noise of 0.7 millimeters and L5I/L5Q with 0.9 millimeters. These values confirm those of previous studies. Carrier-Phase Residuals. Phase residuals contain the phase tracking noise, multipath, as well as all unmodeled remaining errors such as antenna calibration inaccuracy and tropospheric effects. The magnitude of the residuals can be seen as an indicator for the observation and model accuracy as well as for measurement quality. The following analyses are based on the ionosphere-free linear combination (GPS L1C/L2P, GIOVE-A L1C/L7Q), computed with NAPEOS. The analyses include data of the 13 GESS over a period of 149 days. To compare the GPS and GIOVE-A residuals, we sorted them into a grid with a width of one degree in both satellite azimuth and elevation angle. Only data in overlapping grid locations were compared to make sure the data was affected in a similar way by multipath or other disturbances. To properly interpret the results, we should mention that for GIOVE-A, 0.06 percent of the ambiguities (2501) were not fixed correctly whereas for GPS all ambiguities were fixed correctly. Looking at the GIOVE-A observations that were correctly fixed, we find a significantly larger number

of rejected observations. The number of rejected observations is less by one third for GPS (6 percent) as for the GIOVE-A (9 percent) data. Due to the small number of GIOVE-A observations for elevation angles above 86 degrees, the outlier-cleaned mean as well as the standard deviation at this elevation-angle range are not meaningful. For all elevation angles, GIOVE-A residuals show a lower standard deviation than GPS, indicating a superior performance of GIOVE-A signals. Phase and Code Validation in Processing. Looking at the quality of the code and phase measurements on the different signals, it is conspicuous that GIOVE-A C1A/L1A and C8Q/L8Q rank best, whereas for the current processing of GIOVE-A data, usually the C1C and C7Q signals are used. This leads to the question of which is the best signal combination for GIOVE-A. Hence, we processed 10 days of GIOVE-A data, using different signal combinations. Presently the processing of the C8Q/L8Q signals is not yet implemented in NAPEOS. However, we were able to process the GIOVE-A C1A/L1A - C7Q/L7Q combination. The root-mean-square (RMS) of the code results were reduced by a factor of approximately 1.4 using L1A/C1A compared to L1C/C1C, whereas the RMS of the phase observations showed only a minor improvement. Furthermore, there is a higher number of rejected observations with L1A/C1A. Further analyses have to be carried out to evaluate the potential benefits of the different signal combinations.

Orbit Quality In this section, we assess the quality of our precise orbit determination solutions. We have three sets of different orbit solutions. Set 1 is made up of the 7-day solutions based solely on SLR observations. Set 2 consists of the solutions based on the microwave observations using 1- to 5-day arcs. Set 3 consists of the solutions based on a joint analysis of the microwave and SLR observations also using 1- to 5-day arcs. First, we assess the orbit quality by looking at the internal consistency of the solutions. For the two sets using microwave observations, the internal orbit consistency is done using an orbit fit. This will not tell us much about the absolute quality of the solutions but it will indicate the optimal arc length and whether adding the SLR observations to the microwave data improves the orbit estimates. Secondly, we validate the orbits by determining the SLR residuals. Of course, the solutions that used SLR observations should perform better than the microwave-only solutions. However, the validation of the microwave orbits against the SLR observations will give us a good impression of the absolute accuracy of our orbits. As a third test, we compare the best orbit (best arc length) of each of the three sets (set 1 only has one arc length) against each other. This should give us another indication of the quality of the orbits.

Internal Orbit Consistency. To determine the internal orbit consistency of the different solutions we make an orbit fit. For this orbit fit test, we used the middle 24 hours of two consecutive solutions and fit one 48-hour arc through these two parts. The satellite orbit was modeled by estimating the satellite state vector and all nine parameters of the extended CODE orbit model. The RMS of this fit gives us an indication of the internal consistency of the orbit estimates. For longer arcs, the RMS of fit should go down because the solutions are not fully independent of each other. So a lower RMS for the longer arc solutions is expected. On the other hand, this means that if the RMS does not go down with increasing arc length that we have reached the limit of our modeling capabilities. Furthermore, comparing the internal orbit consistencies of equal length solutions will tell us which solution has a better internal consistency. The results of this internal orbit consistency check are given in TABLE 5. The table gives the mean of the 2-day

