

CDMA Forward Link Coverage Field Testing

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Abstract

CDMA challenges system designers with new measurement requirements. System parameters and performance are measured primarily by signal to noise ratios (e.g. E_c/I_o) instead of signal strength (dBm) and frequency re-use has been replaced by code re-use patterns. The author presents a method and system of propagation analysis to measure pilot signals from both neighboring CDMA transmitters and multipath reflections in E_c/I_o or signal strength. The system has many advantages over carrier wave (CW) coverage propagation analysis because it uses pseudo noise (PN) modulation, measures pilot signals from neighboring transmitters with PN time offsets and measures multipath from the local transmitter and neighboring transmitters. The system is based on the Crocodile™ transmitter and the Super Eagle™ pilot scanner. Utilization of the transmitter and receiver to make CDMA measurements, including PN Offset and measurement of E_c/I_o are presented.

1. Introduction

IS-95 Code Division Multiple Access (CDMA) challenges system designers with new planning requirements[1]. It is the author's experience that most CDMA system designers make use of tools designed for FDMA or TDMA systems. Typically, the tools and methods employ CW transmitters and receivers for propagation analysis. Verification of coverage with modulated signals does not typically occur until actual Base Station (BS) sites have been at least partially constructed. This verification uses the actual Base Station hardware and subscriber units and occurs relatively late in the system planning cycle. Effects from multipath, hand-off thresholds, PN reuse and PN pollution cannot be measured or considered until this late stage; these CDMA specific measurements are based on signal to noise ratios (e.g. E_c/I_o which is later defined) not signal strength that CW measurements yield. This article presents an introduction to CDMA measurements and the design of CDMA field test equipment.

2. CDMA Metrics

Each CDMA BS transmits a pilot code to aid the handset with demodulation and to measure BS strength. The pilot code is actually the same for each BS, but *PN Sequence Offsets* are assigned to each BS. The PN Sequence Offset specifies delay between the Global Positioning System's (GPS) even second tick and the start of the PN code sequence. See figure 1.

E_c/I_o is the CDMA specific measurement of choice for the forward link. This is the ratio of the energy of the pilot signal being measured to the total power in the channel. The total power in the channel includes the pilot signal being measured, pilots from other BSs, traffic and other channels from BSs and noise.

Pilot coverage from neighboring BSs must overlap in fringe areas to accommodate hand-off. However, the overlap should not be excessive or have a large number of BS in the same overlap. Each BS that has significant power in the overlap area will raise I_o , decrease E_c/I_o and capacity and quality will suffer in the geographic area. This phenomena is known as *Pilot Pollution*.

3. Rational for CDMA Specific Coverage analysis equipment

Digitally-modulated RF signals manifest unique characteristics in the presence of reflections at PCS frequencies. These reflections cause unphased additions of data symbols which result in bit errors. Simple signal strength measurements at PCS frequencies (envelope detectors measuring narrow bandwidth signals such as CW) are deceiving because the signal may measure strong, but when digitally-modulated, E_c/I_o can be surprisingly poor. Multipath reflections (also known as time dispersion) of the RF carrier is when two or more signals of the same origin arrive at the receive antenna delayed in time because they traveled different path lengths or because of reflections and scattering in the propagation environment. This deterioration of the signal must be considered when planning and optimizing high-rate digital radio systems [2].

CDMA systems are unique in the RAKE type receiver employed for demodulation. The RAKE receiver can demodulate different multipath reflections that are sufficiently distant in time, but Multipath reflections too close in time cannot be combined and represent interference to the receiver.

