# A Proposal for Aircraft Tracking Satellite System

## ~ Never to repeat the disaster of MH370~

Osamu Ichiyoshi
Human Network for Better 21 Century
http://www5e.biglobe.ne.jp/~kaorin57/

## Abstract

Malaysian Airways Flight370 (MA370) lost contact with the air traffic controllers on 8, March, 2014 and was never discovered since. The fate of the flight with 239 people onboard is totally unknown. The failure of the rescue operation is due to the lack of knowledge about the location of the aircraft after its last contact with the air traffic controllers. The lack of the knowledge about the location of the aircraft caused waste of the precious initial time for the rescue operations.

It is clear the existing aircraft tracking systems have serious defects. The GPS provides exact positioning tool for the mobile user but it was useless in this case where the communication links between the aircraft and ground controllers were lost.

The requirements for the aircraft tracking system shall be (1) frequent contacts, i.e. about once every second, (2) Exact location determination with triangulation through more than 3 satellites, (3) Non-ceasing contacts during flights.

In reality we have many communication satellites in operation. Theoretically there are sufficient numbers of satellites for triangulation functions in many parts of the world. In order to use them for the aircraft tracking system, we need to add more requirements; (4) the newly added aircraft tracking system shall not inflict any serious degradation for the existing services. Practically those satellites operate in different radio frequencies and polarizations conditions. Thus we need an additional requirement; (5) The added aircraft tracking system must be flexible to function in different RF conditions.

This paper makes a proposal of a system that meets the above requirements and describes the principle and major specifications of the operations. It is the author's wish that such a system will be realized as early as possible.

## Keywords

MH370, Aircraft Tracking Satellite System, GPS, Triangulation through 3 satellites, CDMA, Spectrum Spreading, High Process Gain, TDMA, Existing SATCOM systems, Degradation, Interferences,

## 1, Disaster of MH370

Malaysian Airways Flight370 (MA370) headed for Beijing, China from Kuala Lumpur, Malaysia lost contact with the air traffic controllers on 8, March, 2014 and was never discovered since. The fate of the flight with 239 people onboard is totally unknown. The failure of the rescue operation is due to the lack of knowledge about the location of the aircraft after its last contact with the air traffic controllers at 1:19. The lack of the knowledge about the location of the aircraft caused waste of the precious initial time for the rescue operations. Large scale search operations were made by cooperation of many countries in the Thailand Bay, South Indian Ocean and other areas for months but none of the aircrafts remains were found.

## 2. Critical Communication Links for Aircraft Tracking System

The MH370 disaster revealed the essential defects of the current aircraft tracking system. The positioning systems today are based on GPS for its accuracy and low operation cost. The MH370 event has revealed the essential defect of the current aircraft tracking system is possible loss of communication. It is suspected that the communication link between MH370 and the air traffic controllers were deliberately cut off. Therefore the new aircraft tracking system must provide a communication link that can not be intentionally cut off by anyone onboard the aircrafts.

## 3. Availability of Multiple Satellites for Positioning Functions

The positioning systems can be classified into 3 categories; passive, active and hybrid [1]. The passive positioning systems including GPS require a simultaneous view of 4 satellites for positioning in order to determine the three spaces and one time coordinates. The positioning function is conducted by the mobile terminals. No two-way communication between the systems and mobile terminals are required. On the other hand, the active positioning methods require two way communications between the system and mobile terminals. The system conducts the positioning functions and the position of the mobile is notified of it through the communication link. The feature of the active positioning method is that the required number of the satellite links is 3, one less than the passive positioning systems as GPS. The hybrid positioning system is the combination of the passive and active methods.

The desired aircraft tracking system we want to develop here requires the active positioning system; the integrated communication and positioning services. It is also classified as Radio Determination Satellite System (RDSS). One such system titled as GEOSTAR was once planned and partially constructed [2]. Unluckily GEOSTAR system did not take off due to satellite failures and other reasons. Anther RDSS services in operations is OmniTracs [3]. The non-geostationary mobile satellite communication systems with CDMA schemes such as Globalstar [4], New-ICO [5] could have provided excellent RDSS services for the aircrafts. It is so unlucky that RDSS systems have not taken off due to the enormous success of GPS and terrestrial mobile communication networks for the past 20 years.