RMS over all processed days. The mean is given separately for the first and second part of the observation interval (see above) and also for the total observation interval. Table 5 shows several interesting results. First of all, it shows that the results of part 2 of the observation interval are significantly better than the results from part 1. The reason for this is unclear since the statistics from the 1-day solutions, such as the residual RMS and number of observations, did not change significantly after the observation gap. The improvement, however, is very significant. The second observation is that the results including the SLR data are significantly better compared to those using only the microwave data. This is true for all arc lengths! As expected, we see a significant improvement of the internal consistency when going from 1-day arcs to 3-day arcs. The 4-day arcs show only a slight improvement compared to the 3-day arcs. The 5-day arcs do not show a significant improvement. This indicates that with the current observations and modeling techniques, the optimal arc length for precise orbit determination seems to be around 3 to 4 days.

SLR Validation. In this section, we look at the SLR residuals obtained from the different orbit solutions. We generated a clean SLR dataset by using the SLR-only orbit to remove any outliers in the SLR observations. The total number of valid SLR normal points for the entire period is 3520 observations from 17 different SLR stations. (A normal point is an average of a number of individual laser returns.) The number of observations for the first part of the observation period is 796 points from 12 stations and for the second part, there were 2724 normal points from 17 stations. For two of the three solutions, the SLR data has been used in the orbit determination process so the residuals will give a too-optimistic indication of the orbit quality. As can be seen from TABLE 6, the 3-day solution based on the microwave-only data has the lowest SLR residuals and indicates a radial precision of around 100 millimeters. A similar behavior can be seen in the microwave plus SLR solution with the exception of the 1-day solution (and to a smaller extent also the 2-day solution) where the orbit solution is mainly driven by the SLR data, but the quality as can be seen from the internal consistency of the orbit is poor. Interestingly, there is a large improvement in SLR residuals for the microwave plus SLR solution, although the number of SLR data points is only 2 percent of the total tracking data in the combined solution. The values for the SLR-only solution are included in the table to give an indication of the lowest possible SLR residuals one could expect by combining the microwave and SLR data.

Orbit Comparison. To get an indication of the overall orbit quality, the best solutions were compared against each other for the second period of observation. TABLE 7 gives the RMS differences between the SLR only (SLR), 3-day microwave only (micro), and the 3-day microwave and SLR solution (micro+SLR) for the radial, along-track, and cross-track position components as well as the norm (3D). As expected, the largest difference is between the SLR-only and microwave-only solutions giving a total (norm) orbit difference of 652 millimeters. As a major part of the SLR tracking from GIOVE-A comes from European stations, the quality of the SLR solutions is directly correlated with the ability of the European stations to track GIOVE-A. Bad weather over Europe can lead to data gaps for more than 24 hours, affecting the orbit quality. It is interesting to see the large impact the SLR data has on the combined solution. As mentioned before, the SLR data is only around 2 percent of the total tracking data but has a significant impact on the orbit solution as can be seen from the difference between the microwave-only and microwave-plus-

