GPS TRANSLATOR APPLICATION CONSIDERATIONS FOR TEST RANGES

JOHN B. McCONNELL
Senior Operations Analyst
Requirements and Analysis Division
Western Space and Missile Center
Vandenberg Air Force Base, CA

ROBERT B. PICKETT
Manager
Systems Performance Analysis Department
Federal Electric Corporation
Vandenberg Air Force Base, CA

ABSTRACT

Tracking system implementations based on the retransmission of Global Positioning System (GPS) satellite signals from a test vehicle with signal tracking and trajectory estimation performed by ground-based range equipment are addressed. Two types of vehicle-borne frequency translators are described, techniques for correcting translator local oscillator error are proposed and potential techniques for receiving, recording and relaying translator signals using IRIG standard telemetry equipment are suggested.

INTRODUCTION

The potential use of the Global Positioning System (GPS) on the test and training ranges was investigated by a tri-service committee commissioned by the Office of the Undersecretary of Defense for Research and Engineering. The key findings of the study are that GPS is a viable option for making trajectory measurements in most types of range scenarios and a family of GPS range instrumentation should be developed(1). A significant conclusion of the study is that GPS translators will be useful in a variety of range applications, particularly those involving destructive testing (e.g., missiles) and when no more than five or six test articles are active at the same time in the same arena.

Figure 1 illustrates the components of a GPS translator tracking system. The translator receives CPS L-band signals and retransmits them on another frequency, f_x . The translated signals are received, recorded and processed at one or more receive sites.