In reality we need to reuse existing satellites in operations. In order to provide a universal RDSS services for the aircrafts, we need as many satellites as possible to realize triangulation everywhere.

## 4. The Proposed Aircraft Tracking System

### 4.1 System Architecture

The proposed system architecture is depicted in Figure 1.

The operational principle of the proposed aircraft tracking system (ATS) is described as follows.

[1] The aircraft is equipped with a communication system that can transmit and receive signals through multiple satellites in its view.

[2] The “Gateway Stations” are equipped with the “Satellite Links Delays Measurement Function” with communication links to the aircrafts through their satellites.

[3] The gateway stations are linked with “ATS center” through the Internet.

[4] The ATS center requests the gateways to measure the satellites links delays to the target aircrafts.

[5] The gateways provide ATS center with the measured satellites links delays data.

[6] ATS center calculates the positions of the target aircrafts.

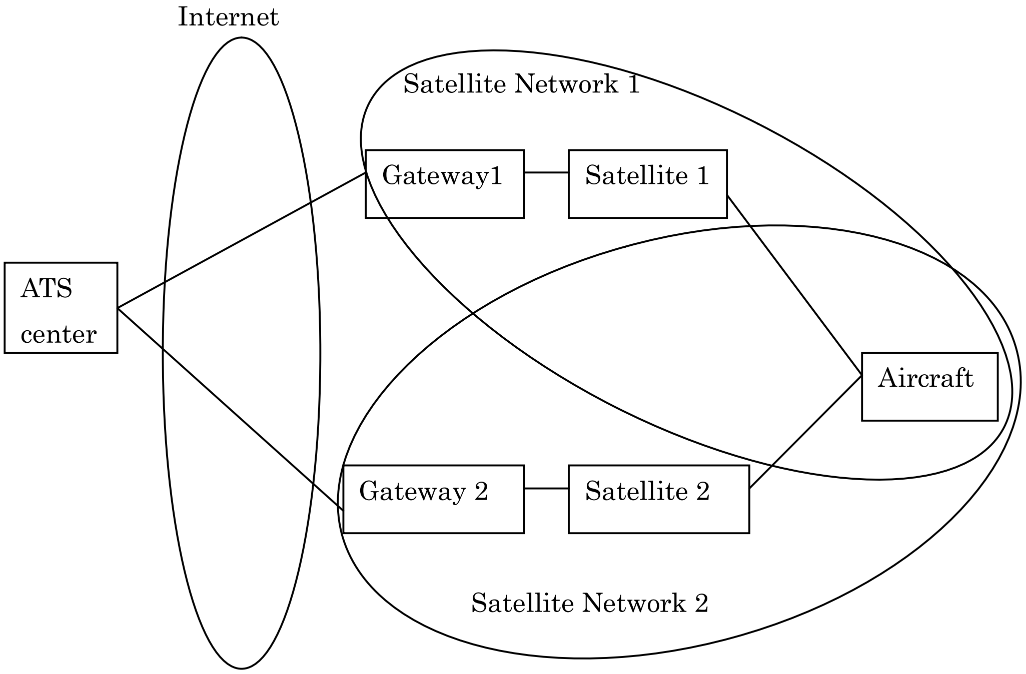

Figure 1 System Architecture of the proposed aircraft tracking system

### 4.2. Performance Requirements

The following requirements for the proposed aircraft tracking system (ATS) must be met based on the lessons from MH370 disaster and reuse of the existing satellites systems.

(1) Frequent contacts, i.e. about once every second,
(2) Exact location determination with triangulation through more than 3 satellites,
(3) Non-ceasing contacts during flights; intentional cutting of the satellite links shall be impossible.

From reuse of existing satellites in operations;

(4) The added ATS shall not inflict any serious degradation for the existing services
(5) The added ATS must be flexible to function in different RF conditions.

## 4.3. System Design

### 4.3.1. Adding ATS to existing satellite communication systems

At the gateway stations the ATS subsystems will be added to the existing systems at IF commonly at 70, 140MHz or at L bands. The ATS signals are of sufficiently low level to avoid giving interferences to the existing services. The ATS signals need to be of wide bands in order to achieve enough timing precision. Those requirements can be met by spectrum spreading technology.