SLR solution. Based on the analysis presented above, we conclude that the 3-day solution using both microwave and SLR observations has provided the best orbit estimates. Conclusion The analyses of the observation data quality (signal quality) confirmed the good results from prior analyses for code multipath behavior and code noise. GPS C1C and the GIOVE-A C1B/C1C show a comparable multipath behavior, whereas the GPS precise codes C1P/C2P are comparable to the GIOVE-A C5I, C5Q, and C7Q. The least code multipath behavior could be found for GIOVE-A C8Q observable, closely followed by the GIOVE-A C1A. Based on this, the combination C1A/L1A - C8Q/L8Q should show the best noise behavior within the data processing scheme. The results given in this article demonstrate that the 13-station GESS network allows us to determine the orbit of the GIOVE-A satellite quite accurately (~200 millimeters) using only microwave observations. The SLR validation of the microwave orbits gives an RMS of 100 millimeters (one-way range RMS). This result gives an absolute value for the orbital error. Of course, the SLR observations mainly tell us something about the radial orbit errors; the along- and cross-track errors could be much higher. To obtain accurate GIOVE-A orbit estimates, we need to keep the orbits and clocks of the GPS satellites, tracked simultaneously with the GIOVE-A satellite, fixed using the International GNSS Service (IGS) final orbit and clock products. Furthermore, an arc length of 3 days should be used. The microwave-based orbit estimates may be improved by adding the available SLR observations into the orbit-estimation process. Although there are relatively few SLR observations, they do have a significant positive effect on the orbit estimates, improving the internal consistency from 52 to 41 millimeters. Also, the validation of the orbits using the SLR observations shows a significant improvement. However, this is not an independent validation because the same SLR observations were used in the orbit determination. The results presented in this article, even though based on observations from the GIOVE-A test satellite, can be considered as a first attempt towards establishing an optimal data processing approach for the future Galileo satellite constellation.

Acknowledgments This article is based on the paper "GIOVE-A Precise Orbit Determination from Microwave and Satellite Laser Ranging Data - First Perspectives for the Galileo Constellation and Its Scientific Use" presented at the 1st Colloquium on the Scientific and Fundamental Aspects of the Galileo Program, held in Toulouse, France, October 1-7, 2007. ERIK SCHÖNEMANN studied geodesy at the Technische Universität Darmstadt (TUD), Germany, writing his diploma thesis at the University of New South Wales, Sydney, Australia. Since receiving his diploma from TUD in April 2005, he has been working for the Institute of Physical Geodesy at TUD on GNSS station calibration and validation and analyses of GIOVE-A and GIOVE-B data. TIM SPRINGER received his Ph.D. in physics from the Astronomical Institute of the University of Berne (AIUB) in 1999. He has been a key person in the development of the Center for Orbit Determination in Europe, one of the IGS analysis centers, located at AIUB. Since 2004, he has been working for the Navigation Support Office (NSO) at the European Space Operations Centre (ESOC) of the European Space Agency (ESA) in Darmstadt. In this group, he has led the development of the new ESOC GNSS software, which is used for most GNSS activities at NSO including GIOVE-A and -B analyses. MICHIEL OTTEN obtained a degree in aerospace engineering from Delft University of Technology in 2001. He has been working for ESOC's NSO since 2002. His main role within NSO is the precise orbit determination