CDMA systems are also unique in the way BS exist in re-use patterns. BS transmit on the same frequency and at the same time; they do not interfere excessively with one another through code division techniques. Neighboring BS have unique identification numbers and each identification number corresponds to a different time offset used to delay the start of the BS's pilot code. A very useful artifact of the time offset is that the user's handset can demodulate the neighboring BS as "multipath". The same RAKE receiver can be used to demodulate and combine multiple paths from the nearest BS and paths from neighboring BS. The paths from neighboring BS are necessary for hand-off. As stated, multipath reception from the nearest BS and "multipath" reception from neighboring BS can be beneficial. These multipaths can also degrade CDMA system performance. Multipaths too close together cannot be demodulated, but represent interference. Neighboring BS signals that propagate too far should not be considered for hand-off and also represent interference (e.g. Pilot Pollution).

The ideal tool for CDMA system planing should be: simple, practical for use in the early stages of system planning, measure E_c/I_o (direct paths and multipaths) from both the nearest BS and neighboring BS sites and allow examination of pilot pollution, hand-off areas and thresholds.

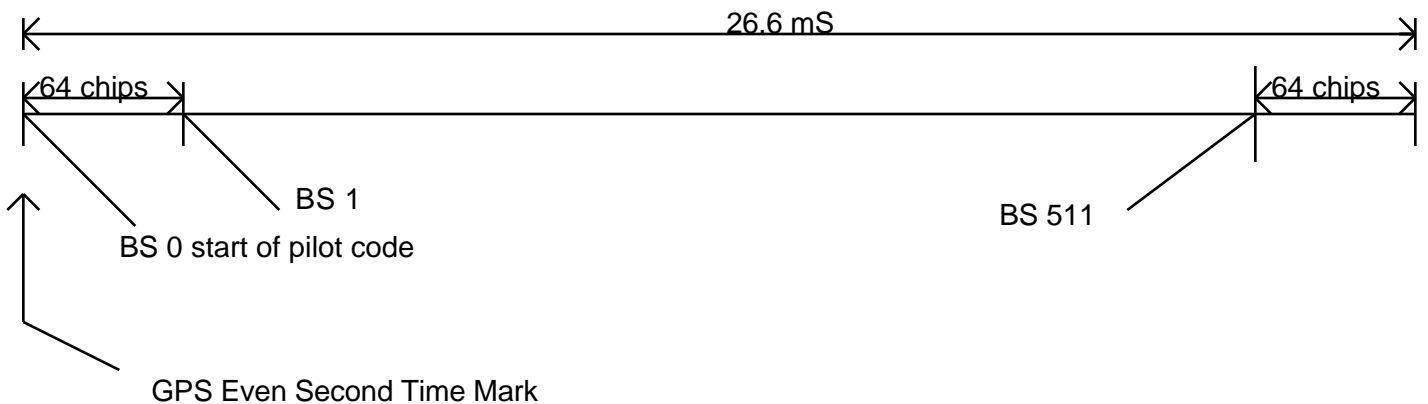


Figure 1. Diagram of Base Station offset number and the phase of the Pilot code.

