Continuous Spectrum Planetary Ranging Operational Software

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The Planetary Ranging Operational Software has been expanded to provide continuous spectrum ranging in addition to the already existing discrete spectrum mode. The new functions are considered in this article.

I. Introduction

The Planetary Ranging Operational Program has been expanded to provide continuous spectrum ranging. The discrete spectrum version of the program was described earlier (Ref. 1). Either mode can now be selected, depending on mission requirements. Both code types provide high precision range measurements to spacecraft at planetary distances. The equipment is operational at DSSs 14, 43, 63, 71, and CTA 21.

Four continuous spectrum modes are provided. A short code using pseudonoise (PN) components of lengths 2, 7, 11, 15, and 19 or a long code using lengths 2, 7, 11, 15, 19, and 23 can be selected. Either code length can be used with differenced range versus integrated doppler (DRVID) during acquisition, or a faster acquisition with DRVID after acquisition only can be performed.

The short composite code length is $2 \times 7 \times 11 \times 15 \times 19 = 43{,}890$ bits. With a bit period of approximately one microsecond, the maximum round-trip light time that can be measured without ambiguity is about 43 milliseconds, corresponding to 6500 kilometers in one-way range. Since the spacecraft position is normally known much more accurately than this, the short code is usually adequate to unambiguously refine the range.

If necessary, a longer code containing components of lengths 2, 7, 11, 15, 19, and 23 can be selected. It has an ambiguity interval of about 150,000 kilometers.

The continuous spectrum ranging code has the advantages of a PN code: its spectrum is similar to white noise, hence it is relatively immune to interference from other spacecraft signals; further it does not degrade the other channels more than white noise would. An exception is the 500-kilohertz clock and its odd harmonics, which appear as sharp spectral lines in the composite signal.

The composite PN from the transmitter coder is transmitted regardless of which component is to be received. The advantage of this approach is that a new acquisition can be started immediately, without having to wait a round-trip light time for the correct component to be received. On the other hand, the ranging power must be shared between all components, so acquisitions take considerably longer. For example, the short code clock correlation is 0.33, which is equivalent to a 9-dB loss compared to a discrete spectrum acquisition.

II. Hardware

The continuous spectrum coders consist of short PN code generators of lengths 2, 7, 11, 15, 19, and 23 bits. The composite code is obtained by a modified majority logic of the PN sequences. The longer components have a higher error probability simply because they have more bit positions to be integrated, hence more opportunities for noise to be misinterpreted as the correlation peak. The longer components are therefore given a larger share of the ranging power, maximizing the acquisition probability for the entire code. The code structure is described in more detail in Ref. 2.

The local reference signals to the two correlators depend on the code type and the acquisition phase. The channel A reference can be any component or the composite code. The channel B reference can be any component or the composite delayed by one bit time, or the clock lagged by 90 degrees.

The entire receiver coder can be shifted in 16 range unit steps for clock phase adjustment. Each component other than the clock can be stepped one bit time, which is equivalent to 1024 range units. Stepping a component affects the composite code, but not the other components.

III. Acquisition Sequence

The acquisition sequence consists of the following steps:

(1) Measure the clock phase, then shift the receiver coder to place the clock at the nearest positive peak. The amount that the clock is shifted, in range units, becomes the least significant 11 bits of the range number.

(2) Determine S_i, the number of bit positions each PN component must be shifted to reach its correlation peak.

(3) Subtract $2^{10}S_iX_i$ from the range number, where X_i is the Chinese number (defined below) for that component.

(4) Evaluate the range number module $2^{10}\Pi_{i=1}^{n}L_i$ if it goes negative. L_i is the length of the ith component.

(5) Return each component to its correlation peak with additional shifts.

Step 1 is the same as for a discrete spectrum acquisition. The equation

$$\tau = 512\left(1 - \frac{A}{|A| + |B|}\right)\frac{B}{|B|} \tag{1}$$

produces a number between −1024 and 1023, which is the initial clock phase in range units. The correlator local references for the clock integration are in-phase clock to correlator A and clock lagged by 90 degrees to correlator B.

After clock integration the entire receiver coder is shifted to place the correlator A output to a positive peak of the clock. This step insures that one of the PN correlations per component will be exactly at the peak. Since the clock is not shifted more than one PN bit position, no Chinese number need be used.

The execution of step 2 of the above algorithm depends on whether DRVID is being processed or not. If DRVID during acquisition is required, the correlator A local reference is one of the PN components, while the clock delayed by 90 degrees is fed to correlator B for DRVID sensing. The component is stepped one bit per integration interval. The channel A correlation voltage from each bit position is stored in an array. After the last bit position has been integrated the array is scanned to find the most positive entry, which is the correlation peak. The array subscript of the most positive entry is S_i, the number of shifts required to reach the correlation peak.

If there is no DRVID during acquisition, both correlator channels are used to integrate two bit positions simultaneously. This is accomplished by feeding the component delayed by one bit time to correlator B. The component is stepped two bit positions between integrations in this case. The array of correlation voltages is filled two locations at a time, but the range computation is otherwise the same as when DRVID is being processed.

In step 3, above, the Chinese number is the number of bit positions the composite code is shifted for a single shift of a component. This effect can be easily seen in Fig. 1. If the 7 component is right-shifted one place, the pattern which is shown around bit position zero becomes displaced to position 22. The Chinese number is 22 in this case. An algorithm for determining Chinese numbers is given in Ref. 3.

