TEST EQUIPMENT SYNCHRONIZATION: PROBLEMS AND SOLUTIONS

With the introduction of CDMA it has become clear that plain old CW scanning receivers do not serve well for network planning. The deployment of CDMA emphasizes even stronger demand for specific tools to set up new networks and troubleshoot existing ones. Pilot pollution, island cells and rogue pseudorandom noise (PN) are just a few of the problems with which network specialists must deal. That is why, during 1998, the amount of pilot scanner products on the market increased from one or two to approximately 10. Each of these devices has a different architecture and performance (from a simple CDMA phone with special software to a silicon-intensive fast PN scanner).[1] One thing is common: All of the pilot scanners have a correlating receiver that allows the operator to monitor the strength of signals received from each base station (BS) instead of measuring only the total energy in the RF channel as in the case of FDMA or TDMA.

Several levels of synchronization are required in a pilot scanner. At the system level, the start of the PN generator in a receiver must be synchronized to a Coordinated Universal Time (UTC) even second since the pilot repeats 75 times every two seconds. The BS identifier (ID) determines its pilot offset from the even-second time mark. Appropriate reference of the receiver's PN generator allows determination of each received pilot's ID without demodulation. The chip offset from the position where each BS pilot was transmitted describes a propagation distance from the BS to the monitoring receiver.

The RF receiver reference frequency can be recovered from a received carrier or must be close in frequency to it. The longer the correlation length, the closer the frequencies must be. Calculations and experiments show that in order to provide a correlating receiver sensitivity of approximately –20 dB in terms of Ec/Io, the required length of a correlator must be more than 1000 PN chips and the required accuracy of the RF reference oscillator must be better than 0.1 ppm.

The chip rate for digital synchronization in a correlating receiver must be the same as in the transmitter to provide the repeatability of the measurements during each search over PN positions. The position of a correlation peak will slide if even a small difference exists between the chip frequency in the receiver and the BS.

Pilot scanners represent just one class of field propagation tools that require a careful approach to synchronization. Another example is channel sounders that employ a spread spectrum technique to study the amplitude and phase characteristics of a propagation channel.[2] The channel sounder is usually a pair of devices: a transmitter that outputs a

[Continued on page 122]

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is channel sounders that employ a spread spectrum technique to study the amplitude and phase characteristics of a propagation channel.[2] The channel sounder is usually a pair of devices: a transmitter that outputs a spread spectrum biphase-shift keying or quadrature phase-shift keying modulated RF signal and a correlating receiver that monitors the distortions of a correlation peak due to multipaths and fading. The PN length can be chosen to be much shorter than in an actual CDMA communication system, thus providing correlation over the entire PN. At the same time, the chip rate in a sounder is usually higher to provide better multipath resolution. This higher chip rate imposes even stronger limitations on the inaccuracy and instability of the reference frequency in a sounder receiver.

Ideally, to measure the absolute time of arrival of each multiple path and the phase characteristics of a channel, the reference frequency in the receiver must be identical to the reference frequency in the transmitter. The trade-off between the high accuracy of an RF reference frequency and the high stability of the digital clock phase (depending on characteristics of the test equipment) can simplify the required synchronization circuit. Two rules should be followed. The first rule is obvious and applies to systems with high chip rate and multipath resolution: Keep the digital clock phase deviation at a minimum. The second rule is less obvious: Provide an accuracy for the RF reference clock in the receiver such that the period of the beat frequency is at least four-times longer than the correlation length. This procedure is enough to support the accuracy of the measurements to better than 1 dB.

Assuming that only the pilot signal is received, the energy of the received pilot is expressed as

$$P = I^2 + Q^2 \qquad (1)$$

where I and Q are baseband in-phase R_i and quadrature phase R_q components of the received signal correlated to the pilot p_i:

$$I = \int_0^{T_c} R_i P_i dt$$

$$Q = \int_0^{T_c} R_q P_q dt$$

In these equations, T_c is a correlation length.