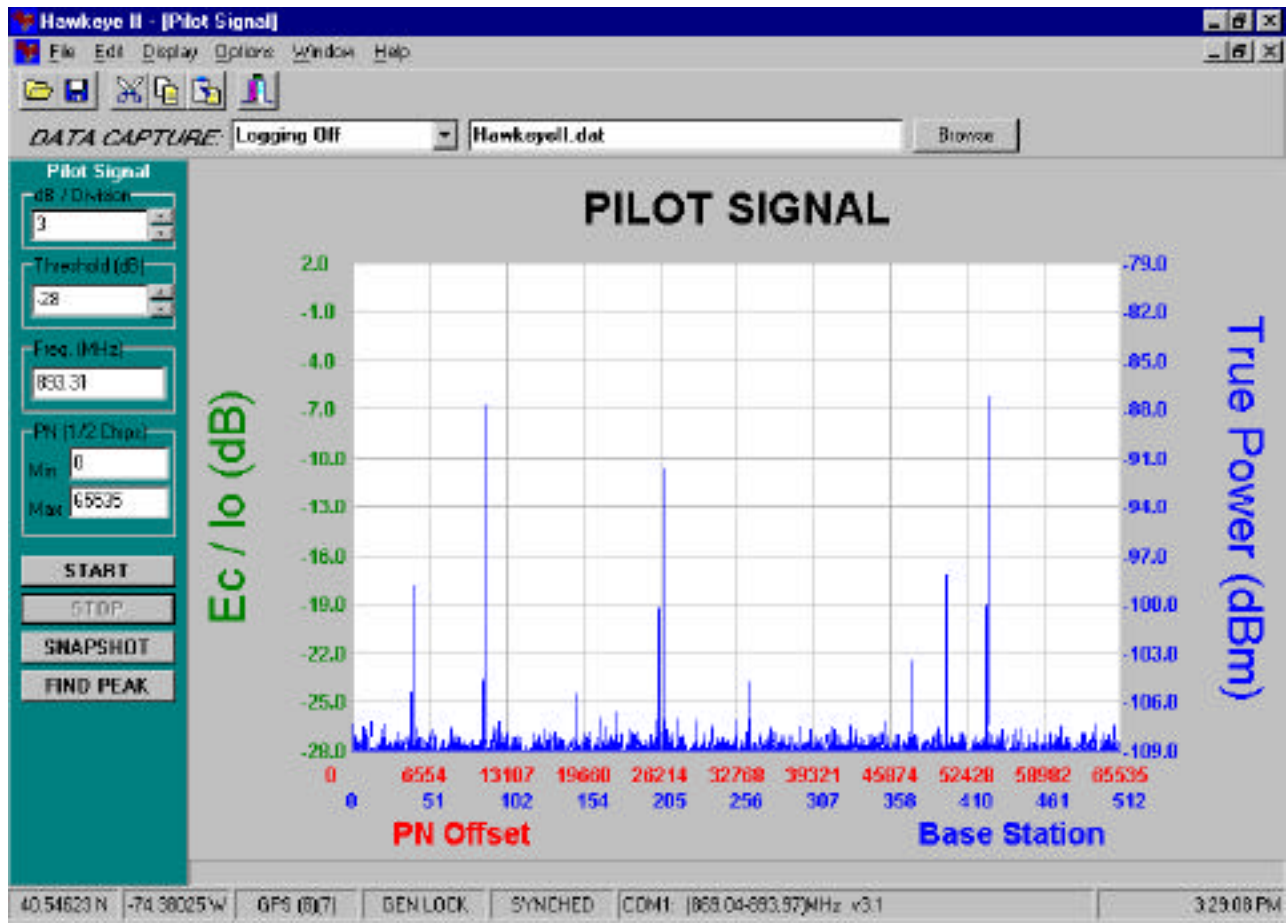


Figure 2. Screen shot of the Super Eagle™ Pilot Scanner. This screen depicts magnitude (in dBm and E_c/I_o along to y axis) of pilot signals versus time of arrival for all 512 Base Stations. Time of arrival is expressed in 1/2 chips (0-65535) and Base Stations (0-511). The data includes both direct and multi-path pilot signals.

4. The Crocodile™ Transmitter and the CDMA Forward Link

The Crocodile transmitter is designed to simulate a BS for propagation studies before the actual BS hardware is located and constructed. Therefore, the transmitter has concepts and hardware similar to the actual BS including: a Precision time base, PN Offset and Pilot Codes. A functional block diagram the transmitter system is shown in figure 3.

The Crocodile transmitter produces the IS-95 I and Q pilot codes in the PCS or cellular frequency band. The PN signal is produced by a pair of 15 bit code generators. These shift register based code generators can produce any 15 state linear code, of which the pilot PN codes are a subset. The code generators do have the capability to append a zero to the end of the PN code to form the pilot code as specified by IS-95[1]. The output of the code generator is over sampled by the FIR filters, and the data stream is then low pass filtered by the FIR filters to eliminate out of band components. The output of the filters drive a pair of D/A converters and is sent to the I/Q modulator. The I/Q modulator is used to produce a QPSK modulated signal. The signal is then up converted to RF and amplified to a maximum of 10 Watts CDMA output.