The ATS subsystem added to an existing gateway station is depicted in Figure 2. The ATS subsystem onboard the aircraft is depicted in Figure 3. In the figures the dotted lines show non real-time data and solid lines are real time time-sensitive signals.

### 4.3.2. Operation of the Proposed ATS system

[1] System Time Base

The ATS center and ATS subsystems at the gateways are synchronized to form System Time Base. GPS will used to synchronize the System Time Base.

[2] Forward ATS Frame Signal

The Forward Frame Signal is generated at TX Frame Generator & Modulator ( TX Fr.Gen.&Mod). The information contained in the TX Frame includes Time Stamp, GW ID and Location Data, Satellite ID and Location Data, and Acquisition Control Signals for the Aircraft ATS terminals. The frame timing ( frame period is 1 sec) is given by the Time Base. The TX Frame Signal is modulated at a common IF frequency (i.e. 70MHz). The TX Frame signal is then spectrum-spread by TX PN Generator which generates a Pseudo-Noise (PN) signal with the code designated by the controller (Cont.) and at the timing given by the Time Base. The Controller (Cont) controls the operation of the ATS subsystem through the satellite link, exchanging data with the ATS Center. The Controller also provides Man-Machine Interface for the operator. The Spectrum-spread TX Frame signal is sent to the existing Gateway system for transmission over the forward satellite link.

[3] Aircraft Terminal

The Aircraft terminal receives the forward satellite link signal which is the superposition of the ATS Forward Frame Signal and existing communication signals. The power level of the ATS signal is even lower than the thermal noise in order to avoid giving interferences to the existing services. The receive signal is put into PN Code correlation circuit (PN Code Corr.) which enhances the ATS signal as much as the spreading ratio. The PN code for the satellite link is a priori known by the aircraft. The

PN Code Correlation circuit establishes the system timing of the aircraft terminal. The aircraft Time Base is reset by the detected Forward Link ATS Frame timing. If the aircraft terminal receives Forward ATS signals through 4 satellites, it can conduct its positioning by the same principle as GPS (passive positioning).

For active positioning, the aircraft generates a Channel Request signal including its ID, modulates and spectrum spread by the ALOHA PN Generator. The PN code is designated by the Controller (Cont) which also provides the man-machine interface for the user. The ALOHA PN code is also a priori known through the system.

The Gateway ATS receives and regenerates the ALOHA request signal by correlation detection with the ALOHA PN code followed by demodulation. Then the gateway ATS controller allocates a Channel Code and the Time Slot on the Return Frame for transmission of its signal.

The aircraft terminal decodes the PN Code and Time Slot channels allocated to it. The aircraft ATS then generates the Return signal including its ID, designated Return Frame Timing. The Return signal is modulated and spectrum-spread by the assigned Channel PN code and at the designated timing given by the Time Base.

[4] Return Frames Signals for Satellite Links Round Trip Delay Measurement

The Gateway ATS receives the Return signals, which is processed by PN Code Correlator. The PN Code is designated by the controller (Cont). The PN Code Correlation enhances the carrier to noise ratio (C/N) of the wanted signal and simultaneously detects the receive timing of the signal from the aircraft. The detected timing is fed to Satellite Link Delay Detection (SLDD) circuit, which detects the round trip satellite link delays to/from the aircraft against the System Time Base. The detected satellite link delay data is put into the controller (Cont) which transfers the data for the ATS Center.

[5] ATS Center

The ATS center exchanges data with many Gateways for the Aircraft Tracking System operations.

<1> ATS Center holds the list of aircrafts in its User File.

<2> The aircraft, after taking off, achieves synchronization with the Forward Frame Signal which is spectrum- spread by a PN Code commonly known in the system.

<3> The aircraft requests allocation of the Channel Code and Time Slot by sending the ALOHA signal at a random timing.

<4> Upon detection of the ALOHA signal, the Gateway notifies the ATS Center of the aircraft requesting for the service.

<5> The Gateway allocates the Channel Code and Return Frame Time Slot to the

aircraft through the Forward Link Frame Signal.

<6> The aircraft sends its signal in the designated Time Slot and spectrum spread with the designated PN Code. .

<7> The Gateway conducts the satellite link delay measurement for the aircraft and delivers the data to ATS Center.

<8> The ATS Center conducts the above operations with multiple satellite systems.

