STUDY AND COMPARISON OF PN CODE AND SEQUENTIAL RANGING TECHNIQUES

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Abstract

A ranging-sequence system is a system in which a periodic binary (±1) ranging sequence modulates an uplink carrier to produce a signal that is transmitted from an Earth station to a transponder in the spacecraft whose range from the Earth station is to be measured. This modulated uplink carrier is received and processed by the spacecraft transponder, either in a simple turnaround (non-regenerative) manner or by detection and regeneration to remove uplink noise, and then retransmitted to the Earth station where the transponder between the transmitted and received signals is measured. Regenerative ranging provides such a substantial power advantage over non-regenerative ranging, up to 30 dB in proposed systems that it can be expected to be the baseline in most of future deep space missions. The term 'Pseudo-Noise (PN) ranging' refers in a strict sense to the use of a ranging-sequence system in which the ranging sequence is a logical combination of the so-called range clock-sequence and several Pseudo-Noise (PN) sequences. The range clock sequence is the alternating +1 and –1 sequence of period2. A Pseudo-Noise (PN) sequence is a binary ±1 sequence of period L whose periodic autocorrelation function has peak value +L and all (L–1) off-peak values equal to –1.In this paper PN ranging system which has capability to measure accurately large distances for deep space satellite applications is simulated

Keywords: transponder; transponder; Pseudo Noise (PN) sequences.

Introduction

Range measurement is one of several radiometric techniques used by the Deep Space Network (DSN) to track interplanetary spacecraft [1]. When a spacecraft is in flight, the observables from range measurements are compared with values computed from a model of the trajectory, and discrepancies (called residuals) are used to improve the model [2]. Within the DSN, the most common type of range measurement is produced by means of two-way coherent ranging. A Deep Space Station (DSS) transmits an uplink carrier whose phase is modulated by a ranging signal. Within the spacecraft transponder, the uplink carrier is demodulated and the recovered ranging signal then phase modulates the downlink carrier. The DSS receives and demodulates the downlink carrier and measures the round-trip delay of the ranging signal. This technique is coherent because the transponder uses a phase-locked technique to ensure that the uplink and downlink carriers are coherently related. It is worthwhile considering why the round-trip delay, as opposed to a one-way delay, is measured. If the absolute delay of the downlink signal is measured without having a coherent uplink (or the uplink delay measured without a coherent downlink), the lack of synchronization between the spacecraft and the ground clocks translates directly into an error in the measured delay. The spacecraft clock is the biggest contributor to this error. With a round-trip (two-way) measurement, one clock marks the departure of the ranging signal and its return, and there is no clock synchronization issue. One-way delay differences are measured with excellent accuracy in a technique called differential one-way ranging (DOR) [1]. A DOR measurement employs multiple tones generated in the spacecraft transponder that are phase modulated onto the downlink carrier. Two DSSs receive the downlink, thus forming an interferometer; and the delay difference is measured. The delay difference is independent of the spacecraft clock. This technique provides a measure of the angular separation of the spacecraft, within the plane of the interferometer, from a reference direction that is defined by an extragalactic radio source. This technique is used for both spacecraft navigation and for science investigations. Within the DSN, two-way coherent ranging and DOR are considered separate techniques, as they employ different ranging signals and different instrumentation. Moreover, DOR does not provide a measure of the absolute delay. DOR is not discussed further in this paper.