The PN generators are synchronized by the Global Positioning System time and the assigned PN Offset. At the start of transmission, the counter is started by the PPS and counts down the PN Offset in chips. The Frame start signal then initializes the PN pilot generator. The PN generators do not drift significantly over a day

of testing because of the Rubidium's high stability. The transmitter also has several monitors that check hardware functionality and shuts-down the power amplifier under an error state.

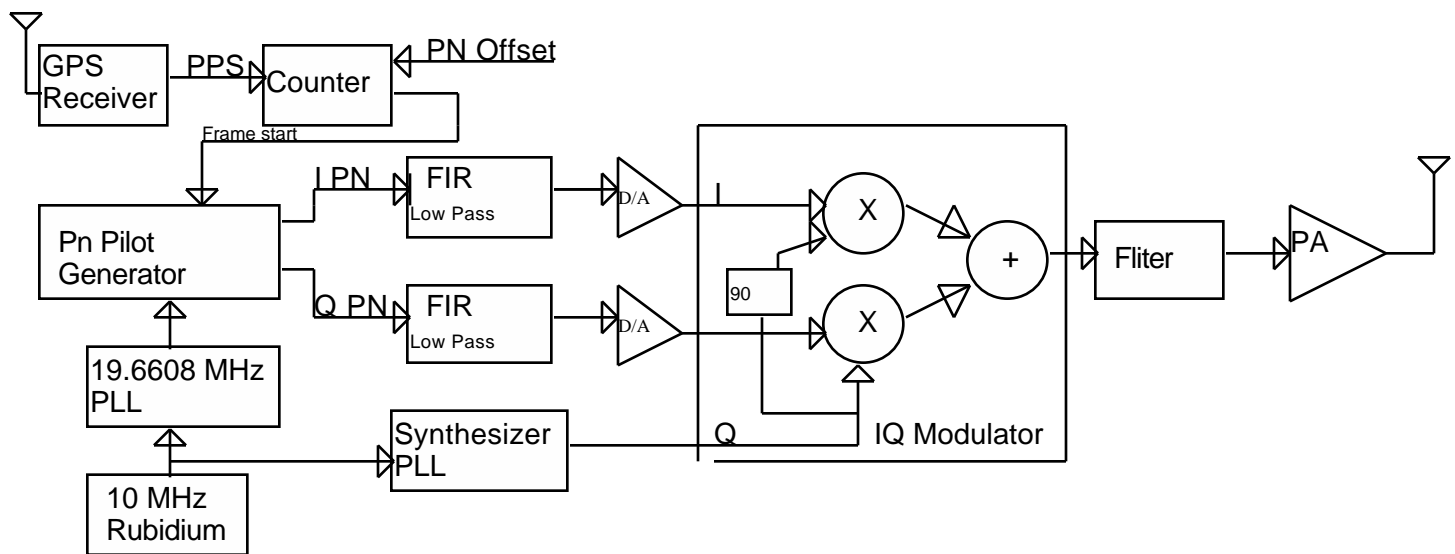


Figure 3. Block Diagram of the Crocodile™ Transmitter.

5. The Super Eagle™ Receiver

The Super Eagle is a pilot scanner that measures pilot signals in the selected RF channel and graphically presents the magnitude in E_c/I_o or E_c . The Receiver can measure IS-95 type pilots from the Crocodile test transmitters, actual Base Stations or a combination of test and actual transmitters. The receiver can be used for propagation study and site selection through site verification and maintenance. The functional block diagram for the receiver system is shown in Figure 4.

The reference frequency for the Synthesizer and 70 MHz PLLs is generated by the Genlock circuitry which is described in the following section. The Genlock trains its Voltage Controlled Temperature Compensated Crystal Oscillator (VCTCXO) with the GPS PPS to provide a precision reference frequency, f .

