STUDY AND IMPLEMENTATION OF SPREAD SPECTRUM RANGING SYSTEMS FOR SATELLITE COMMUNICATION

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Abstract

Spread Spectrum Techniques, in recent years, have produced amazing results in communication, navigation and test systems that are not possible by standard signals. In this paper it is attempted to survey the ranging systems based on spread spectrum systems and the implementation of spread spectrum ranging systems. Every RF signal will be having same propagation rate. And the signaling waveforms or modulations are functions of time. The difference of delay in a signaling wave at the receiver, when compared to the transmitted signal, can be directly related to the distance between them and used to measure that distance. Every signal used will be subjected to the same distance-time relationship. In that case the advantage of using spread spectrum signal is that we can have more resolution because of its easily resolvable phase modulation.

Keywords: Spread Spectrum, Ranging, Modulation .

I. INTRODUCTION

Every transmitting or modulating system has unique characteristics such as the frequency at which the signal is centered and bandwidth of the signal. The frequency domain representation of a signal is called its spectrum.

Spread spectrum systems can be defined as a system which uses a signal with a much wider bandwidth than the minimum required bandwidth. The spreading is done by modulating the signal with a random fashioned code which has a very high bit rate. The dispreading of the code is done by correlating the received signal with an internal reference code which is synchronized with the original code. Any signal which is not a replica of the reference code will be spread by the reference code.

Two important modulation techniques employed are :-

A) Direct Sequence system.

Here the carrier is modulated by a digital code sequence whose chip rate is
much higher than the information signal bandwidth.

B) Frequency hopping system.

Here the transmitted signal frequency shifts from the frequency to frequency in a fashion determined by the code sequence.Hybrid systems making use of the combination of the common modulation techniques are also common. Because of the unique property of spread spectrum signals, ie, the code modulation, it has various applications such as interference rejection, code division multiple access etc. Another important application based on code modulation is ranging.

In this paper, it is attempted to discuss some of the raging systems implementation using the principle of Direct Sequence and Frequency Hopping. Also we can see some of the important areas in which spread spectrum systems are used for ranging.

II. Ranging Techniques

A. Direct Sequence Raging Systems

The most commonly used spread spectrum ranging technique is Direct Sequence ranging systems. In direct sequence ranging, code modulation and demodulation are performed in exactly the same manner as in a communications systems, ie, the code employed phase shift modulates the carrier.

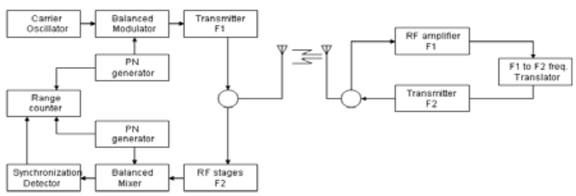
The two common and important direct sequence ranging systems are:

1) Simplex :
   Transmit-then-receive system.
2) Duplex :
   Transmits and receives simultaneously.

In both the cases, the transmitter sends a pseudo-noise code-modulated signal.For the sake of comparison we can discuss the duplex ranging method first.

B. Duplex ranging system

In the duplex ranging system, the transmitter and the receiver operates simultaneously.



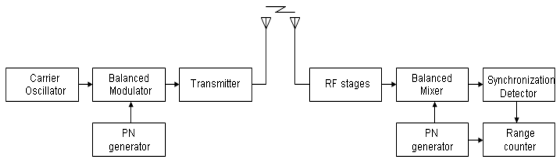
(a) Duplex ranging systems.

As we can see in fig.1, at the receiver the transmitted frequency F1 is translated to a different frequency F2 and is retransmitted. The receiver subsystem located at the original transmitter location, synchronizes to the return signal. Measuring the number of chips of code delay between the signals being transmitted and received, we can determine the range from itself to the repeating station. Obviously the time delay corresponds to the two-way propagation delay.

Here we should employ two separate PN code generators for transmitter and receiver subsystems as by definition, the code at the receiver should be out of phase with the transmitted code.

C. Simplex ranging system

Unlike the duplex systems, in the simple time sharing ranging systems the transmitter and the receiver do not operate simultaneously. But the operating principle is the same.



(b) Transmit-receive ranging systems.

Here the transmitter would transmit a signal and remain for a period equal to which the transmitter thinks the receiver would need to synchronize with the signal. At the receiving end, the signal is matched with its internal code reference. Once the internal acquisition is acquired, the transmitter stops transmitting and gives a command to the responder to retransmit. The transmitter or the interrogator then switches to receiving mode. The responder will be locked to a coded signal which is offset from the original code by an amount of range delay and will transmit using the same code. So the interrogator has to adjust its code phase by an amount equal to twice the delay in order to match with the receiving signal.

