X-531-68-112

NASA TM X-63167

MODULO ACQUISITION OF AMBIGUITY RESOLVING TRACKING CODES

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GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Hard copy (HC) 3.00

Microfiche (MF) 65

ff 653 July 65

MARCH 1968

GSFC

GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND

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INTRODUCTION

In a sidetone ranging system, such as the Goddard Range and Range Rate system (reference 1), all distances are measured modulo the longest wave length used. As a result, an ambiguous determination is produced when the two-way range is greater than one wave length. Ranging systems with long pseudo-random codes are used when larger unambiguous distance measuring capabilities are required.

One of the basic operating steps in both ranging systems is the matching in phase (or correlation) of the signal from the spacecraft with a locally generated model. This process is called acquisition. In a sidetone system, it is accomplished simply by means of phase locked loops. In a pseudo-random system it is somewhat complicated in that a series of operations is required. The received code and the local model must first be driven by the same received clock (which must also be acquired); then the local model must be shifted bit by bit with respect to the received code until correlation (i. e. a bit by bit correspondence between the two codes is obtained).

The acquisition time required for a code only ranging system is a function of the code length. A ranging code which is capable of unambiguous ranging to lunar distances must have a period of more than 2.5 seconds. A typical code such as that being built by the Jet Propulsion Laboratory for the Apollo mission (reference 2) achieves this by means of a 5,456,682 bit code operating with a 1 microsecond clock. The code, however, is composed of four carefully chosen subcodes combined in a boolean manner, which allow the subcodes to be acquired serially. This still requires a total of 232 shifts.

THEORY OF MODULO ACQUISITION

The ambiguous measurement made by the sidetone system is an exact modulo determination of the distance to the spacecraft. The modulo measurement is converted to an unambiguous measurement by the addition of the required number of modulo range units (i. e 1/2 the wave length of the lowest sidetone used).

In a Hybrid system (such as that described in reference 3) which uses sidetones for fine range resolution and codes for modulo range determination, the ambiguous modulo range given by the sidetone portion of the system can be used to automatically shift the local model of the received code the exact number of bits required for acquisition of the coded portion of the system. It is done by the following three step process:

1. Synchronize the locally generated version of the received code (or decoder) to the code generator producing the code being transmitted (or encoder) to create a zero phase shift (or bit difference) between the codes.

2. Use the start pulse generated at the beginning of the sidetone range measurement to stop the clock driving the decoder, and the stop pulse generated at the end of the sidetone measurement to reintroduce the clock signal. During the no clock interval the clock signal to the decoder is switched from that of the encoder to that of the received code. This delays the decoder by the modulo time interval. If the range is less than one modulo distance (i.e. one period of the longest wave length used) correlation will exist and acquisition will have been made.

3. If acquisition has not been accomplished in step two, the decoder is further delayed in modulo steps (equal to that of the lowest sidetone period used) until correlation is obtained. Usually the approximate range is known in advance, and the proper number of modulo steps can be set into the system automatically without waiting for the step by step correlation check to have been made.

It should be pointed out that since the decoder is being driven by the received clock, all changes in range occuring during the short acquisition process are automatically accounted for, since the doppler shift on the clock signal updates all changes in range.

EXPERIMENTAL IMPLEMENTATION

A typical modulo acquisition circuit is shown in figure one. Before acquisition is initiated, the decoder is driven by the received clock, has its normal feedback logic, and no modulo code shifting pulses are generated. The acquisition process is initiated by the push button, which puts flip flop #1 in the reset state. This action transfers the clock signal driving the decoder from that of the received code to that of the encoder; transfers the decoder input logic to that of the synchronizing signal from the encoder; resets the free running correlation interval generator to zero; and resets flip flop #3. After a time interval (set by the time delay) of sufficient duration to insure that the decoder has been synchronized to the encoder, the first sidetone time interval unit (TIU) start pulse sets flip flop #1. This restores the normal feedback logic to the decoder; allows the correlation interval generator to start generating timing pulses; removes all clock inputs to the decoder; and enables the next sidetone TIU stop pulse to set flip flop #2. This arrangement of flip flops assures that a start pulse will always be recognized before a stop pulse when the system is first energized. The stop