The received spread signal is down converted to an intermediate frequency (70 MHz IF). An AGC system maximizes the dynamic range of the receiver during pilot analysis. The output of the IF amplifier goes to an I/Q demodulator. The output of the I/Q demodulator is sampled with a pair of A/D converters running at twice the chip rate (1.2288 MegaChips/second X 2).

The digital correlators are a matched filter type. The digital correlators correlate a 1024 bit section of the I pilot code and a 1024 bit section of the Q pilot code against the demodulated stream. This arrangement provides a complete scan for all BSs and BS multi-paths in one pilot frame (approximately 27 mS). The correlator is very fast and silicon intensive, about 400,000 gates. The correlation length may be increased by correlating successive frames with different sections of pilot code, shifting the results and adding the correlations. Extended sensitivity of the receiver is achieved by correlating with sequential sections of code; the correlation is increased and it is not a simple averaging filter. At a correlation of 16 frames, the Super Eagle can detect pilot signals with E_c/I_o less than -26 dB.

The correlation results are sent to a digital signal processor, which performs high speed thresholding and outputs the data above the selected E_c/I_o threshold via serial port at 115k baud to a lap-top for real-time display and storage.

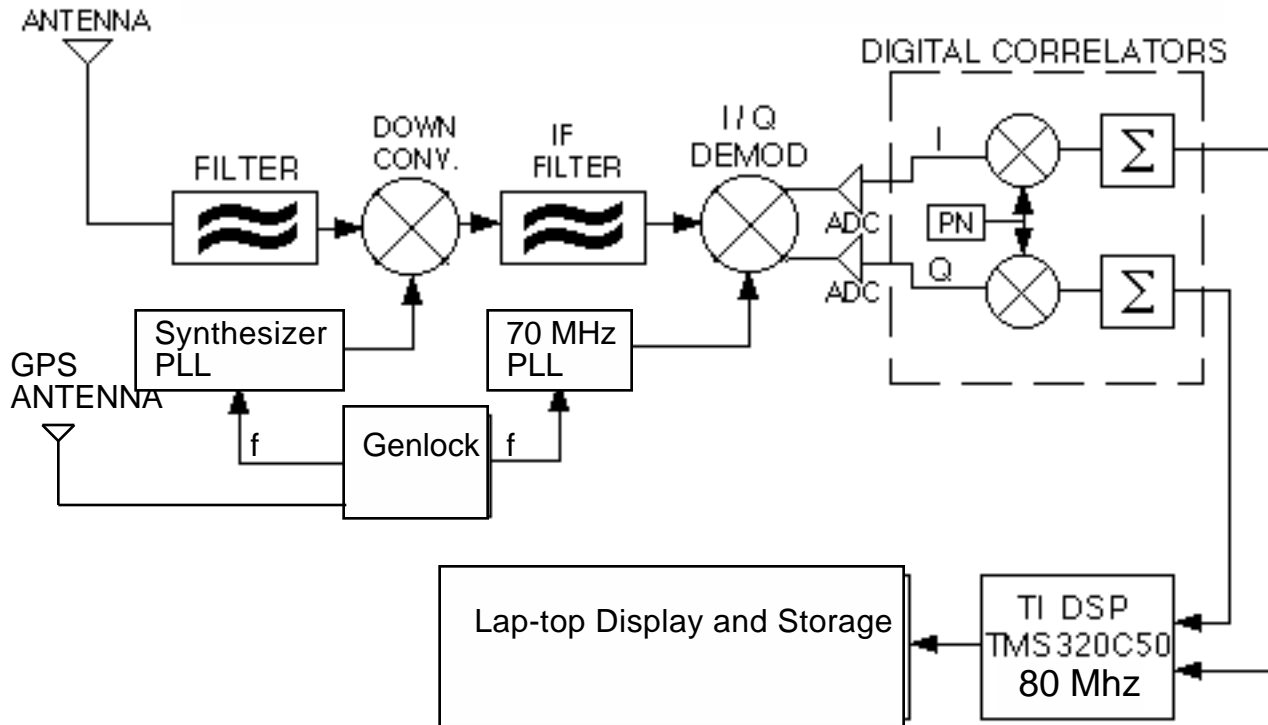


Figure 4. Block diagram of the Super Eagle™ Receiver. Details of the Genlock circuit are shown in figure 5.