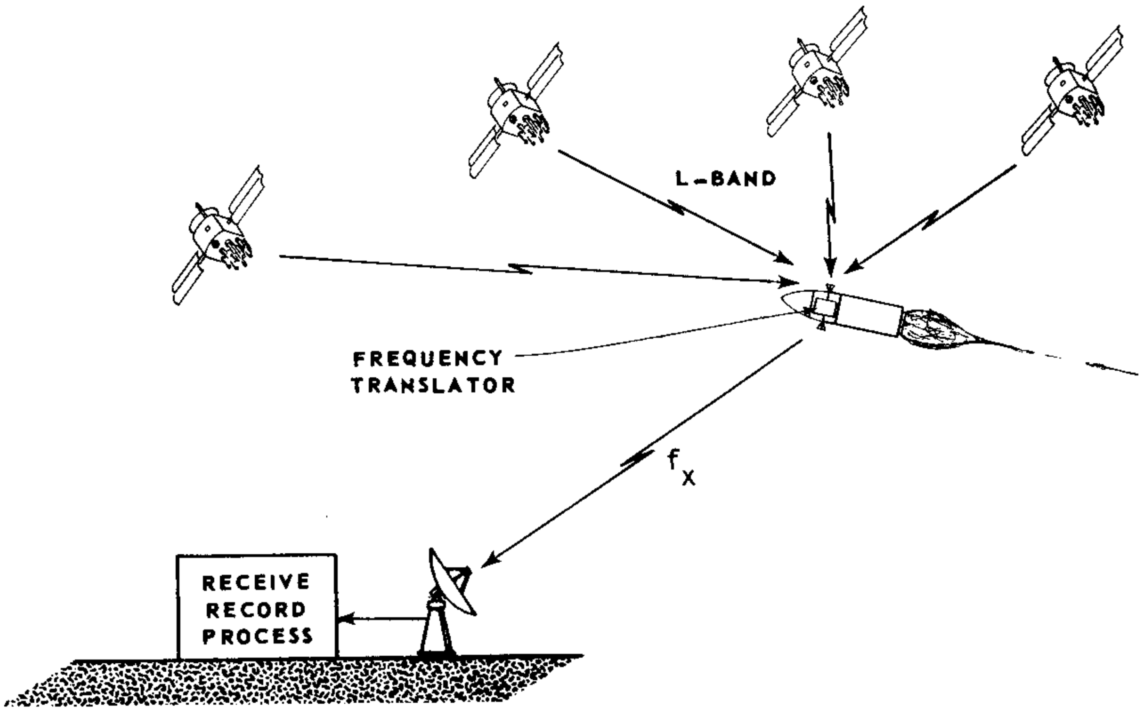


Figure 1   Translator Tracking System

GPS SIGNAL CHARACTERISTICS

The GPS satellites continuously broadcast on two L-band frequencies, 1575.42 MHz (L_1) and 1227.6 MHz (L_2). Superimposed on these carriers are two coded signals unique to each satellite: a precision code (P-code) pseudorandom noise (PN) signal with a 10.23 MHz chip rate and a course/acquisition code (C/A code) PN signal with 1.023 MHz chip rate. The L_1 frequency contains both the P-code and C/A code while the L_2 frequency contains either a P or C/A code. Superimposed on the P and C/A codes are 50 Hz chip rate navigation data containing the navigation message.

A "typical" receive level in a 1.5 MHz bandwidth for the L_1 C/A signal at a ground station is -160 dBW from a 0 dBi antenna.

When a translator is employed, the GPS signals are degraded by the translation process and by sidebands on the output carrier which may induce noise at the receiver input. The transmitted signal-to-noise ratio, S/N_t, may be expresse as:

$$S/N_t = S/N_{sr} \left(\frac{1}{N_1}\right) \left(\frac{1}{N_2}\right) \qquad (1)$$

where:

S/N_{sr} = translator received signal-to-noise ratio,
N_1 = degradation due to the translation process, and
N_2 = receive system degradation due to transmitter induced noise.

Accurate trajectory measurements can be obtained even when S/N_t is as low as -30 dB in a 1.5 MHz bandwidth since there is a recovery of 40 dB or more after the signals are despread.

The output spectrum of a translator can be characterized as band-limited noise so that the signal-to-noise ratio at the remote receiving site S/N_{tr} , is:

$$S/N_{tr} = S/N_t \left(\frac{P_R}{P_R + P_N} \right) \tag{2}$$

where:

P_R = power of the translated signal at the receiving system input, and
P_N = receiving system noise power referenced to the receiver input.

TRANSLATOR TYPES

Two types of translators, analog and digital, are suitable for test range applications. These translators operate with the L_1 C/A signals to conserve spectrum and power.

Analog Translator

The analog translator receives the satellite signals and retransmits them on another frequency. The first generation analog translator used conventional heterodyne techniques and class A amplification to ensure that nonlinearities did not introduce phase noise on the satellite signals. A second generation miniaturized analog translator is being developed using limiting and class C amplification to reduce power requirements.

Figure 2 is a simplified block diagram of an analog translator.