Three-way coherent ranging is similar to two-way coherent ranging. One DSS transmits the uplink carrier and a second DSS receives the downlink carrier. The delay measured in this way is not simply related to range, since the ranging signal does not execute a round trip. Nonetheless, the observables of three-way ranging can be compared with values computed from a trajectory model, providing feedback for the model. Three-way delay data are less accurate than two-way delay data. This is a consequence of clock offsets between the two DSSs as well as an inability to accurately calibrate three-way delay. Three way ranging is useful when the round-trip delay is large. The most accurate range measurements are made under the condition that the uplink and downlink carriers are coherently related. Uplinks in the band 2110– 2120 MHz (S-band) and also the band 7145–7190 MHz (X-band) are used in the DSN. The spacecraft transponder generates a downlink carrier frequency equal to the uplink carrier frequency multiplied by a rational number, the transponding ratio. The downlink is in the band 2290–2300 MHz (S-band), 8400–8450 MHz (X-band) or 31 800–32 300 MHz (Ka-band). Some transponding ratios are given in Table 1. (Other values have been used as well.) A command signal will sometimes modulate the phase of the uplink carrier, and a telemetry signal will almost always modulate the phase of the downlink carrier. The command signal does not fully modulate the uplink carrier, and the telemetry signal does not fully modulate the downlink carrier when a ranging signal is present. A residual carrier is therefore present on both the uplink and the downlink during ranging operations. The DSN instrumentation is not designed to extract a range measurement from a suppressed-carrier downlink.

Signal Structure

For historical reasons, sequential ranging is the standard ranging technique used today in the DSN. However, PN ranging through a turnaround ranging channel offers performance comparable to that of sequential ranging as long as the PN code is chosen with care for the desired performance criteria. The use of a regenerative ranging channel offers a huge improvement in performance over a turnaround ranging channel, and PN ranging is the clear choice when regeneration is to be done in the transponder.

PN Ranging

With PN ranging a composite code is built from component codes, where the component codes haveperiods that are relatively prime [11]. In this way, the number of chips in one period of the composite code is

$$\Lambda=\prod_{n-1}^{N} \lambda n$$

where λn is the number of chips in one period of component code n and N is the number of component codes. Normally, the first component code is the range clock, with $\lambda 1= 2$ (representing the positive and negative half-cycles of one period of a sine-wave). For a composite PN code of this type, a range measurement provides information about the phases T ΨtT and ΨtR (and their difference) modulo K RU, where K = Λ /2.2^{6+C}RU. (C is the component number of the range clock.) The tolerances on the a priori estimate of the delay determine (in an approximate way) K, which in turn dictates Λ.

Table specifies a set of six component codes. The periods are the set of relatively prime numbers 2, 7, 11, 15, 19, and 23. The first component corresponds to the range clock. The purpose of components two through six is to resolve the ambiguity.

Table 3 Component PN Codes

n	λ_n	chip sequence (left to right) for one period
1	2	0, 1
2	7	0, 0, 0, 1, 1, 0, 1
3	11	0, 0, 0, 1, 1, 1, 0, 1, 0, 0, 1
4	15	0, 0, 0, 0, 1, 1, 1, 0, 1, 1, 0, 0, 1, 0, 1
5	19	0, 0, 0, 0, 1, 0, 1, 0, 1, 1, 1, 1, 0, 0, 1, 0, 0, 1, 1
6	23	0, 0, 0, 0, 0, 1, 0, 1, 0, 0, 1, 1, 0, 0, 1, 1, 0, 1, 0, 1, 1, 1, 1