6. GPS Genlock and Base Station Time Offsets

CDMA systems, as well as many other PCS formats, typically lock the BS's system time and clocks to the Global Positioning System's (GPS) time. A GPS receiver, located at the BS, determines time and position by measuring the time of arrival of spread spectrum signals from orbital satellites. Of particular interest is the Pulse Per Second (PPS) signal generated by the GPS. This signal is a seconds tick with jitter in the 200 ns range[3]. The PPS is used to control the start of the Pilot code generator at each BS and to phase lock the Pilot code generator to the PPS and to other code generators in the system.

Code division in the forward link is not accomplished by using different spreading codes. Actually, the same code is used at neighboring BS, but the codes are started at different times. As described earlier, a correlator will respond when its code phase is aligned to the code phase of the received signal. A code, regardless if it is from multipath or from a BS producing the same code offset in time, will not highly correlate when not aligned to the correlator's code phase.

It is evident that the alignment between pilot code generators in a CDMA system is critical. The same alignment is also critical for a Crocodile transmitter set at candidate BS sites.

Another use for the GPS is at the Super Eagle receiver. A GPS receiver may not be practical for a subscriber unit, but is very useful for a test instrument. The Super Eagle receiver's code generator can be started at the GPS' even second pulse tick. If propagation delays are neglected, a Crocodile's signal with a PN offset of zero will be received by the receiver co-incident with the GPS' even second tick. All pilot signals measured are recorded with a PN Offset calculated from the receiver's PPS, and are binned into the corresponding BS.

A combination of Crocodile transmitters can be set with different offsets at different candidate BS sites. A Super Eagle receiver can then measure multiple path strength from the nearest transmitter and multiple path strength from neighboring transmitters.

The GPS is also used to generate a precision time base for the Super Eagle receiver. Note that this does differ from the Crocodile transmitter which uses the Rubidium as a precision time base. The reference VCTCXO oscillator is phase locked to the PPS. Importantly, the code generators and chip rates of the transmitter and receiver are phase locked to a standard reference, the PPS. The frequency of the PPS is too low to be used in a conventional phase lock loop circuit. Instead, the PPS is used to estimate the frequency of the reference oscillator during each second. The processor reads the number of pulses accumulated in the counter, CNT, during a second, compares this number with the expected count and increases or decreases the frequency of the VCTCXO. This servo-system regulates the chip frequency in the transmitter and receiver for changes in temperature and inaccuracy of the oscillators. The measured accuracy of the oscillators was improved from 2.5 part per million to 25 part per billion. A second counter is used to accumulate any difference between the PPS and the code generator's clock. The algorithm attempts to keep this counter equal to zero for perfect phase locking.

Lab testing verifies that the system can phase lock a receiver with a jitter of about \pm chip at a chip rate of 1.2288 MHz. A block diagram of the phase locking system appears in figure 5.