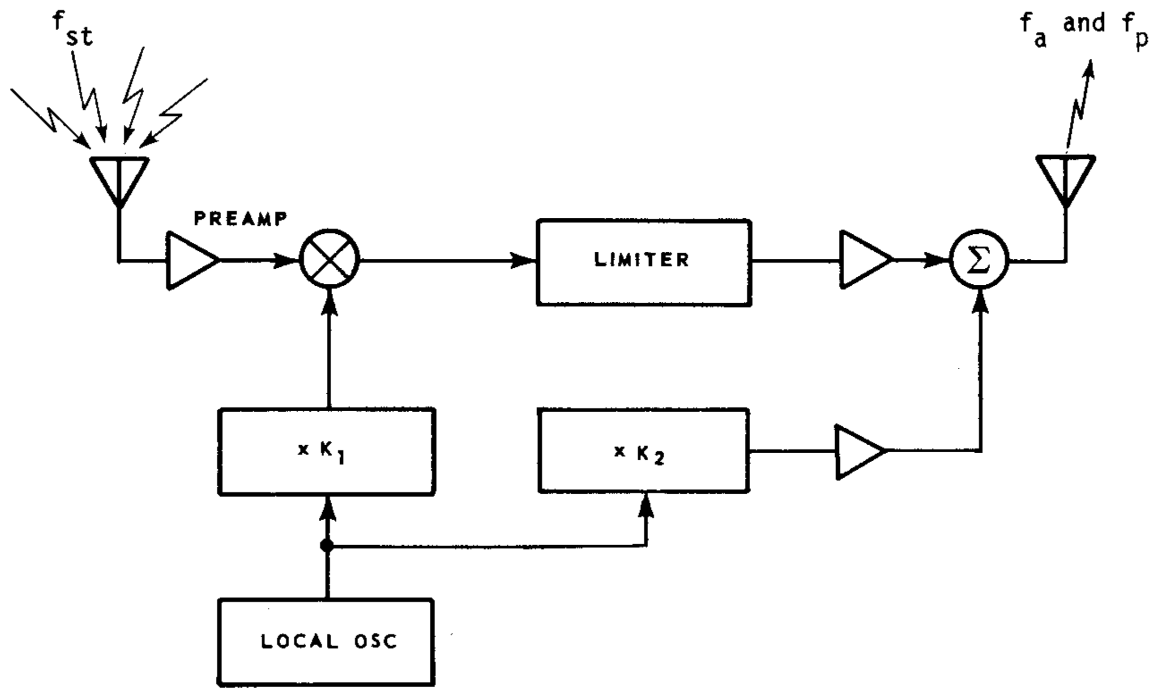


Figure 2 Analog Translator

The translator input contains several satellite signals. In an earth-fixed reference frame each signal's carrier has Doppler shifted frequency, f_{st} :

$$f_{st} = L_1 \left(1 - \frac{\dot{R}_t}{c}\right) \Big/ \left(1 + \frac{\dot{R}_s}{c}\right) \tag{3}$$

where:

$L_1 = 1575.42 \times 10^6$, Hz

$\dot{R}_t$ = range rate between a satellite and a translator due to translator motion, m /s,

$\dot{R}_s$ = range rate between a satellite and a translator due to satellite motion, m/s, and

c = velocity of light, m/s.

The received GPS signals are translated to the output frequency, f_a:

$$f_a = f_{st} + K_1 (f_{lo} + e) \tag{4}$$

where:

K_1 = multiplication factor,

f_{lo} = nominal local oscillator (LO) frequency, Hz, and

e = LO error, Hz.

Also, a pilot tone, f_p , is synthesized from the same LO:

$$f_p = K_2 (f_{lo} + e) \tag{5}$$

where:

K_2 = multiplication factor.

The pilot tone can be used for telemetry tracking, to aid GPS signal tracking, and to correct translator LO error.[1] The tone is placed 1.8 to 1.9 MHz below the carrier and the level is set as low as practical to conserve spectrum and minimize satellite signal degradation.

An analog translator is used in the TRIDENT SATRACK system.

Digital Translator

Figure 3 is a simplified block diagram of a digital translator.