While it is not obvious, each range between 0 and $\Pi_{i=1}^{n} L_i$ bit positions will result in a different combination of component shifting and the algorithm will produce a unique (and correct) range number from each combination.

Each component is shifted to the correlation peak after the maximum correlation of all positions has been determined. This is accomplished by continuing to step the component in the same direction as was used to search for the maximum. Since the code is cyclic, the effect is the same as backing up the code to the peak. This step does not affect the range determination, but causes unity correlation after acquisition when the composite code is selected. The composite code is used for DRVID after the acquisition is complete.

Figure 1 shows an example of the PN acquisition sequence. A code containing components of lengths 2, 7, and 11 is shown. This abbreviated code is not implemented but is shown here for simplicity.

IV. DRVID

Only one correlator channel is available for DRVID sensing during acquisition. The in-phase clock cannot be measured. Since a single value cannot be used to compute phase, the correlation voltages from the clock integration are used to derive the in-phase voltage by the relationship $A_i \cong |A_c| + |B_c| - |B_i|$, where A_c and B_c are the clock correlations. This derived value of A_i, along with the measured value of B_i, is used in Eq. (1) to compute clock phase.

The derived value of A_i is valid only if the amplitude of the ranging signal remains constant during acquisition. Amplitude variations do not result in large DRVID errors, however, since the clock is servoed to null the quadrature channel. Amplitude variations affect the servo gain. Short-term DRVID variations are not followed as accurately if the amplitude changes, but slow changes are still accurately tracked.

After acquisition the receiver coder is switched to the composite code. All components are then correlated simultaneously, resulting in a stronger detected signal. The receiver coder is also shifted by ¼ clock cycle at this time. DRVID is then derived from the two composite correlations rather than from the clock. The clock correlation is 0.33 for the short code, 0.25 for the long code, and unity for the composite code. DRVID jitter is thus reduced after acquisition.

DRVID after acquisition is computed from the equation $\tau = 512 \cdot (B-A)/(B+A)$. The signals are shown in Fig. 2. The equation is valid only to ±90 degrees of the clock, or ±512 range units. Since the receiver coder is shifted back to the null at each DRVID time, arbitrarily large DRVID excursions can be tracked provided DRVID does not change by more than 512 range units during a single sample interval. Such a large step is unlikely.

The discrete spectrum DRVID performance has been improved by shifting the clock to the 45 degree point after acquisition. Equation (1), which is used also for discrete spectrum DRVID, provides an estimate of phase that is less sensitive to noise when $A = B$. DRVID jitter is reduced by $\sqrt{2}$. Reference 4 indicates that somewhat more improvement will occur with a spacecraft because the transponder attenuates the higher harmonics and shifts their phase.

The discrete and continuous spectrum DRVID signals are shown in Fig. 2. At a given signal level the continuous spectrum mode produces twice as much jitter.

V. Summary

Numerous refinements have been made in the program for the continuous spectrum release, particularly for operator convenience. The rules for entering the initialization parameters have been simplified, and variables are now displayed in a more legible format. Portions of the program were rewritten for greater efficiency, since most of memory is being used.

Much of the code is common to all modes of operation, hence much that was described for the discrete spectrum version (Ref. 1) applies also to the continuous spectrum version.

References

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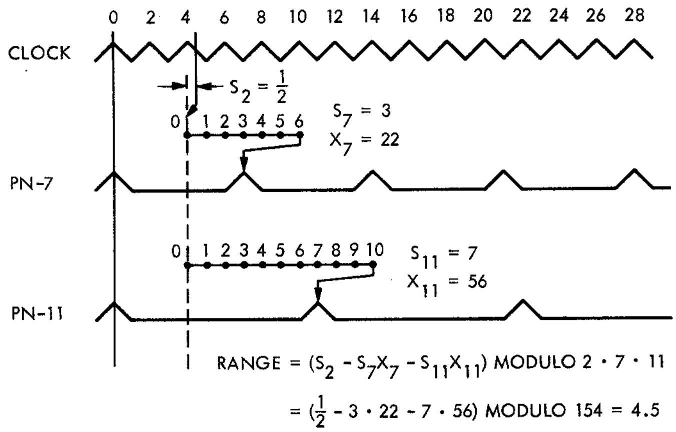

Fig. 1. PN acquisition sequence

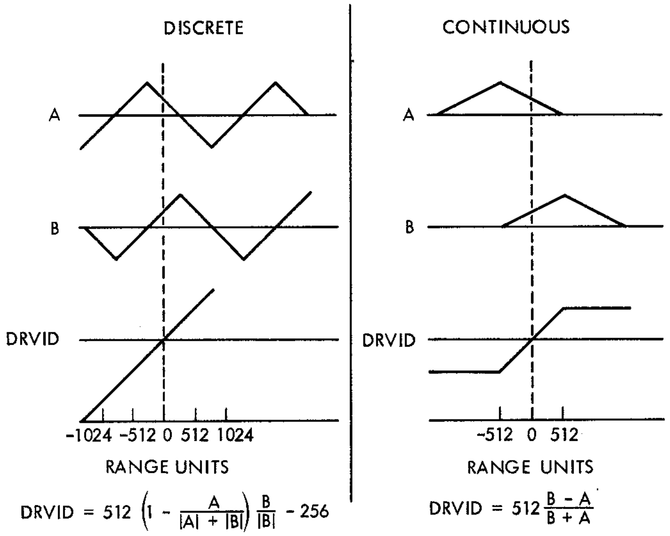

Fig. 2. DRVID waveforms