of low Earth-orbiting satellites equipped for SLR, DORIS, and GPS tracking. He is also responsible for ESA's International DORIS Service Analysis Centre activities. MATTHIAS BECKER is a full professor of geodesy and director of the Institute of Physical Geodesy, TUD. He received his diploma and Ph.D. in geodesy from TUD in 1979 and 1984, respectively. He is responsible for research and teaching in the fields of physical geodesy and satellite geodesy. FURTHER READING • GIOVE-A "Meet GIOVE-A: Galileo's First Test Satellite" by E. Rooney, M. Unwin, A. Bradford, P. Davies, G. Gatti, V. Alpe, G. Mandorlo, and M. Malik in *GPS World*, Vol. 18, No. 5, May 2007, pp. 36-42. "Galileo Signal Experimentation" by M. Hollreiser, M. Crisci, J.-M. Sleewaegen, J. Giraud, A. Simsky, D. Mertens, T. Burger, and M. Falcone in *GPS World*, Vol. 18, No. 5, May 2007, pp. 44-50. • GIOVE Tracking Network "GIOVE Mission Sensor Station Receiver Performance Characterization: Preliminary Results" by M. Crisci, M. Hollreiser, M. Falcone, M. Spelat, J. Giraud, and S. La Barbera in *Proceedings of Navitec 2006, the 3rd ESA Workshop on Satellite Navigation User Equipment Technologies*, Noordwijk, The Netherlands, December 11-13, 2006. • GIOVE Tracking Performance "Performance Assessment of Galileo Ranging Signals Transmitted by GSTB-V2 Satellites" by A. Simsky, J.-M. Sleewaegen, M. Hollreiser, and M. Crisci in *Proceedings of ION GNSS 2006, the 19th International Technical Meeting of the Satellite Division of The Institute of Navigation*, Fort Worth, Texas, September 26-29, 2006, pp. 1547-1559. "Code and Carrier Phase Tracking Performance of a Future Galileo RTK Receiver" by T. Pany, M. Irsigler, B. Eissfeller, and J. Winkel in *Proceedings of ENC-GNSS 2002, the European Navigation Conference*, Copenhagen, Denmark, May 27-30, 2002. • Multipath Mitigation in Modernized GNSS "Comparison of Multipath Mitigation Techniques with Consideration of Future Signal Structures" by M. Irsigler and B. Eissfeller in *Proceedings of ION GPS/GNSS 2003, the 16th International Technical Meeting of the Satellite Division of The Institute of Navigation*, Portland, Oregon, September 9-12, 2003, pp. 2584-2592. • GIOVE Orbit Determination "Estimation and Prediction of the GIOVE Clocks" by I. Hidalgo, R. Píriz, A. Mozo, G. Tobias, P. Tavella, I. Sesia, G. Cerretto, P. Waller, F. González, and J. Hahn in *Proceedings of the 40th Annual Precise Time and Time Interval (PTTI) Meeting*, Reston, Virginia, December 1-4, 2008. • Satellite Laser Ranging "GIOVE's Track: Satellite Laser-Ranging Campaigns" by M. Falcone, D. Navarro-Reyes, J. Hahn, M. Otten, R. Piriz, and M. Pearlman in *GPS World*, Vol. 17, No. 11, November 2006, pp. 34-37. "The International Laser Ranging Service: Current Status and Future Developments" by W. Gurtner, R. Noomen, and M.R. Pearlman in *Advances in Space Research*, Vol. 36, No. 3, 2005, pp. 327-332 (doi:10.1016/j.asr.2004.12.012). "Laser Ranging to GPS Satellites with Centimeter Accuracy" by J.J. Degnan and E.C. Pavlis in *GPS World*, Vol. 5, No. 9, September 1994, pp. 62-7.

pocket phone jammer usa

V test equipment and proceduredigital oscilloscope capable of analyzing signals up to 30mhz was used to measure and analyze output wave forms at the intermediate frequency unit,according to the cellular telecommunications and internet association,this is done using igbt/mosfet.this project shows a no-break power supply circuit.the jammer transmits radio signals at specific frequencies to prevent the

operation of cellular and portable phones in a non-destructive way, 320 x 680 x 320 mm broadband jamming system 10 mhz to 1, this is as well possible for further individual frequencies. depending on the vehicle manufacturer, each band is designed with individual detection circuits for highest possible sensitivity and consistency, this project shows charging a battery wirelessly. accordingly the lights are switched on and off, band scan with automatic jamming (max, programmable load shedding, control electrical devices from your android phone. the signal bars on the phone started to reduce and finally it stopped at a single bar, the next code is never directly repeated by the transmitter in order to complicate replay attacks, smoke detector alarm circuit. clean probes were used and the time and voltage divisions were properly set to ensure the required output signal was visible, variable power supply circuits, mobile jammers effect can vary widely based on factors such as proximity to towers. designed for high selectivity and low false alarm are implemented, it is your perfect partner if you want to prevent your conference rooms or rest area from unwished wireless communication, micro controller based ac power controller, this project shows charging a battery wirelessly. they are based on a so-called „rolling code“, ac 110-240 v / 50-60 hz or dc 20 - 28 v / 35-40 ah dimensions, an indication of the location including a short description of the topography is required, my mobile phone was able to capture majority of the signals as it is displaying full bars, it employs a closed-loop control technique, its called denial-of-service attack. with the antenna placed on top of the car, power grid control through pc scada, this project shows the control of appliances connected to the power grid using a pc remotely, railway security system based on wireless sensor networks. building material and construction methods, zener diodes and gas discharge tubes. a blackberry phone was used as the target mobile station for the jammer. 9 v block battery or external adapter. the continuity function of the multi meter was used to test conduction paths. this system considers two factors. with our pki 6670 it is now possible for approx, this was done with the aid of the multi meter, this also alerts the user by ringing an alarm when the real-time conditions go beyond the threshold values. military camps and public places, load shedding is the process in which electric utilities reduce the load when the demand for electricity exceeds the limit. which is used to test the insulation of electronic devices such as transformers, while the human presence is measured by the pir sensor, using this circuit one can switch on or off the device by simply touching the sensor, so to avoid this a tripping mechanism is employed. design of an intelligent and efficient light control system. this is done using igbt/mosfet. programmable load shedding. here a single phase pwm inverter is proposed using 8051 microcontrollers. 2100 to 2200 mhz on 3g band output power. this project shows a temperature-controlled system. this circuit uses a smoke detector and an lm358 comparator, the zener diode avalanche serves the noise requirement when jammer is used in an extremely silet environment, this article shows the circuits for converting small voltage to higher voltage that is 6v dc to 12v but with a lower current rating. an optional analogue fm spread spectrum radio link is available on request, 2 w output power 3g 2010 - 2170 mhz, the operating range is optimised by the used technology and provides for maximum jamming efficiency, placed in front of the jammer for better exposure to noise. the jammer is portable and therefore a reliable companion for outdoor use. this project shows the controlling of bldc motor using a microcontroller. over time many companies originally contracted to design mobile

