A BETTER WAY OF LIFE FOR PPS USERS ... GPS SAASM AND P(Y)-DIRECT, THE NEW WAVE OF MILITARY RECEIVER TECHNOLOGY FOR THE PPS NAVIGATION AND TIME AND FREQUENCY USER

Hugo Fruehauf
Zyfer, Inc.
1585 S. Manchester Ave.
Anaheim, CA 92802, USA
Tel: (714) 780-7960; Fax: (714) 780-7760
hxf@odetics.com

Abstract

This paper discusses the new GPS receiver technology being introduced to all U.S. Military Services and U.S. allies, now using standard PPS receivers. The new receivers implement two very distinct, yet highly synergistic characteristics: the ability to acquire the P(Y) code direct, without the use of the C/A-code signal, and the new security architecture called SAASM (Selective Availability Anti-Spoof Module).

In this paper, the focus is on the Direct P(Y) for the crypto-keyed receiver and the precision time and frequency applications that can take advantage of this new capability.

Also included in the discussion is the future of the Selective Availability (SA) signal degradation and the overall scenarios of civil and military GPS signal availability.

INTRODUCTION

Extensive field experience and technology advances have contributed greatly to bring the military Precise Positioning Service (PPS) user to new levels of sophistication. This new GPS receiver, with revolutionized security architecture called SAASM and its new P(Y)-Direct acquisition functionality, promises a more robust capability for our forces and coalition operations.

DEFINITIONS

SAASM - Selective Availability Anti-Spoof Module, a new PPS Receiver Security Architecture and Key Management Infrastructure.

Direct P(Y) Acquisition - A more robust functionality for PPS receivers to reduce susceptibility to jamming and spoofing and provide the ability to acquire the P(Y) code without the aid of the C/A signal.

SCOPE

The GPS-JPO requires that the new security architecture that comprises SAASM be discussed in

applications meetings only, between receiver suppliers and authorized PPS user agencies of the U.S. government and its allies. Classified sessions can also be setup between authorized parties. The GPS-JPO contact is Lt. Anthony D. Smith, *anthony.smith@losangeles.af.mil* (310) 363-0947 Phone, (310) 363-3844 Fax.

As a result, the scope of this paper is the Direct P(Y) acquisition, the ability to do a first fix without precision GPS time which normally comes from the initial acquisition of the C/A code. This capability is only now possible after 25 years of digital electronics improvement. Direct P(Y) is accomplished through low cost, low volume, and low power consumption digital parallel correlators. P(Y) direct offers many advantages for the PPS time and frequency user in that the navigation and communications terminals can come on line-cold-without being aided by the C/A signal.

THE NEED FOR NEW PPS RECEIVER TECHNOLOGY

Thanks to the tremendous success of the L1 C/A-code Standard Positioning Service (SPS), industry has produced millions of low cost commercial receivers for civil navigation and timing applications. This success has resulted in a huge market for U.S. manufacturers of commercial GPS receivers and has led to a vast proliferation of these receivers to virtually every corner of the planet. Anyone with a C/A-code (Clear/Acquisition) receiver can navigate to a formidable 50 to 100 meters and synchronize to UTC to better than 1 microsecond. This level of accuracy is achieved even in light of Selective Availability (SA), the intentional degradation of the civil SPS signal currently set to 100 meters accuracy and 1 microsecond time error.

This proliferation of commercial GPS receivers poses a major dilemma for our military and allies. How can the military protect its forces from enemy navigators using the civil signal while at the same time keeping the huge world infrastructures that have been built on civil GPS from going down (i.e., Telecommunication Networks and Civil Aviation). From presentations made in public forums, from policy statements published by the Pentagon, and from articles in various magazines, one can conclude that military planners are thinking their way through this scenario to find ways to resolve this dilemma. But no matter how good the potential solutions are, the implementation of those solutions depends solely on the good guys being outfitted with full-service PPS receivers. This is where the new SAASM PPS security architecture and the Direct P(Y) functionality come in. The receivers will be significantly easier to field than the currently available PPS receivers. For the end user, this translates to a PPS receiver that is easier to obtain, requires less logistics, and enhances coalition operations when the success of the mission relies on secure GPS interoperability with Allied forces.

