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Instruction Manual

FAA RADAR TRACKER

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1.0 INTRODUCTION

The air traffic control radar on Pico del Este near Humacao produces L-band signals that can interfere severely with our L-band spectral line observations. The FAA Radar Tracker, described in this manual, is a receiver/range tracker that locks onto the radar signal and produces a blanking pulse for the spectral line correlator. The length of the blanking pulse is adjustable, but is normally set to the first 400 microseconds, which is sufficient to blank the direct radar pulse as well as ground clutter and echoes from close-in planes and ships.

For increased availability, the FAA radar has two transmitters that feed a single antenna. Normally both operate. The first produces a 6 microsecond pulse at 1350MHz. The second follows immediately with a 6 microsecond pulse at 1330MHz. Normally both operate, but during FAA maintenance periods, only one transmitter is active.

Five radar pulses from each transmitter are sent every 14105 microsecond period. Within this overall period, pulses from the first transmitter begin at 0us, 2633us, 5454us, 8200us, and 10795us. The blanker produces pulses that turn on 10usec before the the arrival of each pulse pair (or pulse, if only one radar is active).

2.0 GENERAL DESCRIPTION

The Tracker consists of a frontend section, mounted on the platform, and a backend section, located in the control room. The frontend includes a helical antenna pointed toward Humacao. A local oscillator at 1340MHz produces a 10MHz IF signal from the input signals at either 1330MHz or 1350MHz. The backend contains a limiting IF amplifier, envelope detector, and a phase-lock loop to lock a voltage controlled crystal oscillator (VCXO) to the FAA radar's period. This circuit uses a split range gate phase detector in a conventional 2nd-order Type II loop. Figure 2.1 is a block diagram of the tracker.

3.0 OPERATING INSTRUCTIONS

The tracker can operate constantly and be always connected to the correlator. The correlator software will make use of the blanking pulses or ignore them as commanded.

Track will normally be broken only when the FAA radar goes off the air or we have a power failure. Once the radar and the tracker are again working, unaided acquisition should take place within less than 1 second.

The status of the radar and tracking circuitry are indicated on the backend section by two front panel LED's and a meter. One green LED lights when the FAA radar is on. The red LED lights when the tracker has lost lock. A front panel switch determines whether the meter indicates the VCO control voltage or the radar signal strength. Meter readings should be approximately mid-scale when the unit is tracking properly.

The backend unit also has a front panel rotary switch to select the length of the blanking pulse that goes to the correlator. The selections are 100, 200, 300, 400, 500, 750, or 1000 microseconds.

4.0 SPECIFICATIONS

Input frequencies : 1330 and/or 1350 MHz
Input bandwidth : 2MHz at each frequency
IF frequency : 10 MHz
Period : 14105 us
Pulse start times within overall period : 0,2633us, 5454us, 8200us, 10795us
Blanking pulse (front or rear panel) : TTL, drives 50 ohms
Detected output (front panel) : Analog, drives 50 ohms

Tracking loop parameters:

- VCO constant, Ko : 0.0836 rad/sec/volt
- Phase detector constant, Kd : 75V/rad

Loop natural frequency : 8Hz
Damping coefficient : 0.4

5.0 THEORY OF OPERATION

5.1 Frontend

The frontend uses a LO at 1340 MHz so that either the 1330 MHz or 1350 MHz will appear at the 10 MHz IF. This unit is mounted in a waterproof box on the platform and includes a small helical antenna. Radiation of the 1340 MHz LO is minimized by the rf amplifier, a circulator, and a rf absorbent pad behind the door.

5.2 Backend

The control room unit first amplifies, limits, and detects the 10MHz IF signal. The limiter is needed because of the extreme variations in signal strength caused by a 5 rpm azimuth scan of the radar antenna.

The phase detector is based on two analog switches, called the early gate and the late gate. These gates are closed on each radar pulse for 4 microseconds. The late gate closes just as the early gate opens. A capacitor is charged negatively while the early gate is closed and then positively while the late gate is closed. The capacitor charges twice as fast on the early gate as compared to the late gate. If the early gate is not centered around the positive going edge of the detected pulse, the charge and discharge are unequal, leaving a net voltage on the capacitor. This voltage is immediately captured by a sample-and-hold circuit before it can discharge. The output of the sample-and-hold circuit is then the phase error signal which is integrated by the loop filter and then applied to the VCXO. Although the phase error signal is sampled, the sampling rate is much faster than bandwidth of the loop, and thus the loop can be modeled on a continuous time 2nd-order Type II loop.