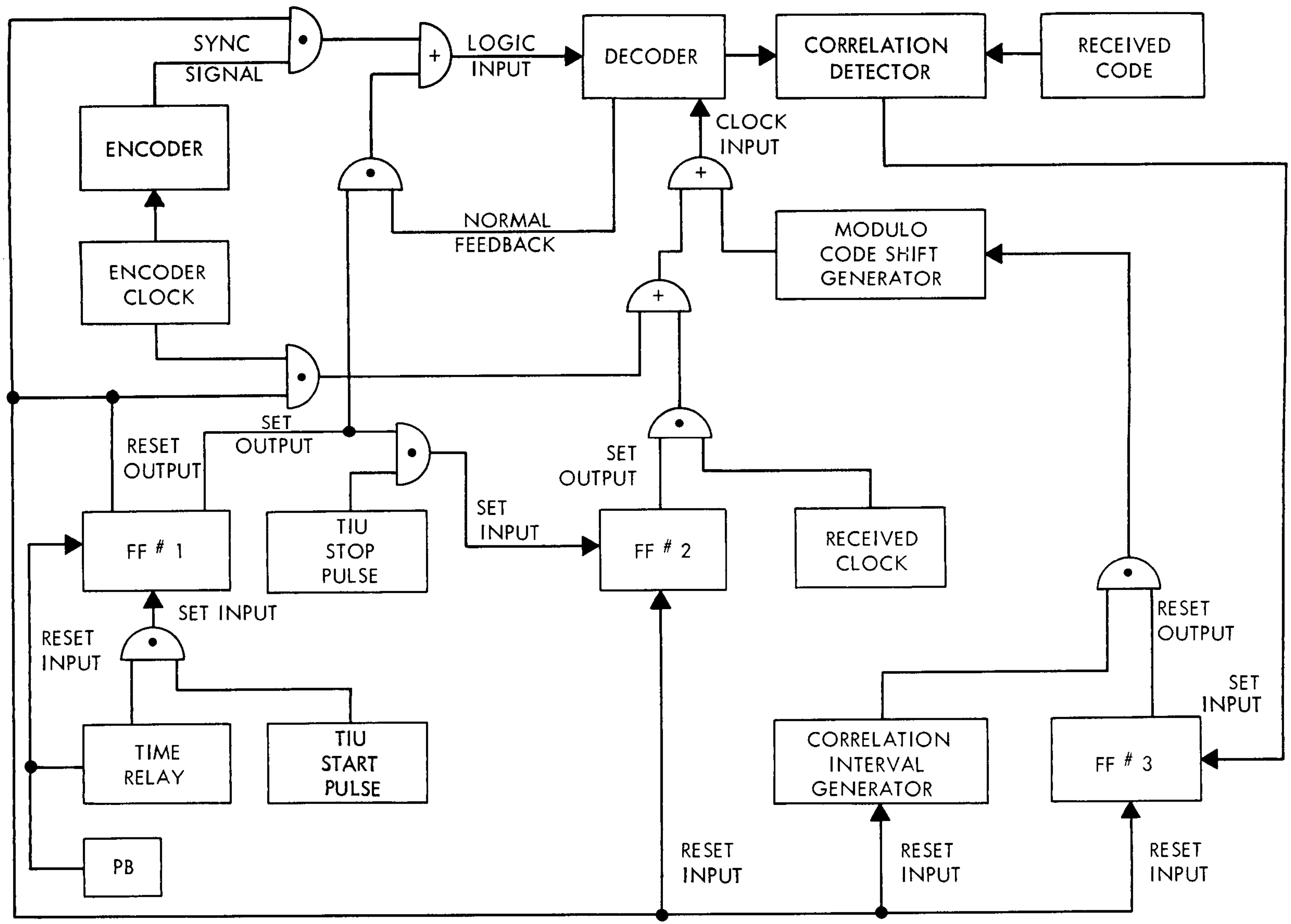

Figure 1. Typical Modulo Acquisition Circuit.