<9> Based on the satellite links delay data through multiple satellite links, the ATS Center calculates the location of the aircraft.

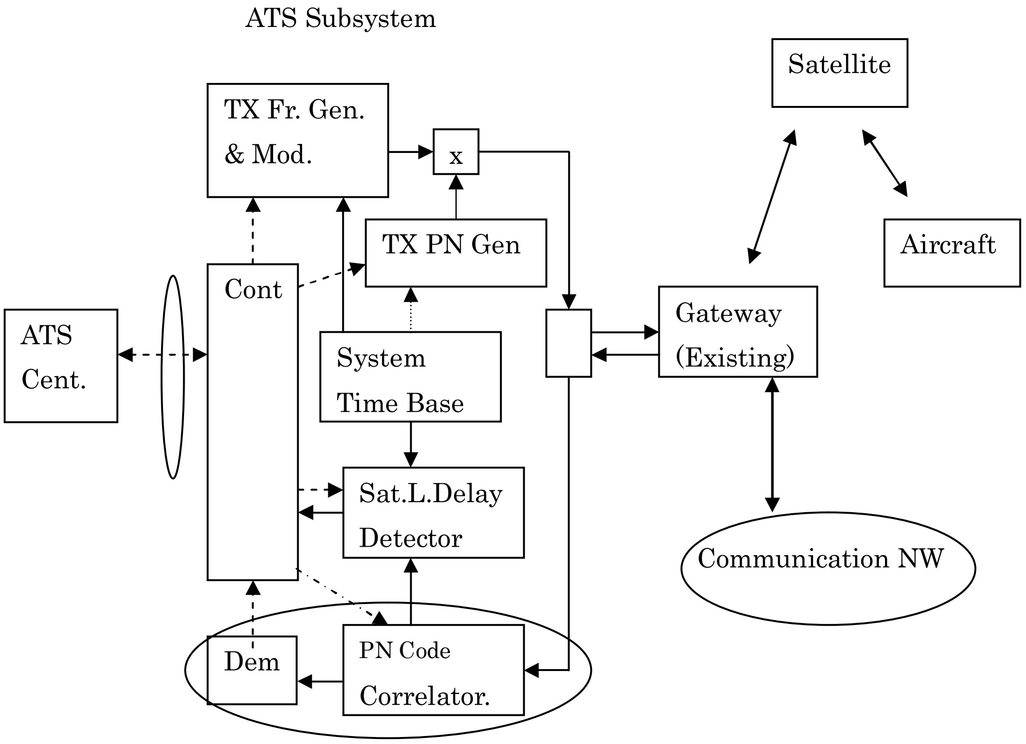

Figure 2 ATS Subsystem Added to Existing Gateway Station

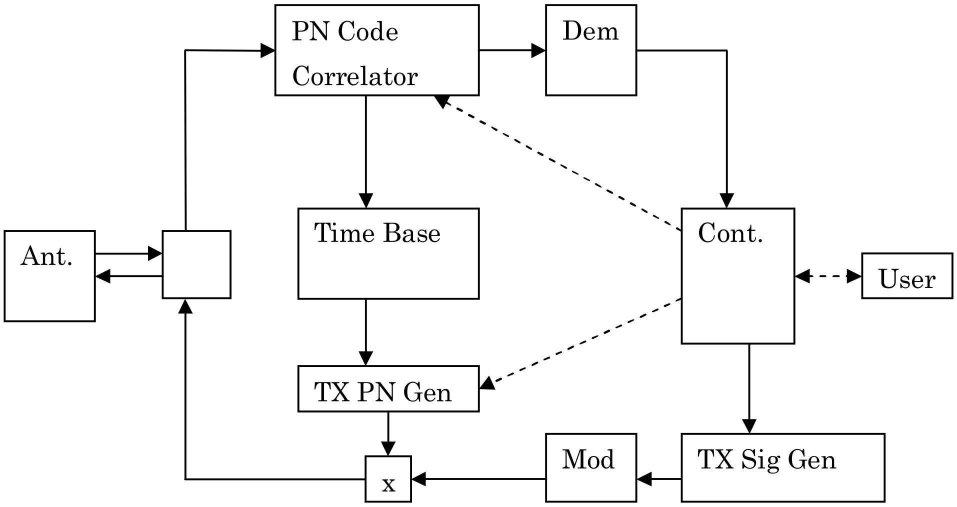

Figure 3. ATS subsystem on Aircraft

### 4.3.3 Major system parameters

| | |
|---|---|
| [1] Symbol rates of ATS signals | : 1kbaud |
| [2] Chip rate for spectrum spreading | ; 10 (Mchip/s) |
| [3] Process gain; | ; 40 (dB) |
| [4] Operating conditions of existing systems; | |
| (1) Operation C/N | ; 13(dB) |
| (2) Degradation caused by added ATS | < 1.0 (dB) |
| [5] Positioning Errors (km) | < 1.0 |

### 4.3.4 Performances

The frequency spectrum is depicted in Figure 4.

[1] Existing communication channel

The parameters for the existing communication channels are as follows.