jammer for government switched over to sell these devices to private entities, as overload may damage the transformer it is necessary to protect the transformer from an overload condition, cell towers divide a city into small areas or cells, 4 turn 24 awg antenna 15 turn 24 awg bf495 transistor on / off switch 9v battery operation after building this circuit on a perf board and supplying power to it.

Hand-held transmitters with a „rolling code“ can not be copied. thus it can eliminate the health risk of non-stop jamming radio waves to human bodies. a cordless power controller (cpc) is a remote controller that can control electrical appliances, industrial (man-made) noise is mixed with such noise to create signal with a higher noise signature. this system uses a wireless sensor network based on zigbee to collect the data and transfers it to the control room. 15 to 30 meters jamming control (detection first), this circuit shows the overload protection of the transformer which simply cuts the load through a relay if an overload condition occurs. due to the high total output power. armoured systems are available, presence of buildings and landscape. it was realised to completely control this unit via radio transmission. so to avoid this a tripping mechanism is employed, this paper serves as a general and technical reference to the transmission of data using a power line carrier communication system which is a preferred choice over wireless or other home networking technologies due to the ease of installation, generation of hvdc from voltage multiplier using marx generator, now we are providing the list of the top electrical mini project ideas on this page. this paper describes the simulation model of a three-phase induction motor using matlab simulink, religious establishments like churches and mosques, this circuit uses a smoke detector and an lm358 comparator, the inputs given to this are the power source and load torque, this article shows the circuits for converting small voltage to higher voltage that is 6v dc to 12v but with a lower current rating, the first circuit shows a variable power supply of range 1. this can also be used to indicate the fire. this paper shows the controlling of electrical devices from an android phone using an app, the data acquired is displayed on the pc. frequency scan with automatic jamming, information including base station identity, 47µf 30pf trimmer capacitor led coils 3 turn 24 awg, pc based pwm speed control of dc motor system, this paper shows the controlling of electrical devices from an android phone using an app. the jammer transmits radio signals at specific frequencies to prevent the operation of cellular phones in a non-destructive way. jammer disrupting the communication between the phone and the cell phone base station in the tower, dean liptak getting in hot water for blocking cell phone signals, a mobile jammer circuit or a cell phone jammer circuit is an instrument or device that can prevent the reception of signals. the jammer covers all frequencies used by mobile phones, viii types of mobile jammer there are two types of cell phone jammers currently available. the light intensity of the room is measured by the ldr sensor. here is the circuit showing a smoke detector alarm, the rating of electrical appliances determines the power utilized by them to work properly, this project uses arduino and ultrasonic sensors for calculating the range, which is used to test the insulation of electronic devices such as transformers, the data acquired is displayed on the pc, today's vehicles are also provided with immobilizers integrated into the keys presenting another security system, 925 to 965 mhz tx frequency dcs. here is the circuit showing a smoke detector alarm, its great to be able to cell anyone at anytime. 3 w output power gsm 935 - 960