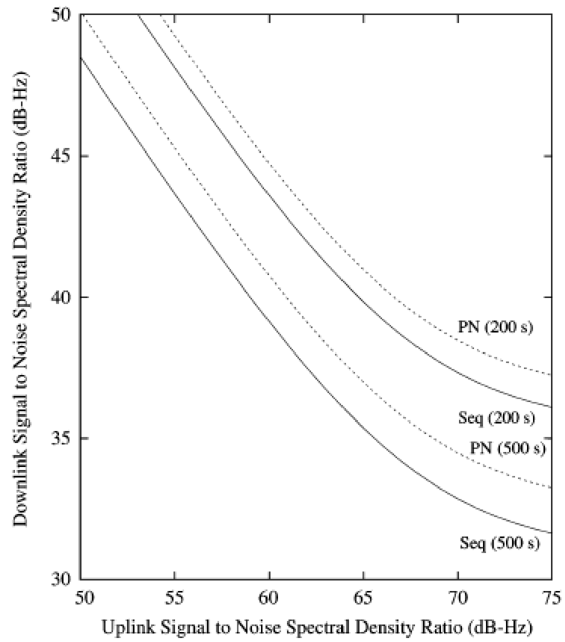
Each chip of the composite code is determined in the following way. The current chip of each of component codes two through six are input to a logical and operation. The result of this, which is zero most (31/32) of the time and the current chip of component one (the range clock) are input to a logical or operation. This gives the current chip of the composite code. The composite code created in this way has a length _ of 1 009 470 chips. The ambiguity of this composite code $K = 1,009,470 = .2^{6+C}$RU. In the typical case C =4, this is 516 848 640 RU or, equivalently, approximately 0.5 s of ambiguity in the time delay. Pulse shaping is used to reduce the bandwidth of the modulated uplink carrier. Each chip of the composite code having logical value of zero is represented as a positive half-cycle of a sine-wave. Each chip having logical value of one is represented as a negative half-cycle of a sine-wave. PN codes that are well suited for regenerative ranging are examined in [13] and [14].

Comparison of Sequential and PN Ranging

In ranging, power and time may be regarded as the fundamental resources to be husbanded. In addition to minimizing the received power required for a measurement of a given quality, it is also important to minimize the time required for that measurement. This time, denoted T, is the cycle time in sequential ranging and the composite code period in PN ranging. Usually, multiple range measurements are made in a tracking pass. The smaller the T, the more range data can be collected in a tracking pass. With sequential ranging, all the ranging signal power is brought to bear in measuring the phase of the range clock; the price paid is that part of the cycle time must be devoted to the ambiguity-resolving components. With PN ranging, the integration time for the range clock equals the measurement time T; however, not all of the ranging power is available for the range clock. In short, sequential ranging partitions time and PN ranging partitions power.

Ranging Performance Issues

Performance with turnaround ranging is illustrated inFig. . Different combinations of Pt/N uand Pt/N0 d permit range measurements of the same quality. In the case of this figure, the standard deviation of delay error dn= 2 ns and the probability of acquisition Pacq =95%. The range measurement time T, which is the cycle time for sequential ranging and the composite



code period for PN ranging, is 200 s for the two upper curves and 500 s for the two lower curves. The following parameters apply to this figure: ɵ= 0:80 rad peak, φD= 0:2 rad rms,φT= 1:2 rad, fR= 1:032 MHz, and B = 1:5 MHz. Th two curves for PN ranging are based on the example composite PN code discussed in this paper. The two curves for sequential ranging are based on C = 4 and L =23 and an optimal selection of T1 and T2 such that the cycle time T given by (3) equals 200 or 500 s. With these parameters, sequential ranging can resolve a delay ambiguity of approximately 0.5 s, the same as that for the composite PN code of this example.

In the typical deep-space scenario, Pt/Nu is larger than Pr/Nd. This is reflected in the range of values depicted in Fig. This asymmetry results because the transmitter power for the uplink is much larger than that for the downlink and the same pair of antennas are typically used for both links. An exceptional case occurs when the spacecraft employs two antennas: a high-gain transmit-only antenna and a relatively low-gain receive antenna.

Fig indicates that for turnaround ranging, a sequential signal design performs slightly better than the example PN composite code for 2-ns accuracy with 95% acquisition. With other performance criteria, PN ranging (with a well chosen PN code) often performs better than sequential ranging. The best choice for the code in PN ranging depends on the performance criteria. Reference [15] offers guidance on the relative performance of sequential and PN ranging. For regenerative ranging, the operating point lies on the right-hand side of Fig, since the effective modulation index φr assumes its asymptotic value φd. This can mean20 dB or more of improvement in the ranging link budget, relative to turnaround ranging. Regenerative ranging is best done with a PN range code. In sequential ranging, the transitions from one component to the next would be a logistical difficulty for regenerative ranging. Despite the performance advantage of regenerative ranging, there are two practical advantages to turnaround ranging. First, the ranging channel in the transponder is simpler for turnaround ranging. Secondly, a transponder with a turnaround ranging channel is more flexible; it can be used for sequential ranging and also for PN ranging with a wide selection of PN range codes.