D. Tone Ranging

This is another type of ranging technique using multiple, coherent tones that modulates a single carrier. As shown in the fig.

Tone ranging.

All the tones should start from the same point. As the tones have unique phase relationship at each point, we can determine the range. One disadvantage is that we can only measure the range less than the period of the lowest tone.

Sources of range errors

All the errors possible are more of less similar. The common errors possible are :

1) Doppler- induced error.

If we have to find the range of a moving target, then the range measurement will be affected by the Doppler effect. This problem can be rectified by inducing an offset, equal to the amount that is likely to be caused by the Doppler effect, to the receiving signal.

2) Clock-rate offset.

If the clock at the transmitter or at the receiver is subjected to an offset, consequently the chips/mile for the ranging measurement will change.

3) Clock-rate error.

If by any chance, an error occurs in the clock-rate it will have the same effect as the clock-rate offset.

4) Bit-count error.

This is a possible error, a function of the accuracy of the responder's clock and would not be resolvable by either interrogator or responder.

E. Frequency Hopping Ranging Systems

Frequency hopping systems are not used as common as direct sequence systems for ranging applications. This is because of low resolution of frequency hopping systems when compared to the direct sequence systems. For direct sequence modulation we use code with high bit rate. But the hopping rate for frequency hopping system is not as high as that. As a result the resolution obtained will be less.

Once high speed frequency synthesizers are implemented, frequency hopping systems will provide high resolution as direct sequence systems.

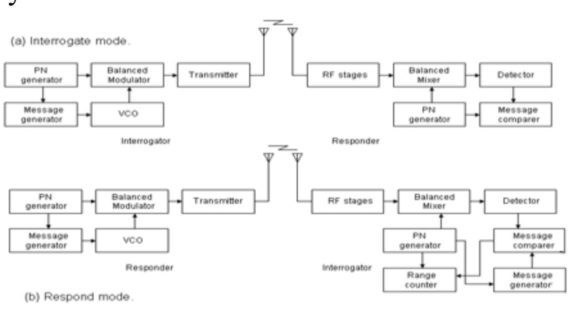
Also if a system with such coherence can be implemented, tone ranging also can be used in frequency hopping systems where the tone's separation from the band center corresponds to a particular hop frequency. This will help to improve the resolution.

Selection of ranging codes

Code sequences for ranging are chosen on the basis of consideration for their autocorrelation and cross-correlation properties and in most ranging systems for sufficient length. In direct sequence systems we have to use codes of length that wouldn't repeat within the range to be calculated. These long codes would need sufficiently long synchronizing time. This problem can be solved by using another ranging technique called Hybrid Ranging technique.

F. Hybrid Ranging Systems

Here a PN code, a thousand chips long along with a digital range message (whose bit rate is equal to the repetition rate of the PN sequence) simultaneously modulates the transmitter. The PN code does not determine the maximum range and so its length can be reduced without affection the cross-correlation requirements so that the synchronization time can be reduced.



First the interrogator transmits a PN modulated signal for a period necessary to synchronize the responder. Then the range message is sent at the PN code repetition rate and is followed by a phase inversion of the message. This information FSK modulates the PN modulated carrier. At the receiver, starts the generation of the exact range message. The transmitter then switches to receiving mode and the responder switches to the transmitting mode.

Responder then transmits the PN modulated signal and at the interrogator it counts the chips required to regain synchronization and stores the count, Then the responder sends the range message along with the PN modulated signal. Interrogator counts the number of chips between the first inversion of the received signal and the next inversion of its own signal. This count is added to the PN chip count and is read as the total delay corresponding to the two way delay.

Thus the use of range message rectifies the resolution problem caused by the short code.

Satellite Ranging using PN codes

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) . 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). 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 have periods that are relatively prime. 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

ΨtT and ΨtR (and their difference) modulo K RU, where $K = \Lambda / 2.2^{6+C}$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.

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.

Composite pn code generation

There are two PN codes recommended for regenerative ranging by the PN ranging standard. Both codes have similar structure and come from the same family of PN codes, but differ in the strength of the ranging clock component. The first PN code is called the weighted-voting (ν=4) balanced Tausworthe code, and is abbreviated asT4B. This code has a stronger ranging clock component, and will provide greater ranging accuracy at the expense of slightly longer acquisition time. Thus the T4B code should be used for ranging systems where ranging accuracy is of primary concern, such as for radio science. The other recommended PN code is the weighted-voting (ν=2) balanced Tausworthe code, abbreviated as T2B. This code has a weaker ranging clock component relative to the other components and will have a faster acquisition time at the expense of greater jitter in the ranging measurements. The T2B code should be used for ranging systems where acquisition time is of primary concern, for example, in missions where the expected ranging SNR is very
low.