Signals R_i and R_q are derived from the RF demodulator as

$$R_i = P_i \cos \omega t$$
$$R_q = P_i \sin \omega t$$

where $\omega = 2\pi(f_T - f_R)$ is a beat frequency due to the difference that exists between the transmitter and receiver frequencies.

$$P_i^2 = 1$$

Hence,

$$I = \int_0^{T_c} \cos\omega t \, dt \qquad (2)$$

$$Q = \int_0^{T_c} \sin\omega t \, dt \qquad (3)$$

Normalized chip energy is derived from Equation 1 using Equations 2 and 3 as

$$E_c = \frac{2\left(1 - \cos 2\pi \frac{T_c}{T}\right)}{\left(2\pi \frac{T_c}{T}\right)^2} = \left(\frac{\sin \pi \frac{T_c}{T}}{\pi \frac{T_c}{T}}\right)^2 \qquad (4)$$

Two obvious conclusions from Equation 4 are

$$E_{cmax} = 1 \text{ if } \frac{T_c}{T} \to 0$$
$$E_{cmin} = 0 \text{ if } \frac{T_c}{T} = 1$$

Any desired accuracy of the E_c measurement between these two extremes can be achieved by providing the corresponding T_c/T. For instance, $T_c/T = 0.25$ provides $E_c/E_{cmax} = -1$ dB as was stated previously.

A number of techniques exist to lock the receiver oscillator to the received signal, including phase-, frequency- or delay-lock loops and combinations of these. While well suited for use in communication system terminals (for instance, mobile telephones), these approaches have certain shortcomings when used in field test and measurement equipment. Signals coming from different BSs (or even different reflections of the same signal) experience different Doppler shifts. Locking the receiver to one of these signals does not necessarily syn-

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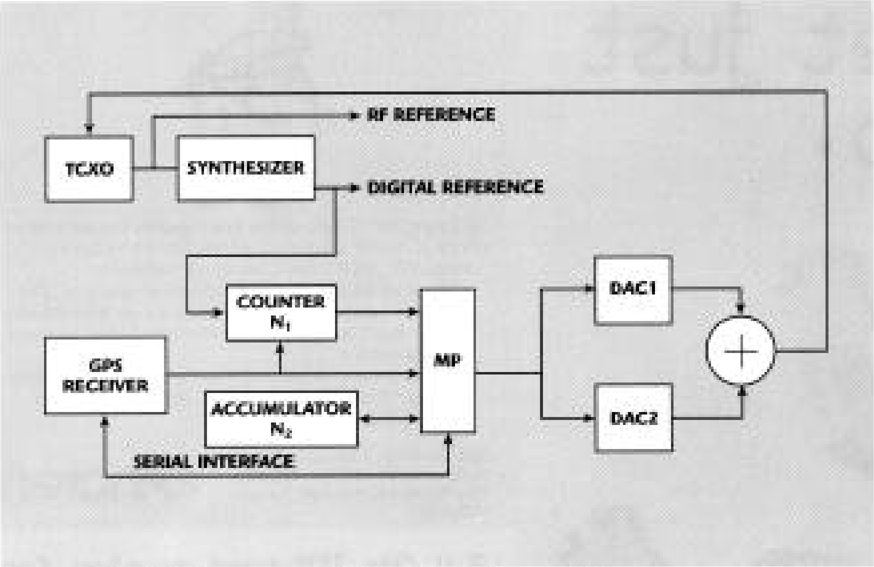

Fig. 1 A typical frequency control circuit for a receiver oscillator.

chronize the reception of each of the correlation peaks. Locking to the strongest signal (received from one BS) renders all of the collected data useless if this particular BS experienced a timing problem during the drive test. The clock synchronization itself does not help to determine the BS numbers. The BS ID can be recovered from a sync channel, however, the instrument that demodulates sync information in addition to pilot scanning is a much more complicated device and probably a slower scanner. In general, field test equipment independent of the network has much more flexibility in determining problems and studying the network.

Luckily, the Global Positioning System (GPS) common reference can be used to synchronize multiple devices in remote locations. GPS receivers are usually used as part of the field test equipment to relate the collected data to a current position of the receiver during the drive study. In addition to navigation information, each GPS receiver provides at least one timing signal 1 pps, which provides 1 Hz pulses aligned to the UTC. A simple circuit that utilizes this signal to control the frequency of the oscillator in the receiver solves most of the problems related to test equipment synchronization. The functional diagram shown in ***Figure 1*** depicts one such device. This circuit is used to derive the digital and RF clocks in all CDMA receivers and Sounders designed and manufactured by Berkeley Varitronics Systems Inc.