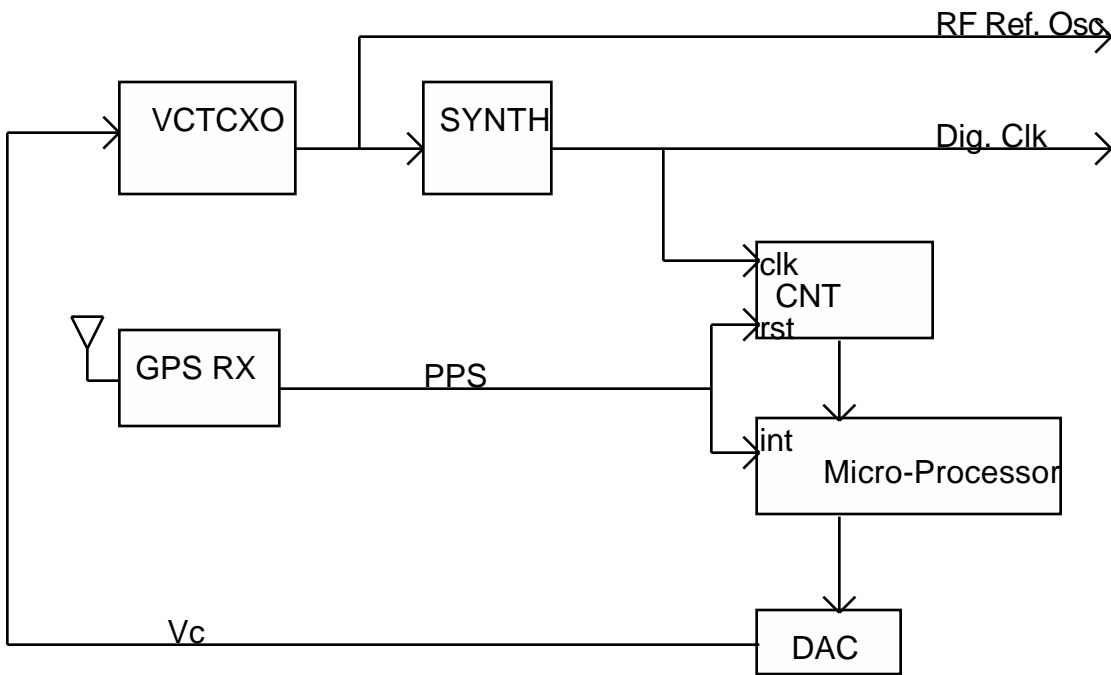


Figure 5 The Genlock circuit.

7. The Power Delay Profile

When a component of the received signal is aligned in phase with the receiver's code generator, it will correlate and its magnitude is recorded. This waveform of correlated energy versus time graphically displays the different multipath components within the system and channel and is defined as the Power Delay Profile. Different paths from the same pilot transmitter or paths from neighboring pilot transmitters with different time offsets will correlate at different times and be displayed. This Power Delay Profile should be of primary interest to the CDMA system planner.