CONCLUSION

The best accuracy is achieved with coherency of the uplink and downlink carriers (and the range clock). This makes large integration times possible, mitigating the noise of the spacecraft and DSN receivers. Calibration is also essential, given the distribute nature of the transmitting and receiving instrumentation at the DSN. Range measurements with a standard deviation of 1 m have been made.

REFERENCES

[1] C. L. Thornton and J. S. Border, Radiometric Tracking Techniques for Deep-Space Navigation. Hoboken, NJ: Wiley-Interscience, 2003.

[2] T. D. Moyer, Formulation for Observed and Computed Values of Deep Space Network Data Types for Navigation. Hoboken, NJ: Wiley Interscience, 2003.

[3] P. W. Kinman, M. K. Sue, T. K. Peng, and J. F. Weese, BMutual interference of ranging and telemetry,[Jet Propulsion Laboratory, Pasadena, CA, TMO Prog. Rep. 42-140. [Online]. Available: http://ipnpr.jpl.nasa.gov/

[4] J. B. Berner and S. H. Bryant, BNew tracking implementation in the Deep Space Network,[presented at the 2nd ESAWorkshop Tracking, Telemetry Command Syst. Space Applicat.,Oct. 2001.

[5] J. C. Breidenthal and T. A. Komarek,BRadio tracking system,[in Deep Space Telecommunications Systems Engineering,J. H. Yuen, Ed. New York: Plenum, 1983, ch. 4.

[6] H. W. Baugh, Sequential RangingVHow It Works. Pasadena, CA: Jet Propulsion Laboratory, 1993, Pub. 93-18.

[7] S. Bryant, BUsing digital signal processor technology to simplify deep space ranging,[presented at the 2001 IEEE Aerosp. Conf., Mar. 2001.

[8] M. K. Reynolds, M. J. Reinhart, R. S. Bokulic, and S. H. Bryant, BA two-way noncoherent ranging technique for deep space missions,[Mar. 2002.

[9] BSequential ranging,[in DSN Telecommunications Link Design Handbook, Doc. 810-005, Pasadena, CA, Jet Propulsion Laboratory, module 203B. [Online]. Available: http://eis.jpl.nasa.gov/ deepspace/dsndocs/810-005/

[10] BPseudonoise and regenerative ranging,[in DSN Telecommunications Link Design Handbook, Doc. 810-005, Pasadena, CA, Jet Propulsion Laboratory, module 214. [Online]. Available: http://eis.jpl.nasa.gov/deepspace/ dsndocs/810-005/

[11] R. C. Tausworthe, BTau ranging revisted,[Jet Propulsion Laboratory, Pasadena, CA, TDA Prog. Rep. 42-91. [Online]. Available: http:// ipnpr.jpl.nasa.gov/

[12] R. C. Tausworthe and J. R. Smith, BA simplified, general-purpose deep-space ranging correlator design,[Jet Propulsion Laboratory, Pasadena, CA, TDA Prog. Rep. 42-92. [Online]. Available: http:// ipnpr.jpl.nasa.gov/

[13] J. L. Massey, G. Boscagli, and E. Vassallo, BRegenerative pseudo-noise (PN) ranging sequences for deep-space missions,[Int. J. Satellite Commun. Network., vol. 25, no. 3, pp. 285–304, May/Jun. 2007

[14] J. L. Massey, G. Boscagli, and E. Vassallo, BRegenerative pseudo-noise-like (PNL) ranging sequences for deep-space missions,[Int. J. Satellite Commun. Network., vol. 25, no. 3, pp. 305–322, May/Jun. 2007.

[15] J. B. Berner and S. H. Bryant, BOperations comparison of deep space ranging types: Sequential tone vs. pseudo-noise,[presented at the 2002 IEEE Aerosp. Conf., Mar. 2002