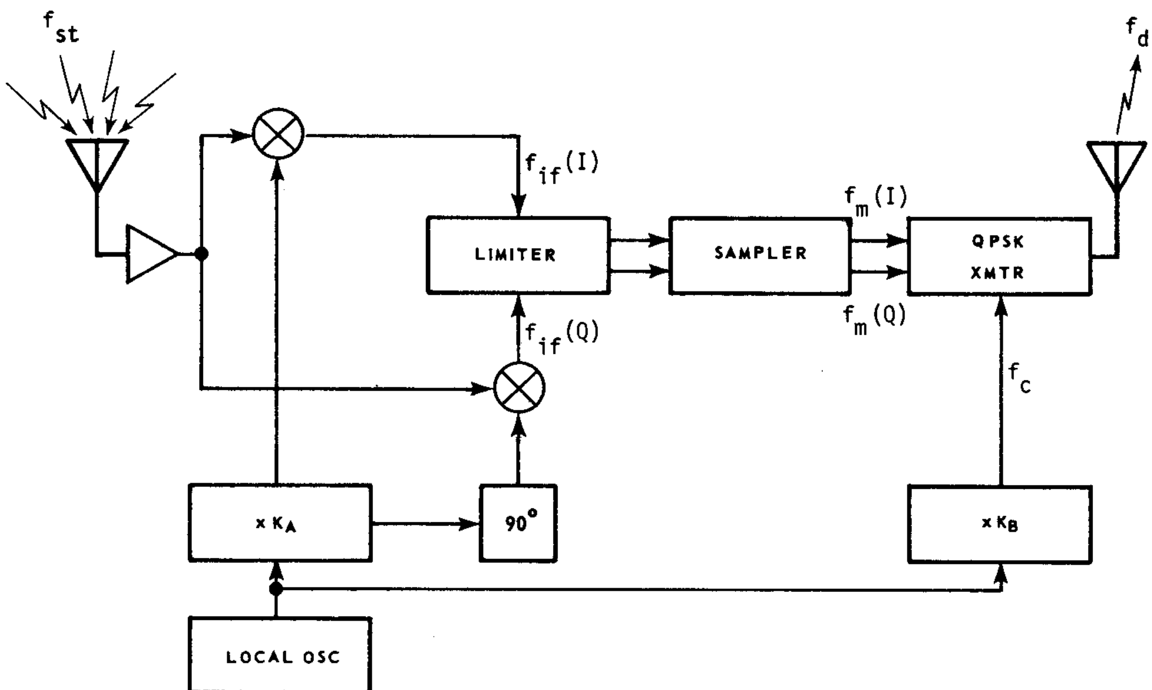


Figure 3 Digital Translator

[1] The LO used in the translation process typically may exhibit offset error as large as 5 parts in 10^6 and drift error as large as 1 part in 10^6.

Each GPS signal's carrier, f_{st}, is shifted to a very low IF and the in-phase, $f_{if}(I)$, and quadrature, $f_{if}(Q)$, components formed. The IF, f_{if}, is:

$$f_{if} = f_{st} - K_A (f_{lo} + e) \tag{6}$$

where:

K_A = multiplication factor.

The in-phase and quadrature signals are one bit quantized to form the modulation signals, $f_m(I)$ and $f_m(Q)$.

The carrier, f_c, is:

$$f_c = K_B (f_{lo} + e) \tag{7}$$

where:

K_B = multiplication factor.

The carrier is quadrature phase shift keyed (QPSK) to form the transmitted signal, f_d. The carrier may be used for the same functions as described for the pilot tone.

Due to the digitization process, the digital translator has a larger N_1 term than an analog translator. For example, at a 2 MHz sampling rate, which is compatible with a 1.5 MHz bandwidth, the degradation with one bit quantization is 2.2 dB(2).

The digital translator is applicable to situations where the transmitted data must be encrypted or when telemetry and GPS signals are to be simultaneously relayed on the same link. However, the digital translator requires higher transmitted power than the analog translator for equivalent performance.

A digital translator is being developed for the Global Positioning System-Sonobouy Missile Impact Location System (GPS-SMILS).

TRANSLATOR LO ERROR CORRECTION

Proposed techniques for correcting translator LO error at the receiving site are discussed below.

Analog Translator

The received analog translator carrier and pilot frequencies are:

$$f_{ar} = f_a \Big/ \left(1 + \frac{\dot{R}_{tr}}{c}\right) \tag{8}$$

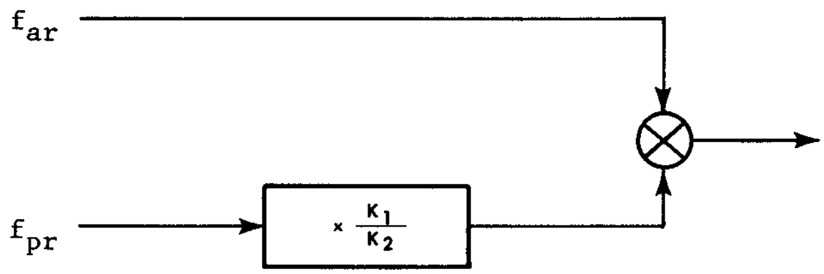
and

$$f_{pr} = f_p \Big/ \left(1 + \frac{\dot{R}_{tr}}{c}\right) \tag{9}$$

where:

$\dot{R}_{tr}$ = the range rate between the translator and the receive site, m/s.

Figure 4 shows a technique for removing the translator LO error using the filtered pilot signal.



$$f'_{ar} = f_{st} \Big/ \left(1 + \frac{\dot{R}_{tr}}{c}\right) \tag{10}$$

Figure 4 Analog Translator LO Error Correction

The result, f'_{ar}, is the translator input, f_{st}, with translator-to-receive-site Doppler. Consequently, only an estimate of the total Doppler, satellite-to-translator and translator-to-receive-site, is needed when signal tracking aids are required by the GPS translator receiver. The extent of tracking aids needed is dependent on vehicle dynamics and the receiver design.