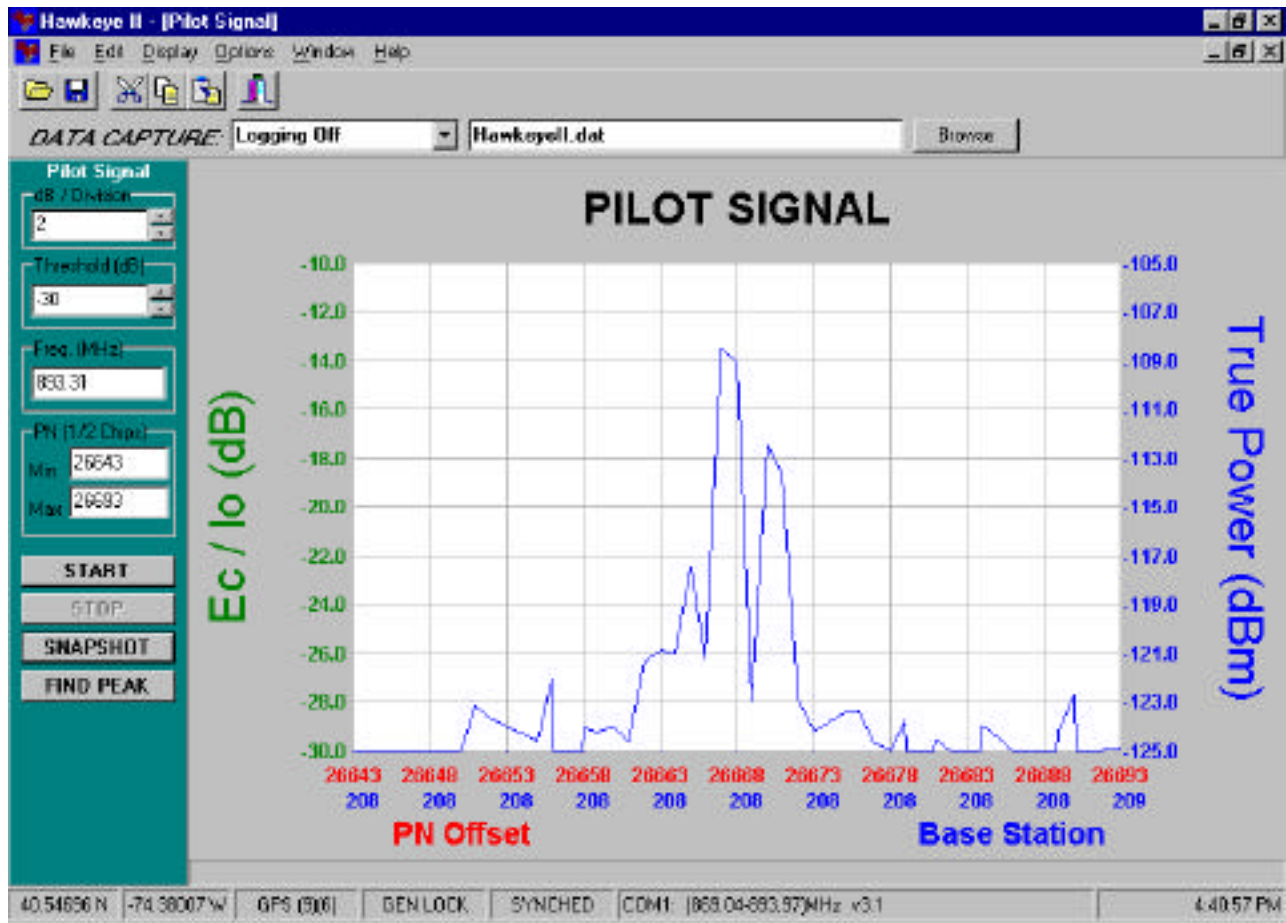


Figure 6. Example of a Power Delay Profile, from the Super Eagle™ screen, showing 2 distinct paths of nearly equal amplitude. The PN Offset scale is zoomed to Base Station 208.

The time resolution (τ) of multipath components for a spread spectrum system is related to the chip period, and for the CDMA rate is:

$$\tau > T_c = 1/R_c$$

where T_c = chip period = 813.8s
 R_c = chip rate = 1.2288MHz

CDMA or spread spectrum systems can resolve two multipath components as long as they are greater than T_c seconds apart [4]. The Super Eagle is limited to resolving multipath to about 813 s and the subscriber handset also has the same limit when detecting and combining multiple paths. Paths that are shorter than the chip period will combine in and out of phase and appear to fade the received path. Figure 6 shows two multipath components delayed slightly more than T_c from each other.

8. Results and Conclusions.

The Crocodile and Super Eagle System meets the author's requirements for the CDMA system planing field tool: it is simple, practical for system planning and optimization. It measures multipath reflections desirable for CDMA operation from both the nearest BS and neighboring BS and measure multipaths that are not desirable because they are from a BS not suitable for hand-off. Multiple Crocodile transmitters can be located at proposed BS sites with the proposed BS Identification (time) offset, and one Super Eagle receiver can measure multiple paths from the Crocodile transmitters in Ec/Io or Ec.

9. Acknowledgments.

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10. References.

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[4] Rappaport, Theodore S., Wireless Communications, Principals and Practice, Prentice Hall, 1996.