The early and late gates are produced by a digital counter circuit which is clocked by the VCXO. The digital circuit also produces a "later" gate for the sample-and-hold, and also the blanking pulse. The acquisition of lock is complicated by the different time intervals between the 5 pulses in an IPP. Acquisition is aided by starting the digital counter that generates the early and late gates on the pulse that follows the longest time interval.

When the FAA radar is off or the 10 MHz IF signal is disconnected from the backend, the control voltage of the VCXO goes to the mid-scale value. This is facilitated by grounding the sample-and-hold input and shorting the loop filter's capacitor. When in lock, the control voltage of the VCXO is close to mid-scale. When acquisition starts, the early gate is totally within the leading radar pulse, and the loop locks rapidly.

There is also digital circuitry that detects if the loop is unlocked while the FAA radar is on. If the FAA radar signal is not present on 80 successive rising edges of the late gate logic signal, the early and late gates are halted and the acquisition sequence restarts.

Consider the calculation of the gain factors of the phaselock loop. The VCXO's frequency f_{vco} is determined by the control voltage v_c. It is divided down to the radar's frequency f_{rad} before it feeds the phase detector. Deviation of the VCXO's frequency at the input of the phase detector is $\Delta\omega = K_o \cdot \Delta v_c$, where K_o is the gain factor and has units of rad/s/V. The VCXO's tuning rate r is $27\text{MHz} \cdot 150\text{ppm} / 4\text{V} = 1012$ Hz/V. Thus, $K_o = 2\cdot\pi\cdot r\cdot f_{rad} / f_{vco} = 0.0836$ rad/s/V.

Assume that the loop is locked, that the phase detector is linear, and that the phase detector output v_d is proportional to the phase difference $\Delta\theta$ between its inputs; that is $v_d = K_d \cdot \Delta\theta$, where K_d is the phase-detector gain factor and is measured in units of volts/rad. $\Delta\theta$ is $2\cdot\pi\cdot\Delta t/T$, where $T = 1/f_{rad}$. The voltage v_d on the phase detector capacitor C after charging negatively for a time $\tau/2-\Delta t$ through the early gate resistor R and charging positively for a time τ through late gate resistor $2\cdot R$ is

$$v_d = -V_o\cdot(\tau/2 - \Delta t)/(R\cdot C) + V_o\cdot\tau/(2\cdot R\cdot C) = V_o\cdot \Delta t/(R\cdot C)$$

Thus, $K_d = V_o\cdot T/(2\cdot\pi\cdot R\cdot C) = 3\text{V}\cdot(0.00282\text{s})/(2\cdot\pi\cdot 18\cdot 10^{-6}\text{ s}) = 75$ V/rad.

The transfer function H(s) for an active loop filter is $-(s\tau_2+1)/s\tau_1$. The natural frequency ω_n and damping factor ξ for a 2nd order Type II loop is $\omega_n = (K_o \cdot K_d / \tau_1)^{1/2}$ and $\xi = \tau_2 \cdot \omega_n / 2$. See Reference 1 for a discussion of 2nd order Type II loops. Note that the natural frequency and damping factor are independent of the radar period.

$$K_o \cdot K_d = [V_o \cdot T/(2 \cdot \pi \cdot R \cdot C)] \cdot [2 \cdot \pi \cdot r/(f_{vco} \cdot T)] = V_o \cdot r/(R \cdot C \cdot f_{vco})$$

Thus, $\omega_n = [V_o \cdot r/(R \cdot C \cdot f_{vco} \cdot \tau_1)]^{1/2}$. This is useful to know when the radar's IPP is variable. However, it is important to remember that a sampled-data feedback loop can be modeled as a continuous time loop only when the sampling frequency is much greater than the loop's natural frequency.

Reference 1 : Phase Lock Techniques, 2nd Edition, Floyd M. Gardner, John Wiley & Sons, 1979