Digital Translator

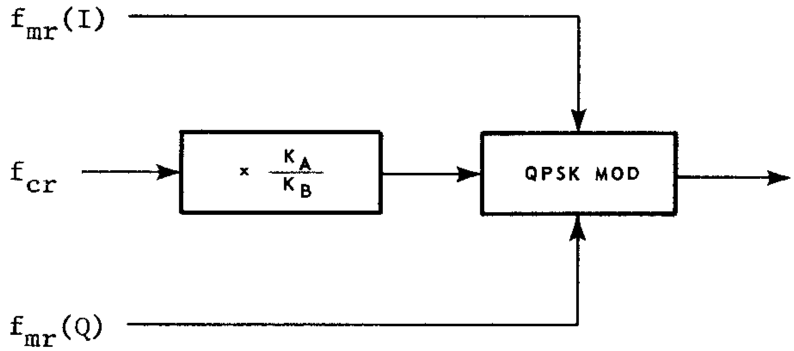
The received carrier and modulation frequencies after demodulation are:

$$f_{cr} = f_c \Big/ \left(1 + \frac{\dot{R}_{tr}}{c}\right) \tag{11}$$

and

$$f_{mr} = f_m \Big/ \left(1 + \frac{\dot{R}_{tr}}{c}\right) \tag{12}$$

Figure 5 shows a technique for removing the digital translator LO error using the recovered carrier and quantized signals from a QPSK demodulator.



$$f'_{dr} = f_{st} \Big/ \left(1 + \frac{\dot{R}_{tr}}{c}\right) \tag{13}$$

Figure 5 Digital Translator LO Error Correction

At a 2 MHz sampling rate, the output signal is the same as for the analog translator except for the 2.2 dB degradation from the translator digitization.

IMPLEMENTATION CONSIDERATIONS

This section describes several receiving site configurations, and proposes a technique for receiving and recording translated GPS signals using standard telemetry equipment.

Minimum Receive Site Capability

A minimum-configured receive site is shown in Figure 6.

The solid lines indicate a configuration that requires a wideband data relay, and signal tracking and trajectory estimation at the central facility. Addition of a GPS receiver (dashed lines) to process translator signals at the remote site allows the use of a narrowband data link. In both configurations the translator signals are received, downconverted to a predetection frequency, wideband recorded, and the translator LO error corrected.

A wideband relay (e.g., commercial T-1 carrier) with 1.5 MHz bandwidth may be used for analog translator predetection signals if the pilot tone is removed. Otherwise, a 3 MHz bandwidth is needed. The digital translator signal may be directly relayed on a 1.5 MHz bandwidth channel. A narrowband relay (e.g., telephone channel) may be used for the processed data.