pulse allows the received clock to start driving the decoder, thus setting the modulo time delay between the encoder and decoder. If the measured distance is less than the modulo distance, the decoder will be correlated with the received code, and the output of the correlation detector will set flip flop #3. This will prevent the output signal from the correlation interval generator from triggering the modulo code shift generator. If correlation is not reached, the output of the correlation interval generator (which consists of a series of pulses at a rate set by the desired correlation time) will allow the modulo code shift generator to delay the decoder in modulo steps until correlation is reached. Since the coding signals are usually composed of several subcodes, the modulo code shifter shifts each subcode the proper number of bits required to delay the overall code by one modulo range interval.

ADVANTAGES OF MODULO ACQUISITION

Ranging systems in which modulo acquisition can be utilized have several important advantages over code only systems. These are:

1. Reduction in Acquisition Time.

   The acquisition time (for both systems) is a function of the S/N conditions of the received signal. Therefore the ratio of the two acquisition times (which assumes equal signal conditions) is used as the basis of comparison.

   The ratio (A) of the reduction in code acquisition time (i.e the ratio between the Hybrid and the code only acquisition) can be computed from the following equation:

$$A = \frac{T + (R/\lambda)\ (t_c)}{N\ (t_c)} \tag{1}$$

where:

- T is the ambiguous time delay between the transmitted and received signals
- R is the range to be measured
- λ is the wavelength of the longest period used in the sidetone portion of the Hybrid system.
- R/λ is therefore the maximum number of modulo bits by which the Hybrid code must be shifted.
- N is the number of bits by which the code would otherwise have had to be shifted in a bit by bit process for the range to be measured.

t_c is the correlation time constant (which is determined by the S/N ratio of the received signal) and is therefore the same for both systems.

Since (R/λ) (t_c) is much greater than T, this equation can be further reduced to

$$A \approx \frac{(R/\lambda)}{N} \tag{2}$$

Assuming a typical lowest sidetone period of 0.125 seconds and the ranging code (reference 2) discussed earlier, the acquisition time of the Hybrid system at lunar distances (2.5 seconds) is only (2.5 seconds)/(232 bits) (0.125 seconds) or 8.6% of the code only time. Since in any tracking mission however, the approximate range is usually known in advance, the maximum number of trials given by R/λ can be reduced to three (i.e the expected value minus one, the expected value, and the expected value plus one). The acquisition time for the Hybrid system would therefore be reduced to 3/232 or 1.3% of the code only time for similar signal conditions.

2. Reduction in Encoder Complexity.

   As opposed to the code only type systems, the acquisition time of the Hybrid system is independent of the code length. Thus systems designed to track satellites with large differences in apogee do not need multi-length encoders to optimize the acquisition time for each mission. A single long code length can be used for all missions.

3. Improved Correlation Detection.

   For modulo two type correlation, a full indication is achieved only when the local code is matched to the received code as a unit. The serial correlation process used to reduce the acquisition time for the code only system can therefore give only a fractional indication. The reduction in indicating level requires a compensating increase in the integration time constant of the correlation circuit to maintain a given S/N condition. Thus modulo acquisition allows either (1) a much shorter acquisition time if an indication equal to that used for the serial acquisition techniques is desired (by permitting a decrease in the integration time constant), or (2) a lower detection threshold if the same integration time constant is retained. It is important to note that a 2:1 improvement in detection level is equivalent to a 6 db improvement in detection threshold. A 50% correlation level is used by the referenced code only system.

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SUMMARY

In a sidetone ranging system, acquisition is accomplished easily by means of phase locked loops; in a pseudo-random coding system, it requires a series of operations. The received code and the local model must be driven by the same clock, and the local model shifted bit by bit with respect to the received code until correlation is obtained. In a Hybrid system which uses both sidetones and pseudo-random codes, it is possible to use the ambiguous sidetone range measurement for an automatic and rapid acquisition of the received pseudo-random code.

As compared to the code only system, the modulo acquisition technique utilized by the Hybrid system reduces the acquisition time to a mere 1.3%, increases the detection threshold by 6db, and reduces the encoder complexity considerably.