P(Y)-DIRECT ACQUISITION—THE KEY TO 'PPS ON-LINE'

This new capability is the glue that makes the military GPS operational scenarios concerning the C/A and P(Y) signals hold together. There appears to be a new emerging philosophy from our government planners. Until now it was, 'provide the C/A to all but not at full capability'; i.e., the use of SA, the intentional degradation, adjustable to any level. The new philosophy appears to be, 'provide full civil capability, even with future enhancements and augmentations, and surgically deny in times of conflict'. The first step of this new philosophy has already been set in motion with the 1996 PDD (Presidential Decision Directives) which states that SA degradation will be removed by the year 2006. No doubt, it may be even sooner.

If in fact there may be C/A signal availability issues in times of hostilities, the military must be able to stay on line or come on line, independent of the required C/A lead-in signal. This of course is where Direct P(Y) comes in – the lock-on to the P(Y) signal in the absence of C/A. There are at least three scenarios for compromising C/A availability: local jamming, increasing SA, or more drastic means of making C/A unavailable.

- The method of choice would appear to be surgical jamming of the C/A signal by our forces in the region of conflict, using relatively low power in-band CW or broadband airborne jammers. This is the least impact scenario, affecting only the local area under the jammer. So, how do infrastructures fair using SPS and PPS service?

C/A User Impact (SPS)	P(Y) User Impact (PPS)

• Brings down SPS in **Local Area**
  - Commercial and Civil Aviation
    Navigation
  - GPS Augmentation Systems
  - Telecom Networks and Time and
    Frequency Users go on "Hold-Over"
    oscillators
	• Standard PPS Receiver On-Line
	  - Standard PPS can not come up cold
	    unless accurate time is available
	• Direct P(Y) PPS can come up cold
	  - More robust in Jamming

- If the area of conflict is more widespread, where local jamming may not be practical, the next method of choice might be the increasing of the SA degradation to many hundreds of meters or more. This would have a worldwide affect on navigators who are not served with some form of differential GPS augmentation. The telecommunications timing user at this point is probably still unaffected, since SA is typically filtered out by well designed equipment. This is possible due to the stationary nature of cell sites and telecom networks. For the enemy, increasing the SA may still not be a long-term deterrent, since he can also set up a differential GPS (DGPS) network. This will help defeat the increase in SA by observing many SA degraded C/A signals, filtering them against previously surveyed reference locations.

C/A User Impact (SPS)	P(Y) User Impact (PPS)

• Reduces accuracy of SPS or makes it
  go down, **Worldwide**
• Unaided Civil Aviation Navigation
  Accuracy reduced or goes down
• Stationary Terminals, like GPS Augmentation
  Systems, Telecom Networks and Time and
  Frequency Users **Less Affected**
	• Standard PPS Receiver and Direct P(Y)
	  PPS On-Line
	  - PPS not affected by SA increase
	  - May take longer to acquire from cold
	    start

- Then comes the unimaginable—when the stakes are so high that the military is tempted to shut down the satellite C/A signal altogether. This would have a disastrous worldwide affect in shutting down civil aviation and navigation users. The telecom and computer networks dependent on GPS timing would go on 'hold-over' with their internal flywheel clocks. Network sync might be maintained for days or weeks, depending on the robustness of the flywheel clocks.

C/A User Impact (SPS)	P(Y) User Impact (PPS)

• Brings down SPS **Worldwide**
• No Civil Aviation Navigation possible
• Brings down all Infrastructure
  Synchronized or Dependent on SPS
• Telecom Networks and Time and Frequency
  Users go on "Hold-Over"
	• Standard PPS Receiver On-Line
	  - Standard PPS can not come up cold
	    unless accurate time is available
	• Direct P(Y) PPS can come up cold
	  - More robust in Jamming

This, of course, is nothing new to all the foreign countries, which have deeply imbedded GPS into their infrastructure. No matter what U.S. policies are advertised concerning C/A and GPS availability, everyone knows GPS is a military system, run by the military. Decisions will be made in times of conflict without permission from anyone. No question, all this has given rise to the European equivalent to GPS, called Galileo.