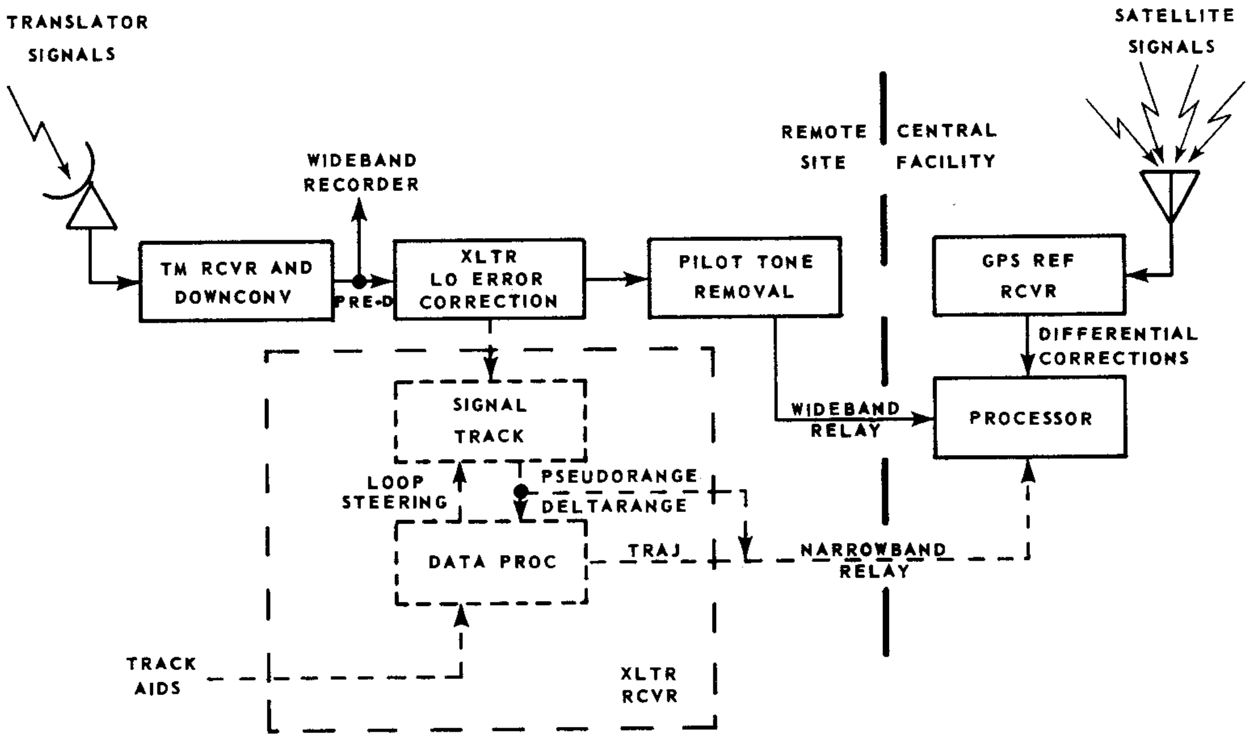


Figure 6   Minimum Receive Site Capability

Both configurations require differential corrections at the central facility and data from a minimum of four satellites for trajectory estimation. The use of differential CPS improves accuracy by correcting errors resulting from satellite ephemerides, satellite clock and ionospheric delay.

Full Receive Site Capability

The configuration shown in Figure 7 provides a capability to generate a vehicle trajectory with differential corrections at the receive site.

Use of a low noise oscillator and synthesizer (dashed lines) to provide common frequency and time references for the telemetry and GPS receivers may allow trajectory estimation with signals from only three satellites if time delays and frequency shifts can be either measured or modeled and estimated.

Receive/Record/Playback with Standard Telemetry Equipment

When analog and digital translator signals are transmitted at S-band, standard telemetry equipment at many test ranges can be used. The S-band signals can be received and downconverted to a suitable record frequency, and possibly wideband recorded and played back when a proper time base error corrector (TBEC) is employed(3). Field test results indicate TBEC equipment may reduce standard recorder time base error sufficiently to