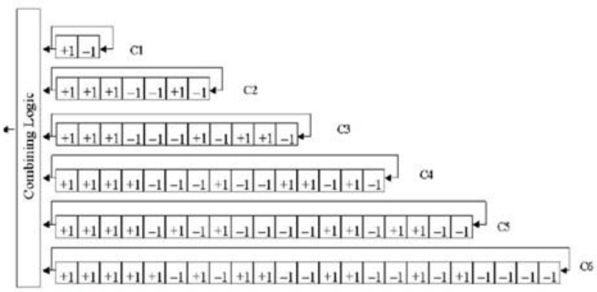
Table 2-1: Component PN Sequences

Code	Component Length	Chip Sequence
C_1	2	1, -1
C_2	7	1, 1, 1, -1, -1, 1, -1
C_3	11	1, 1, 1, -1, -1, -1, 1, -1, 1, 1, -1
C_4	15	1, 1, 1, 1, -1, -1, -1, 1, -1, -1, 1, 1, -1, 1 -1
C_5	19	1, 1, 1, 1,-1, 1, -1, 1, -1, -1, -1, -1, 1, 1, -1, 1, 1, -1, -1
C_6	23	1, 1, 1, 1, 1, -1, 1, -1, 1, 1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, -1, -1, -1

T4B PN Code Structure

The structure of both the T4B and T2B codes is based on a composite code built from logical combinations of six periodic component PN sequences, originally derived by Tausworthe. The six component sequences are shown. Each component sequence is placed in a circular shift register with length equal to the component length and clocked at the chip rate. The T4B composite code is formed from the combination of the shift register outputs using the following formula:

$$C = sign(4C_1 + C_2 - C_3 - C_4 + C_5 - C_6)$$



where the combined sequence is $C = sign(4C_1 + C_2 - C_3 - C_4 + C_5 - C_6)$

Figure 2-2: T4B PN Code Generation

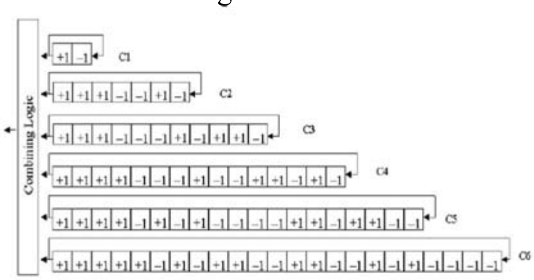
T2B PN Code Structure

The component sequences used for the T2B code are identical to those used for T4B. The combination logic to form the T2B composite code is given by:

$$C = sign(2C_1 + C_2 - C_3 - C_4 + C_5 - C_6)$$

The combination logic is identical to that used to generate the T4B code, except the $C1$ component is weighted only by a factor of two (i.e., two votes).

Thus this code has a weaker range clock component. Figure 2-3 shows a block diagram of the T2B PN code generation.



where the combined sequence is $C = sign(2C_1 + C_2 - C_3 - C_4 + C_5 - C_6)$

Figure 2-3: T2B PN Code Generation

Application of Spread Spectrum Ranging Systems

For the time being, there are not many areas that uses spread spectrum signals for ranging. Some of the important areas are

1) Position Location Systems.

The well known application in this area is GPS (Global Positioning System). Another spread spectrum position location system is PLRS (Position Location and Ranging System).

2) Space Systems.

An important space oriented spread spectrum system is TDRSS (Tracking and Data Relay Satellite System). Spread spectrum signals are also employed for ranging at interplanetary distances.

3) Avionics Systems.

In avionics systems, spread spectrum signals can be employed for ranging, but one major problem is the large and unpredictable range of doppler- frequency offset. One important system in this field is ARC-50.

III. CONCLUSION

Considering all the above said facts, it can inferred that spread spectrum signals can perform as navigational signals very favorably when compared to the other signal formats. The most interesting fact is that though acting as a navigational signal, none of its other unique properties are impaired. Because of the high resolution possible this exceeds the performance of many other ranging methods.

IV. FUTURE STUDY

Spread spectrum ranging systems will always advance with the increasing application in position location systems and space systems etc. Once the hardware implementation in achieved there will always be possibilities in increasing resolution, decreasing ranging time etc.

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