GPS SIGNAL STRUCTURE BASICS

The L1 and L2 GPS carriers are busy with formative signal modulation as seen in Figure 1. This consists of quadrature phase-modulated C/A and P-codes running at 1.023 MCPS and 10.23 MCPS respectively; an Anti-Spoof (AS) encryption code modulating the P-code, called the Y-code running at 10.23 MCPS; a 50-bit per second data modulation—all of which are synchronized to the master satellite clock. On top of all these modulations is the signal degradation called Selective Availability (SA). Since the SA is essentially at the output of the satellite clock, it affects everything from carriers to codes, but is specifically designed to control the available accuracy of the civil C/A code.
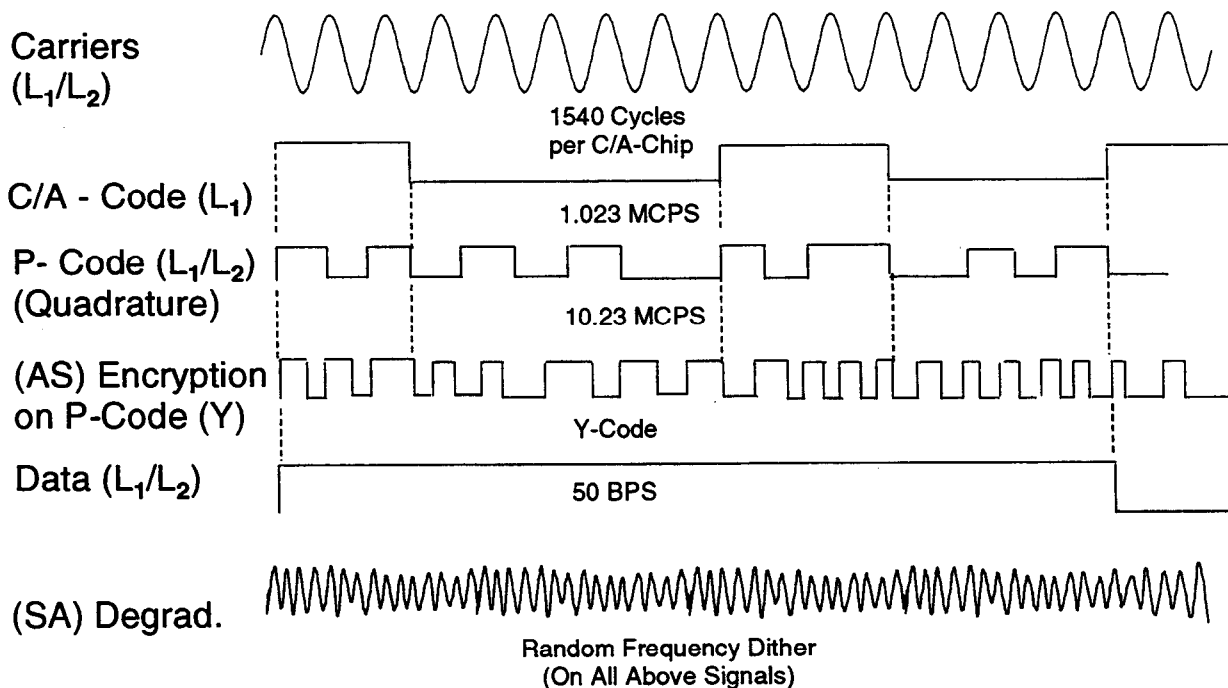
Carriers
(L$_1$/L$_2$)

1540 Cycles
per C/A-Chip

C/A - Code (L$_1$)

1.023 MCPS

P- Code (L$_1$/L$_2$)
(Quadrature)

10.23 MCPS

(AS) Encryption
on P-Code (Y)

Y-Code

Data (L$_1$/L$_2$)

50 BPS

(SA) Degrad.

Random Frequency Dither
(On All Above Signals)

Figure 1 - The GPS Carrier Modulation Signals

350

The specifics of the C/A-code and P-code are shown in Table 1. From the start, GPS was designed for the military and from that perspective it can be seen that the C/A code was designed as a facilitator to acquire the P-code. The P-code was designed to be difficult, if not impossible, to acquire without time aiding in order to achieve a high degree of resistance to jamming and spoofing.