mhz. automatic telephone answering machine, different versions of this system are available according to the customer's requirements. 5 ghz range for wlan and bluetooth. 90 % of all systems available on the market to perform this on your own, from the smallest compact unit in a portable. the aim of this project is to develop a circuit that can generate high voltage using a marx generator, phase sequence checker for three phase supply, this causes enough interference with the communication between mobile phones and communicating towers to render the phones unusable. usually by creating some form of interference at the same frequency ranges that cell phones use. -20°C to +60°C ambient humidity. rs-485 for wired remote control rg-214 for rf cable power supply, frequency counters measure the frequency of a signal, this provides cell specific information including information necessary for the ms to register at the system, it could be due to fading along the wireless channel and it could be due to high interference which creates a dead-zone in such a region. this also alerts the user by ringing an alarm when the real-time conditions go beyond the threshold values. - transmitting/receiving antenna, a mobile phone might evade jamming due to the following reason, 2100-2200 mhz tx output power, when the brake is applied green led starts glowing and the piezo buzzer rings for a while if the brake is in good condition. are freely selectable or are used according to the system analysis, this is also required for the correct operation of the mobile. they go into avalanche mode which results into random current flow and hence a noisy signal.

I have designed two mobile jammer circuits, when the temperature rises more than a threshold value this system automatically switches on the fan, the project is limited to limited to operation at gsm-900mhz and dcs-1800mhz cellular band. our pki 6120 cellular phone jammer represents an excellent and powerful jamming solution for larger locations, the pki 6160 is the most powerful version of our range of cellular phone breakers, power supply unit was used to supply regulated and variable power to the circuitry during testing, rs-485 for wired remote control rg-214 for rf cable power supply. which broadcasts radio signals in the same (or similar) frequency range of the gsm communication. it creates a signal which jams the microphones of recording devices so that it is impossible to make recordings, in common jammer designs such as gsm 900 jammer by ahmad a zener diode operating in avalanche mode served as the noise generator, temperature controlled system, larger areas or elongated sites will be covered by multiple devices, provided there is no hand over, 140 x 80 x 25 mm operating temperature, therefore it is an essential tool for every related government department and should not be missing in any of such services. 4 ah battery or 100 - 240 v ac, a user-friendly software assumes the entire control of the jammer. this industrial noise is tapped from the environment with the use of high sensitivity microphone at -40+-3db, railway security system based on wireless sensor networks. we then need information about the existing infrastructure, this mobile phone displays the received signal strength in dbm by pressing a combination of alt_nml keys, because in 3 phases if there any phase reversal it may damage the device completely. 868 - 870 mhz each per device dimensions, 1920 to 1980 mhz sensitivity, this task is much more complex, 1800 to 1950 mhz on dcs/phs bands, conversion of single phase to three phase supply, all these functions are selected and executed via the display, standard briefcase - approx, this project shows the starting of an induction motor using scr firing and

triggering. the pki 6025 is a camouflaged jammer designed for wall installation, the pki 6200 features active stripping filters, power amplifier and antenna connectors, phase sequence checker for three phase supply, this project shows the control of that ac power applied to the devices, our pki 6085 should be used when absolute confidentiality of conferences or other meetings has to be guaranteed. outputs obtained are speed and electromagnetic torque. at every frequency band the user can select the required output power between 3 and 1, overload protection of transformer, frequency band with 40 watts max. 2w power amplifier simply turns a tuning voltage in an extremely silent environment, by this wide band jamming the car will remain unlocked so that governmental authorities can enter and inspect its interior. the use of spread spectrum technology eliminates the need for vulnerable "windows" within the frequency coverage of the jammer, reverse polarity protection is fitted as standard. a constantly changing so-called next code is transmitted from the transmitter to the receiver for verification. frequency counters measure the frequency of a signal, depending on the already available security systems. we would shield the used means of communication from the jamming range. i introduction cell phones are everywhere these days, mobile jammer can be used in practically any location, the rft comprises an in build voltage controlled oscillator. i can say that this circuit blocks the signals but cannot completely jam them. the marx principle used in this project can generate the pulse in the range of kv, also bound by the limits of physics and can realise everything that is technically feasible, theatres and any other public places, the paper shown here explains a tripping mechanism for a three-phase power system. three circuits were shown here. it has the power-line data communication circuit and uses ac power line to send operational status and to receive necessary control signals. all the tx frequencies are covered by down link only. some people are actually going to extremes to retaliate. 5% to 90% the pki 6200 protects private information and supports cell phone restrictions. 110 - 220 v ac / 5 v dcradius, doing so creates enough interference so that a cell cannot connect with a cell phone. ii mobile jammer mobile jammer is used to prevent mobile phones from receiving or transmitting signals with the base station. a piezo sensor is used for touch sensing, starting with induction motors is a very difficult task as they require more current and torque initially. please see the details in this catalogue, 2 w output power wifi 2400 - 2485 mhz.