| | |
|---|---|
| - Carrier signal power (W) | ; Cc |
| - Frequency Bandwidth (Hz) | ; Bc |

- Noise power density ; $N_o$ (W/Hz)
- C/N ratio without positioning signal ; $(C/N)_{co} = C_c / (N_o \cdot B_c)$

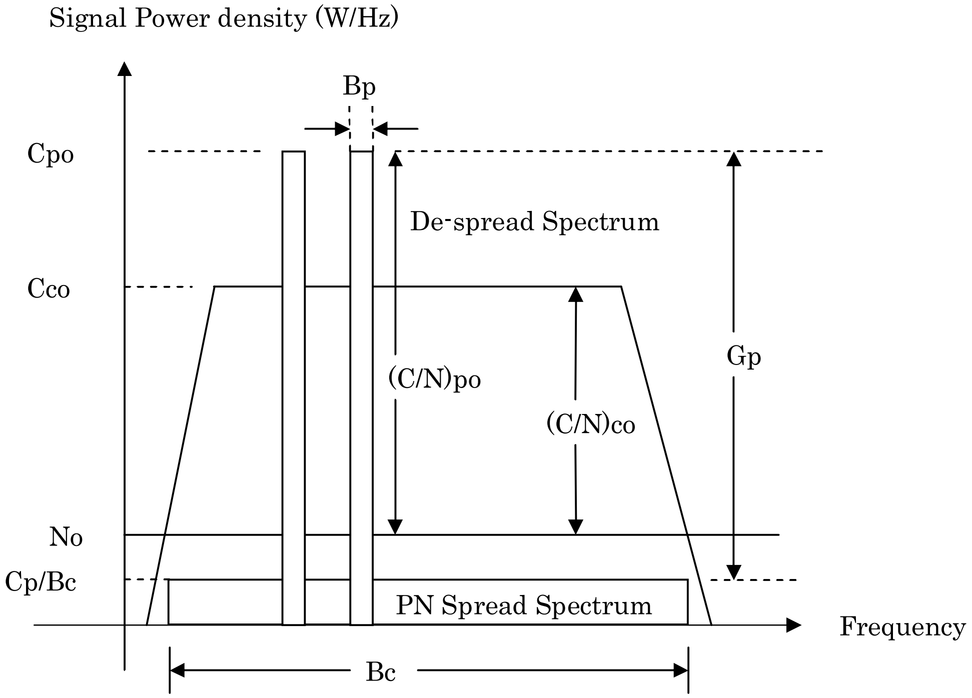

Figure 4 Frequency Spectrum of Communication and Positioning Signals

[2] Added positioning signal

- Carrier signal power (W) ; $C_p$ (W)
- Frequency Bandwidth before spreading ; $B_p$ (Hz)
- Frequency Bandwidth after spreading ; $B_c$ (Hz)
- Spread Ratio or Process Gain ; $G_p$ ( $B_c / B_p$ )

[3] Degradation of existing communication channels by added positioning signals

The added positioning signal is spectrum spread to Bc. The positioning power density is $C_p/B_c$ (W/Hz). If we add n positioning channels, the equivalent noise power density is $N_o + n \cdot C_p/B_c$.