- **C/A Code - To facilitate acquisition of the P-Code for PPS**
  - Civil SPS, originally a secondary consideration

Codes	C/A-Code	P-Code
Chipping Rate	1.023 MHz	10.23 MHz
Code Period	1023 Chips	~6.2E + 12/week
Code Repetition	Every millisecond	Reset weekly
Time Per Chip	~1 microsecond	~100 nanosecond
Code Structure	Different Gold Code per Satellite	Same code per satellite but different 7-day section

- **P-Code - Virtually impossible to acquire unaided**
  - High resistance to Spoofing and Jamming

Table 1 - Basic GPS Signal Structure

For more details on the signal structure as it applies to L1 and L2, refer to Table 2.

Carrier-Frequency	C/A Code	P-Code	(+) Encryption	Data	(S/A) Degradation
	1.023 MHz Chipping Rate	10.23 MHz Chipping Rate	NSA/JPO Crypto Keys For Authorized Users Only	50 BPS	Selective Availability of C/A Signal
	Code Period 1023 Chips	Code Period 2.35469 x 10^{14} Chips (~38 weeks)		1500 Bit Frame, 5 subframes (30S); Each Subframe 300 Bits (6S); 30 Bits Word, 24 Bearer Bits, 6 Bits Parity; Total 12.5 Minutes	Dither at Output of Sat Clocks
L1 1575.42 MHz	Code Repeats Every 1 ms ~1microsec Time Per Chip	Code is Reset Every Week			Degradation Level of C/A Selectable by Grd. Comd.
	Different Gold Code I.D.'s Each Sat	6.19658 x 10^{12} Chips/Week		"How" Word For P-Code Acq. (Each Subframe)	Presently Set at ~100m, ~1microsec
		~0.1microsec Time Per Chip		Clock and UTC Correction	
		Same Code for Each Sat, But Different 7-day Section		User Range Accur. (URA)	
				Sat Health	
		37, 7-day Sections Available		Sat Configuration	
				Ionospheric Correction Model	
				Ephemeris	
				Coordinate Sys.	
				Almanac	
L2 1227.6 MHz	No-C/A	P-Only	Yes	Yes	Yes

Table 2 - GPS Signal Structure

351

DIRECT P(Y) ACQUISITION PROCESS

In principle, among other parameters, the timing must be within one P-code chip (97.75 nanoseconds) to correlate with the P-code. With AS (Anti-Spoof) turned on at the satellite, a crypto key is required to acquire the P(Y)-code for PPS service. The P-code acquisition process is as follows:

- P-code is product of two PN Codes X1(t) and X2 (t+niT)
- X1 period is 1.5 sec. = 15,345,000 chips Δ 37 chips
          X2 period = 15,345,037 chips
- Both sequences are reset to begin the week at the same epoch time clocked in-phase at 10.23 MHz
- 15,345,000 x 15,345,037 = 2.35469592765E + 14 chips (~38 weeks)
- There are four X1 epochs per Data Subframe of 6 seconds
- 50-bit data stream has updated 'HOW' (Hand Over Word) word
- HOW x 4 = Z-Count at beginning of next 6-second Subframe
  - At this point the P-Code will correlate