The microprocessor (MP) reads the GPS receiver status, determines when it locks and starts the measurement of the temperature-compensated crystal oscillator (TCXO) frequency by reading the counter every second. The device compares the counter value N_1 to the expected number N_0 and writes the difference $(N_1 - N_0)$ in the accumulator so that $N_{2i} = \Sigma(N_{1i} - N_0)$. Note that N_1 is proportional to the TCXO frequency measured every second and N_2 is proportional to the current phase. A control voltage is applied to correct the TCXO frequency once every second and is a function of the two variables N_1 and N_2. The algorithm calculates control signals trying to keep $N_{1i} = N_0$ and $N_{2i} = 0$. Two digital-to-analog converters (DAC) are provided — one for coarse and one for fine regulation. It is important to keep either phase or frequency deviation in the system to a minimum to accurately determine the weight of corresponding components in the calculation of the control voltage V_c.

The products mentioned previously use a TCXO with a stability of 2.5 ppm over the temperature range and a standard Motorola Oncore GPS receiver with a 1 pps jitter of approximately 500 ns. The frequency accuracy achieved in one Scanner model is at the level of ±25 ppb. In a Channel Sounder, both the transmitter and re-

(Continued on page 126)

ceiver use a modification of the circuit described. In this case, the most important factor is to keep the absolute position of the correlation peak stable if no change occurs in the distance between two units. It is also important to reflect the changes in the distance if they occur. This Sounder allows long-term measurements to be made with no accumulated error in multiple paths timing; the short-term jitter does not exceed 500 ns.

This described field test equipment synchronization method is very inexpensive and provides sufficient results (at least at the levels that are required in today's PCS and cellular communication systems). Future systems with higher chip rates may require better synchronization, but the future GPS receivers may provide higher stability of the timing signals.

However, there is one problem with using the GPS receiver: Areas exist where the GPS signal is not available or is intermittent. When this situation occurs, frustrated users will complain that synchronization does not work. However, every problem does have a solution or, as in this case, two solutions. One solution is based on the fact that after the GPS is locked it does not degrade the timing quality of the 1 pps signal if it keeps track of at least one satellite. Even after the GPS receiver completely loses the signal, the TCXO maintains the synchronization for a time depending on temperature and other conditions. These observations implemented in the algorithm help to maintain synchronization of CDMA test equipment for up to several minutes after the loss of GPS lock.

The second solution is implemented in the Rhino™ rubidium frequency source, which is designed specifically as a timing reference for test equipment normally synchronized by GPS in the absence of a GPS signal. The heart of this device is a rubidium frequency standard. The system automatically synchronizes itself to UTC at a moment when the built-in GPS receiver locks. The GPS antenna then can be disconnected and the synchronization is provided by the stability of the rubidium standard. Signals with a timing tolerance sufficient for CDMA testing are valid for approximately one day. The next day, a simple and short procedure that locks the unit to GPS must be repeated. The frequency source provides a 1 Hz output synchronized to UTC that helps to provide uninterrupted data collection in areas with an intermittent or unavailable GPS signal (that is, in the downtown areas of large cities, in tunnels, under bridges and, generally, all indoor areas).

The problems described in this article are not the only issues to be dealt with while running CDMA tests. But, hopefully, the suggested solutions can help with some of them. ■

References

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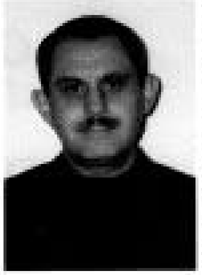
2. Raymond Chadwick and Boris Sheyer, "CDMA Forward Link Coverage and Channel Sounding," *Proceedings of the Seventh Virginia Tech/MPRC Symposium on Wireless Personal Communications*, June 11–13, 1997.



Boris Sheyer *received his MSEE from the Moscow Aircraft University in 1974. He spent the next 18 years with the Avionics Research Institute (ARI), Moscow, Russia, holding different positions from design engineer to head of the electronics laboratory. More than 20 of his innovative designs are registered as inventions by the USSR State Inventions Committee. In 1989, Sheyer concluded his postgraduate studies at ARI and received his doctoral degree. He has been with Berkeley Varitronics Systems Inc., Metuchen, NJ, since 1993 as a senior design engineer. While with the company, he has designed a number of propagation tools for AMPS, GSM, TDMA and CDMA. Sheyer's research focuses mainly on synchronization of the field test equipment. His latest ideas are implemented in the design of a high speed portable channel sounder.*