The resultant C/N for the existing communication channel with n positioning channels is;

$$(C/N)_c = C_c / \{B_c \cdot ( N_o + n \cdot C_p / B_c)\} = (C/N)_{co} / \{ 1+ n / G_p \cdot (C/N)_{po}\}$$

Where

$$(C/N)po = Cp / (No \cdot Bp)$$

The degradation of the communication channel is;

$$[C/N]co - [C/N]c = 10 \cdot \log(1 + n / Gp \cdot (C/N)po) \qquad (dB)$$

$$(=)\ 4.3 \cdot n / Gp \cdot (C/N)po \qquad (n / Gp \cdot (C/N)po << 1)$$

Where (=) means nearly equal.

[3] C/N of positioning signal after spectrum de-spreading

At the receiver, the signal power density of the positioning signal after de-spreading is Cp/Bp. Other signals are noise noise spread over bandwidth Bc. The resultant (C/N)p is;

$$(C/N)p = Cp / \{Bp \cdot (No + (n-1) \cdot Cp / Bc + Cc / Bc)$$

$$= (C/N)po / (1 + (n-1) / Gp \cdot (C/N)po + (C/N)co)$$

$$(=)(C/N)po / (C/N)co \qquad ((C/N)co >> 1 >> (n-1) / Gp \cdot (C/N)po)$$

[4] Noise performances of communication and positioning channels.

An example system design is given as follows.

| | |
|---|---|
| Existing channel; | $(C/N)co = 20$, or |
| | $[C/N]co = 13$ (dB) |
| Spectrum spread ratio; | $Gp = 10000$, or |
| | $[Gp] = 40$ (dB) |

Let C/N degradation of existing communication channel due to a single positioning channel less than 0.1(dB).

$$4.3 / Gp \cdot (C/N)po < 0.1, \quad \text{or}$$

$$(C/N)po < 0.1Gp / 4.3 = 232, \quad \text{or}$$

$$[C/N]po = 10og((CN)po) = 23.7 \ (dB)$$

The actual C/N ratio of the positioning signal is

$$[C/N]p = [C/N]po - [C/N]co = 23.7 - 13.0 = 10.7 \ (dB)$$

[5] Effects of multiple positioning signals

The existing channel degradation is;

$$[C/N]co - [C/N]c = 10 \cdot \log(1 + n / Gp \cdot (C/N)po)$$

$$= 10 \cdot \log(1 + 0.023n) \qquad (dB)$$

$$(=)\ 0.1n$$

The positioning channels can be multiplexed in FDMA ( Frequency Division Multiple Access) mode as depicted in Figure 4. The [C/N]p remains constant as [C/N]co >> 1.

[6] Positioning capacity

The above analysis gives the following positioning capacity.

Each aircraft can transmit three positioning packets every second through three satellites. Each packet has about 300ms duration that can carry about 300 bits for BPSK modulated positioning signal. Up to 10 positioning channels can be transmitted hence about 30 positioning operations can be supported by the system. The precision of the timing measurement is determined by the chip rates of the PN signals. In this case it is 10Mchips/s, that gives the timing precision better than 0.1 $\mu$ s, corresponding to 30 meters in distance.

The speed of the aircraft is about the speed of sound; 340m/sec. The precision of 1 km can be achieved for up to 90 aircrafts. This is achieved for 10MHz bandwidth. The bandwidth of 100MHz, 1GHz can expand the capacity to 900, 9000 aircrafts supported by 3 satellites systems.

### 4.4 Detection of ALOHA channel

The PN code correlation circuits in the Gateway and Aircrafts can be implemented for each CDMA (Ccde Division Multiplex Access) channel by DLL (Delay Lock Loop) [6].

The ALOHA PN code is common in the satellite network. All aircrafts use the same PN code for channel request functions. At the gateway the ALOHA PN correlation circuit must function for all the ALOHA signals from the aircrafts; it must operate in shared mode. A circuit for the Gateway ALOHA common Correlator is given in Figure 5. The ALOHA code C(0), C(1), ,,C(L-1) take values +1, or -1. Each tap output of the shift register is multiplied by C(l) (l=0,1,2,,,,L-1) and then summed up to give the correlation output.