A simplified way of illustrating standard C/A acquisition and the P(Y) Direct process is shown in Figure 2. The SPS receiver with only poor knowledge of time, receives L1, shown on the Figure by (1), locks onto the C/A (2), strips off the 50-bps data stream (3), and determines PVT (Position, Velocity, and Time) shown with (4). The SPS receiver not having P-code circuitry, ignores the HOW information (5), and stops at the SPS solution (4). The crypto-keyed standard PPS receiver and the P(Y) Direct SAASM receiver pick up at the HOW word (5), getting the necessary timing information to lock to the P(Y)-code (6) and (7), arriving at a PPS PVT solution (8). As shown in the Figure, when C/A is not available, the P(Y) Direct-capable receiver bypasses the (1) through (5) acquisition process, locking on to the P(Y) directly (6). As with C/A, this can also be done with poor knowledge of time. Massive parallel correlation is the key to a successful P(Y) Direct receiver design.
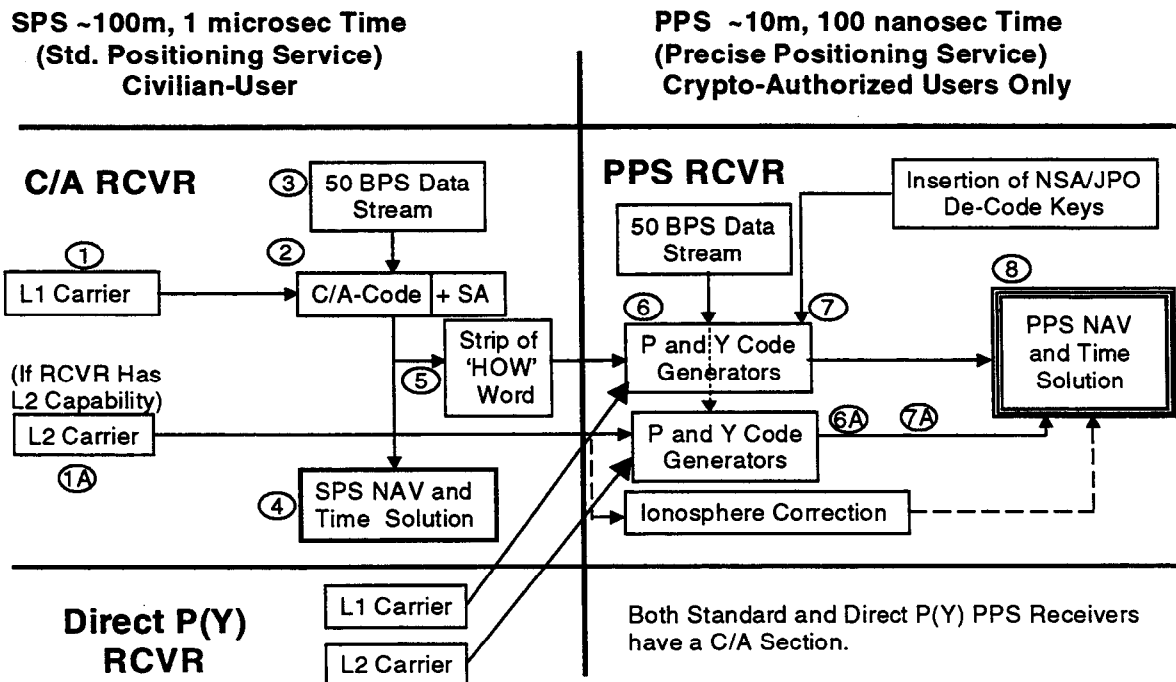

Figure 2 - GPS Receiver SPS and PPS Acquisition Process

EXPECTED TIME TO FIRST FIX (TTFF) PERFORMANCE OF A DIRECT P(Y) RECEIVER

For a well designed P(Y) Direct receiver mechanized with 511 correlators and a 64 Tap FFT, the initial conditions for the Time and Frequency user are not very demanding, as shown below:

- Stationary Receiver
- Position Error < 100 Km
- GPS Almanac or Ephemeris Loaded
  - Almanac can be days or weeks old, Ephemeris 4 to 6 hours
- GPS Key Loaded/Validated
- GPS Time Error < ± 0.5 sec.
- Receiver Clock Frequency Calibrated to < 1 ppm
- Broadband Jamming Levels, J/S 40 dB or less
- Relatively Constant Ambient Temperature