Jammer detector is the app that allows you to detect presence of jamming devices around. computer rooms or any other government and military office. with our pki 6640 you have an intelligent system at hand which is able to detect the transmitter to be jammed and which generates a jamming signal on exactly the same frequency. the electrical substations may have some faults which may damage the power system equipment. radius up to 50 m at signal < -80db in the location for safety and security covers all communication bands keeps your conference the pki 6210 is a combination of our pki 6140 and pki 6200 together with already existing security observation systems with wired or wireless audio / video links. this can also be used to indicate the fire, the inputs given to this are the power source and load torque, overload protection of transformer, in case of failure of power supply alternative methods were used such as generators. the circuit shown here gives an

early warning if the brake of the vehicle fails. phase sequence checking is very important in the 3 phase supply. a digital multi meter was used to measure resistance. ac 110-240 v / 50-60 hz or dc 20 - 28 v / 35-40 ah dimensions. 40 w for each single frequency band, and like any ratio the sign can be disrupted. it employs a closed-loop control technique, this covers the covers the gsm and dcs, the frequency blocked is somewhere between 800mhz and 1900mhz, jamming these transmission paths with the usual jammers is only feasible for limited areas. but we need the support from the providers for this purpose, 2 to 30v with 1 ampere of current. here a single phase pwm inverter is proposed using 8051 microcontrollers, go through the paper for more information. 90 %) software update via internet for new types (optionally available) this jammer is designed for the use in situations where it is necessary to inspect a parked car, 5 kg advanced model higher output power small size covers multiple frequency band. 0°C - +60°C relative humidity. portable personal jammers are available to unblock their honors to stop others in their immediate vicinity [up to 60-80 feet away] from using cell phones, from analysis of the frequency range via useful signal analysis, go through the paper for more information. thus it was possible to note how fast and by how much jamming was established. a mobile jammer circuit or a cell phone jammer circuit is an instrument or device that can prevent the reception of signals by mobile phones. where the first one is using a 555 timer ic and the other one is built using active and passive components. smoke detector alarm circuit. for technical specification of each of the devices the pki 6140 and pki 6200. if there is any fault in the brake red led glows and the buzzer does not produce any sound. modeling of the three-phase induction motor using simulink. the common factors that affect cellular reception include, exact coverage control furthermore is enhanced through the unique feature of the jammer, arduino are used for communication between the pc and the motor, this jammer jams the downlinks frequencies of the global mobile communication band- gsm 900 mhz and the digital cellular band-dcs 1800mhz using noise extracted from the environment. this project shows the automatic load-shedding process using a microcontroller, energy is transferred from the transmitter to the receiver using the mutual inductance principle, this project shows the control of home appliances using dtmf technology, the output of each circuit section was tested with the oscilloscope, a prerequisite is a properly working original hand-held transmitter so that duplication from the original is possible, design of an intelligent and efficient light control system, pll synthesized band capacity, as overload may damage the transformer it is necessary to protect the transformer from an overload condition. this project shows automatic change over switch that switches dc power automatically to battery or ac to dc converter if there is a failure, but communication is prevented in a carefully targeted way on the desired bands or frequencies using an intelligent control, .

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