The frequency errors cause degradation of the correlation detection. Let fe be the signal frequency error at the input of the ALOHA signal correlation circuit. Then the output of the correlation output is;

$$1 + e^{j(\Delta\theta)} + e^{j(2\Delta\theta)} +,,,,+ e^{j((L-1)\Delta\theta)}$$

$$= e^{j((L-1)\Delta\theta/2)} \cdot \sin(L\Delta\theta/2) / \sin(\Delta\theta/2)$$

Where

$$\Delta\theta = 2\pi \cdot fe \cdot Tc$$

Tc is the chip symbol length which is 100ns for 10Mchips/sec.

$$L\Delta\theta/2 = \pi \cdot fe \cdot (Tc \cdot L) = \pi \cdot fe \cdot Td$$

Where Td = Tc・L is data symbol length which is 1ms for 1kbaud symbol rate.

The correlation output is

$$[\text{correlation output}] = e^{j(\pi \cdot fe \cdot Td)} \cdot L \cdot \sin(\pi \cdot fe \cdot Td) / (\pi \cdot fe \cdot Td)$$

Note it equals L for fe = 0.

The amount of degradation for fe.Td =1/2, i.e., fe = 0.5kHz ; the correlation output reduces by 2/π, or 4dB.

As the aircraft terminals regenerate the Forward Frame signal, the forward link frequency errors are compensated. The return links frequency errors can not be compensated by the aircrafts. In a Ka band the above fe = 0.5(kHz) is achieved if the frequency stability of the return links are better than 0.5k/20G = 2.5 x 10^-8.

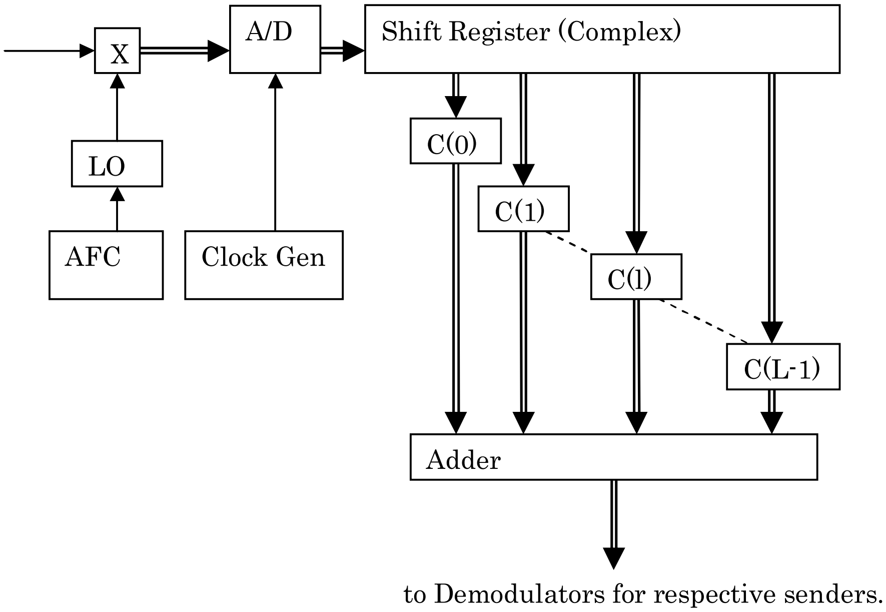

Figure 5 ALOHA PN Correlation Circuit

## 5. Conclusion

By reuse of existing satellites, it is shown that about 90 sonic aircrafts can be continuously tracked within 1km precision using 10MHz bandwidth of 3 satellites systems. The degradation to existing services caused by the added aircraft tracking system is less than 1dB. With 100MHz bandwidth the capacity increases to 900 aircrafts via 3 satellites systems. If 100 satellites can be used globally, the number of the aircraft by the proposed method will be 27,000.

## References

[1] Olof Lundberg, "Cutting the cord, introducing mobile satellite communications"
Never Beyond Reach , Inmarsat, 1989

[2] Martin A. Rothblatt, "Radiodetermination Satellite Service"
2213-7/850000-029 $1.00 1985 IEEE

[3] Omnitracs ; http://www.omnitracs.com/

[4] Globalstar ; http://www.globalstar.com/

[5] Osamu Ichiyoshi, "New ICO, A Proposal for a CDMA Mobile Satellite System"
IEICE Technical Report, SAT2007-42(2007-11)

[6] V.K.Vhargava, D.Haccoun, R.Matyyas and P.P.Nuspl,
Digital Communications by Satellites, John Wiley and Sons, Inc, 1981

---E---