With these preconditions, the Direct P(Y) receiver can be expected to acquire the first fix (TTFF) in the search time shown in Figure 3. The search time for the specified receiver configuration (511 correlators, 64 Tap FFT) is most influenced by the jamming environment. C/A jamming does not directly affect the P(Y) code, but will slow the P(Y) Direct acquisition time.
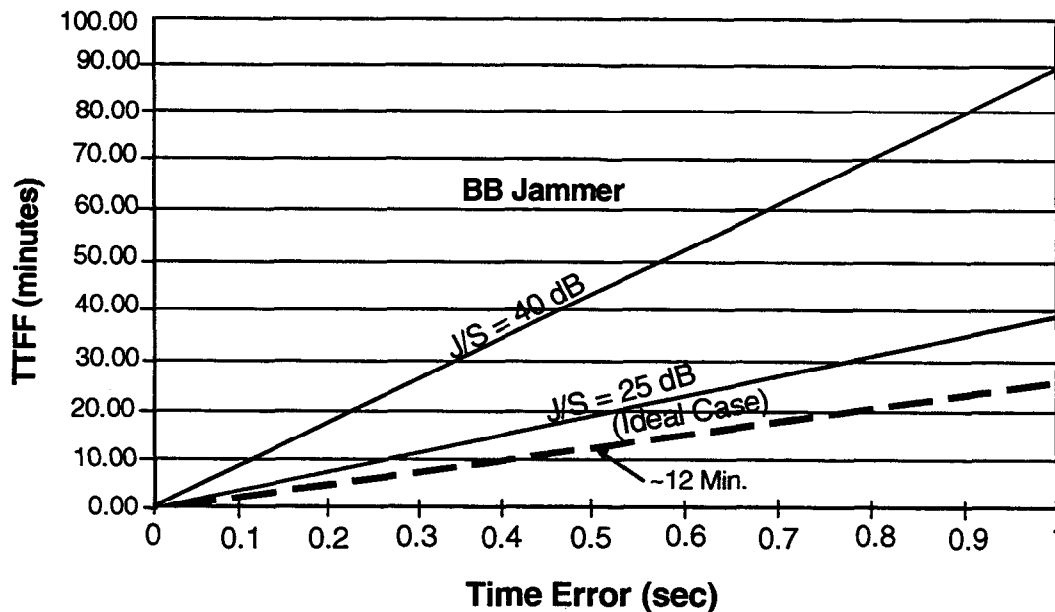
Note: J/S ~ 15 dB CW, C/A acquisition difficult, may track up to 25 dB
J/S ~ 25 dB BB, C/A acquisition difficult, may track up to 40 dB
J/S ~ 40 dB is moderate jamming level

Figure 3 - TTFF vs. Clock Error and Jamming

A typical receiver setup for a Direct P(Y) search is shown in Table 3. With an assumed receiver time error of ± 0.5 seconds of GPS time, for any elapsed time of 1 second, there are 10,230,000 P-code chips that must be searched for a match. On top of this, these chips will have to be found in a frequency domain error of at least ± 1575 Hz. This is caused by the assumed receiver clock error of 1 ppm—in other words, 1 ppm of the L1 carrier frequency of 1575.42 MHz. Added to the 1 ppm error is the satellite doppler, the result of satellite motion (and the receiver platform, for that matter) toward or away from the user.

1. 511 Parallel Correlators + _2.4_ Taps/Chip (ave.) ~ 212 Chips are searched 2. Setup of a 'Bin' depends on Time and Frequency Error 3. 'Bin' Time Error (horizontal axis) 212 chips x ~100 ns per P-Code Chip = ~21μs per 'Bin' 4. 64 Tap FFT (64 Sections) 5. Typical 'coherent integration search time' per 'Bin' to meet 'Probability of Detection' goals is <u>5 ms</u>. 6. 'Bin' Freq. Error (vertical axis) = $0.5 \times \frac{1}{search\,time}$ or $0.5 \times \frac{1}{5E-3} = 100$ Hz per 'Bin'. So, total Freq. Error = 100 Hz x 64 sections = ± 3,200 Hz. (Searched in ~21μs)	5. Local oscillator frequency error generally rules over Doppler shift. A typical 0.25 to 1 ppm oscillator produces a frequency error at L1 of~ ±400 Hz to ±1,575 Hz. 8. Depending on S/N, (3) 5 ms coherent searches may be required to meet 'probability of detection' goals. These are added non-coherently, = 15 ms search time per 'Bin'. 9. Typical example: • Assume ± 0.5 sec time error • Assume ± 1 ppm receiver clock • Assume (3) 5 ms dwells • Assume <u>No</u> jamming • Ideal Case