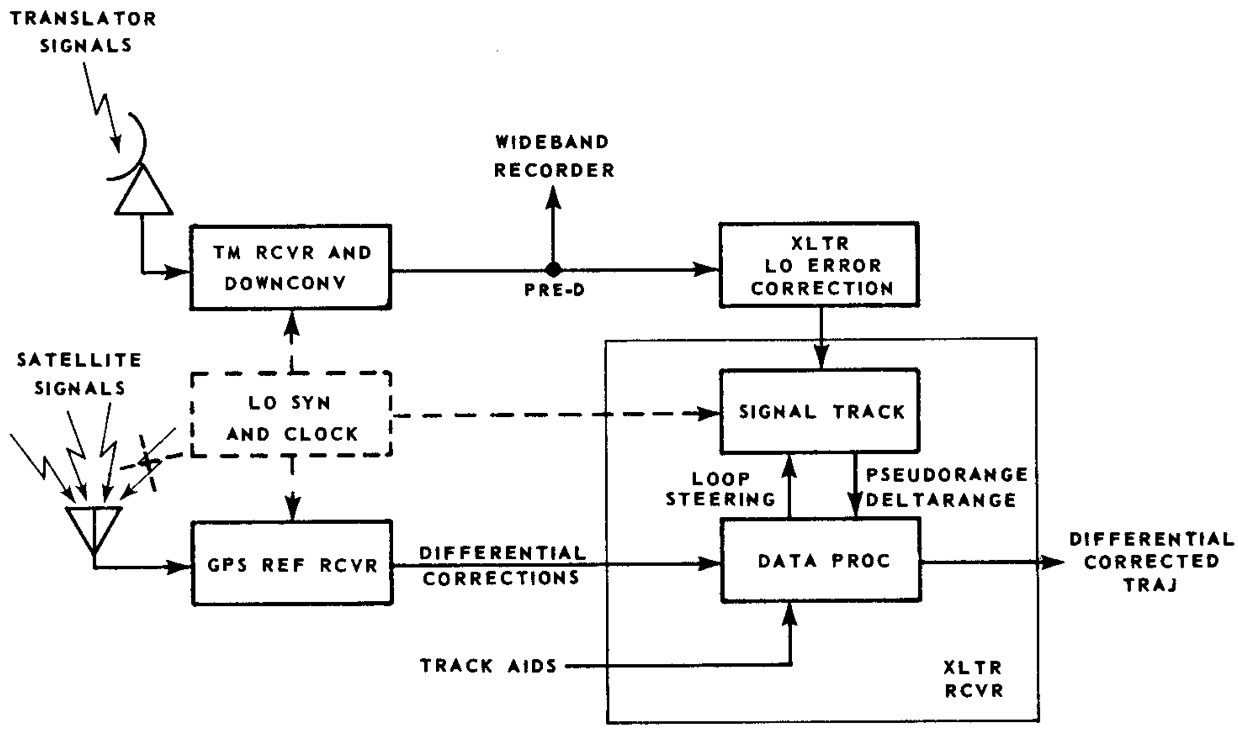


Figure 7 Full Receive Site Capability

allow GPS receiver lockup during playback using conventional 4 MHz telemetry recorders(4).

SUMMARY AND CONCLUSIONS

Two types of GPS signal translators, analog and digital, are useful for test range applications. The analog translator has less signal-to-noise degradation and requires less transmitted power for equivalent performance but the digital translator is applicable when encryption is required or telemetry is relayed on the same link.

When tracking aids are needed, proposed techniques to correct translator local oscillator error may allow the GPS receiver to track translated signals with only an estimate of total Doppler. Consequently, for high dynamic applications of translators or receivers, a single signal tracking design may be feasible.

Minimum receive site equipment is needed when data are relayed for processing at a central facility. When a receive site is configured with a GPS receiver for processing translator signals, a GPS reference receiver, and common frequency and time references, trajectory estimation may be feasible using data from only three satellites.

When GPS signals are translated to S-band and proper time base error correction equipment is employed, standard telemetry receive/record equipment may be used.

The techniques described in this paper have significant implications with respect to development and implementation of translator tracking systems as range instrumentation. The techniques should be tested and their performance levels determined.

ACKNOWLEDGEMENTS

The authors wish to acknowledge contributions made to this paper by: Robert L. Baker and Harold E. Flowers, Federal Electric Corporation, and Richard A. Brooks, Consultant, Federal Electric Corporation. Also, the authors wish to acknowledge useful suggestions provided by Lawrence L. Wells, Interstate Electronics Corporation, Ted D. Ward and Richard C. Badewitz, Cubic Corporation and Edwin E. Westerfield, Johns Hopkins University Applied Physics Laboratory.

REFERENCES

1. George, Kingston A., et al, January 1983, GPS Range Applications Study Final Report, Requirements and Analysis Division, Western Space and Missile Center, Vandenberg Air Force Base, CA 93437, pages 26,27.

2. Horowitz, Larry L., July 1976, Analysis of a Single-Bit Digital Receiver for Carrier and Code Tracking, Technical Memorandum TG 1283, The Johns Hopkins University Applied Physics Laboratory, Johns Hopkins Road, Laurel, MD 20810, page 13.

3. Pickett, Robert B., May 1982, Interfacing GPS Translated Signals with Telemetry Receive/Record Equipment, Technical Note AS300-N-82-16, Systems Performance Analysis Department, Federal Electric Corporation, P.O. Box 5728, Vandenberg Air Force Base, CA 95437, pages 8-11.

4. McKelvey, George R., February 1983, Test Analysis of the Bancomm Tymcor Model 1400 Digital Time Base Correction Equipment, Technical Note AS300-N-83-07, Systems Performance Analysis Department, Federal Electric Corporation, P.O. Box 5728, Vandenberg Air Force Base, CA 93437, pages 4, 5.