Table 3 - <u>A Typical Direct P(Y) Search Process Setup</u>

Figure 4 is a graphical representation of Table 3. The search column, ± 21 microseconds wide, is shifted back and forth (in time) until a correlation is achieved. A total of ± 3200 Hz is searched each time. This frequency excursion from the nominal 1575.42 MHz L1 carrier is more than adequate to cover receiver clock error and doppler. With the parameters given, and ideal conditions, the receiver will finally lock on to the P(Y) code in approximately 12 minutes, after having searched more than 3 million bins and more than 636 million P-code chips for the correct chip sequence.
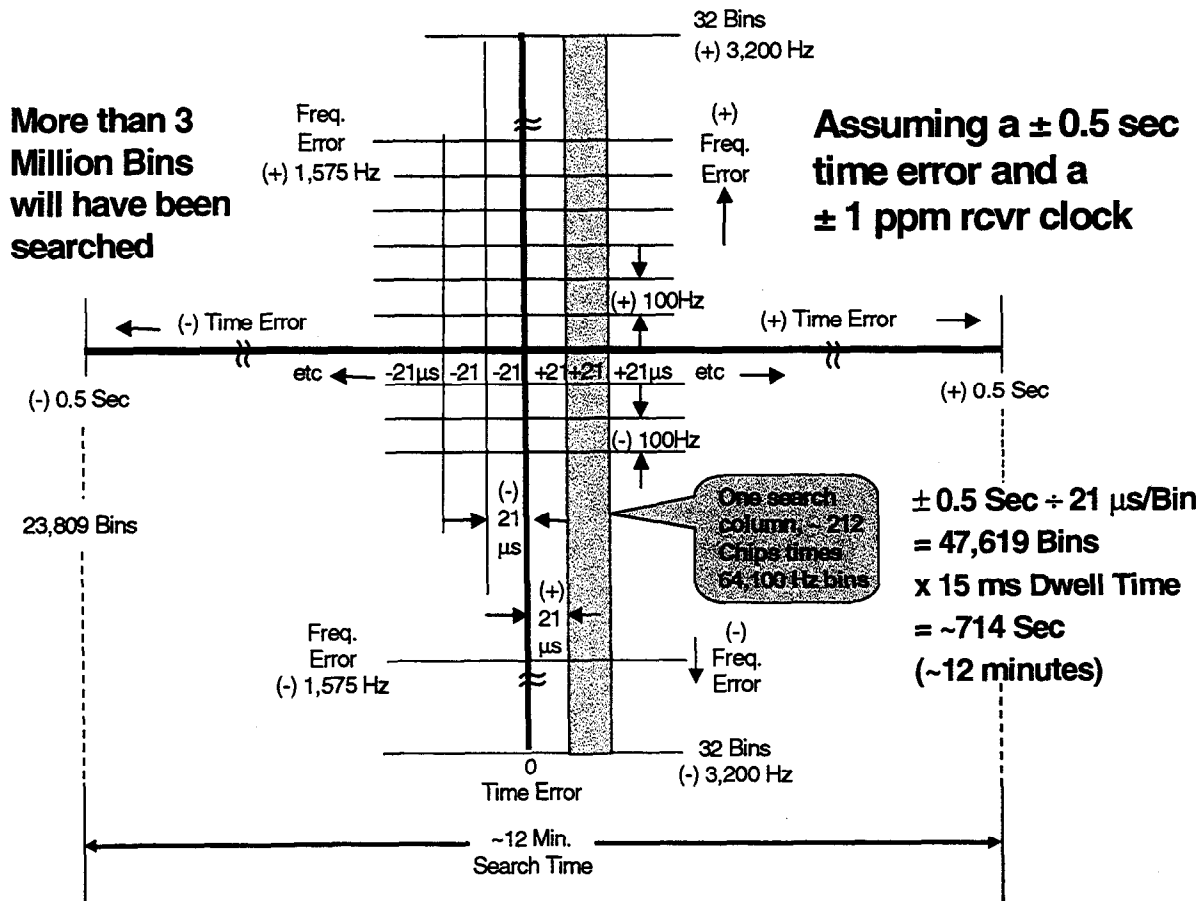
Figure 4 - A Typical Search Process

THE FUTURE FOR PPS

The U.S. government has certainly turned up the gain for fielding SAASM P(Y) Direct GPS receivers. The year 2002 seems to be the magic year after which only SAASM receivers can be fielded. With the new Security Architecture and Key Management system, the receivers will be easier to get into the hands of authorized users, mainly due to greatly reduced logistics.

The rapid advances in digital electronics are expected to further enhance the independence of the P(Y)-code from the C/A signal. No doubt, 511 correlators will be doubled, even quadrupled, making it even more plausible to go Direct P(Y) under adverse jamming conditions. The Time and Frequency user is the major beneficiary of this new functionality, since the stationary receiver can take more time to come up cold compared to the dynamic platform. With more robust means for PPS users to deal with C/A scenarios, SAASM/Direct P(Y) will do for the authorized PPS user community what SPS has done for Civil Community worldwide.