An Internet Controlled Calibration System for TDMA Smart Antenna Wireless Base Stations

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Abstract — **Smart antenna base stations are receiving considerable attention in the wireless marketplace due to their potential for increasing system capacity. These antenna arrays usually require accurate calibration in order to produce high quality steerable beams and direction of arrival measurements. The following work describes the design and measurement results of a new approach to array calibration consisting of a tower top internet controllable high dynamic range data collection system combined with remote data processing. Measurements acquired during a sequence of time slots are used to obtain calibration accuracy of better than 1 degree for phase and better than 1.5% for amplitude. All data was taken on a smart antenna system prototype designed for advanced wireless access applications at our Crawford Hill Laboratory.**

I. INTRODUCTION

The problem of calibrating phased array antennas is one that has been around for quite some time. In the past, phased array antenna systems were limited to military communications, satellite communications [1,2], and radar applications [3] predominantly for two reasons: prohibitive cost and lack of commercial market. Today things are quite different. The field of wireless communications has grown into an enormous business with an insatiable desire for capacity. Spatial diversity is a very attractive way to increase system capacity, however cost and reliability are still very serious issues.

There have been a number of reports recently discussing the design of smart antenna systems for wireless applications [4-7]. The problem of transmit calibration is particularly difficult because the measurement requires monitoring the signal at the top of a base station tower [8,9]. Furthermore, this signal must be transmitted to a place where signal processing can take place so that the relative phase and amplitudes of the array elements can be determined and used for correction. Traditionally, this is accomplished by sending the RF signal down the base station tower where it is processed on the ground [10,11]. It is no surprise that this approach poses many challenges when trying to obtain high accuracy measurements. Noise pickup on 75 - 150 foot coaxial lines positioned as a giant whip antenna can be subject to a wide range of environmental noise sources.

This paper will describe a unique design approach that uses a technique whereby the RF data is collected at the top of the tower using a high dynamic range sampling RF detection system and immediately converted into a small number of digital words. This data is then requested by a remote computer located anywhere on a local network where the data is processed and calibration coefficients are computed and sent via the internet back to the base station for incorporation into system transmissions. Using an efficient family of algorithms, the phase and amplitude calibrations are extracted from a set of scalar measurements thereby reducing the complexity of the calibration hardware. Only a single RS-422 timing signal and a standard ethernet line are required to communicate with the tower top hardware. Nearly identical hardware is used for receive calibration and external transmit calibration, where the software distinguishes collection systems by their unique IP addresses.

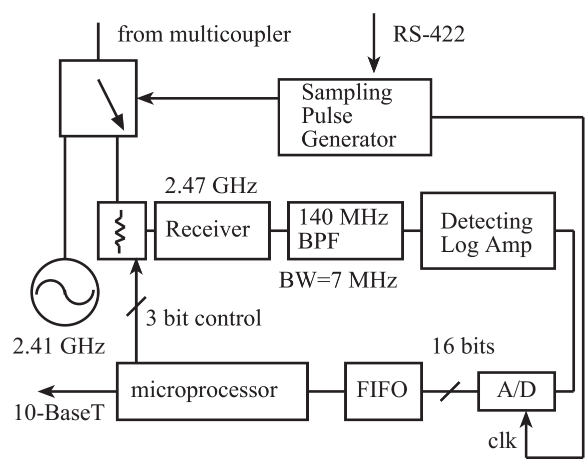

Fig. 1. Tower Top Hardware Block Diagram

II. SYSTEM CONCEPT AND DESIGN

The heart of this design is a 70 dB dynamic range sampled detection system. Such performance can not be accomplished using traditional diode detectors. Instead, this system takes advantage of advances in low cost analog

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integrated circuit design, specifically detecting logarithmic amplifiers. Such devices are now available on the market from vendors such as Analog Devices for mere dollars and

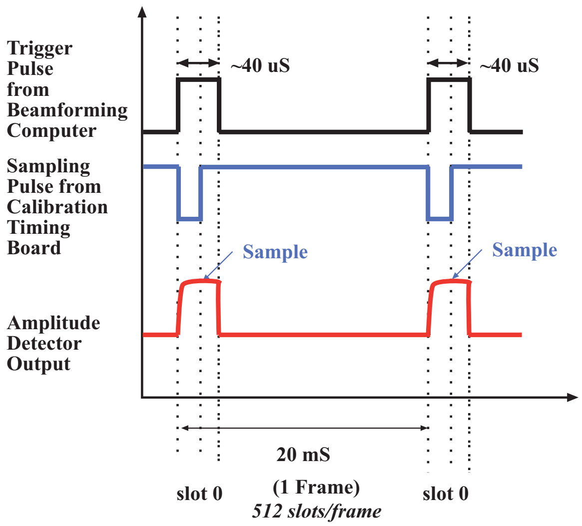

Fig. 2. Calibration Measurement Timing

can have dynamic ranges near 90 dB. The reason for requiring such a high dynamic range is that now the output of the remote detection system can be sampled once or twice per measurement resulting in very low speed and thus inexpensive A/D converter. This system uses a 16 bit 100 KHz A/D with a sampling aperture of 2 µs. Additionally, the required data transfer rate from the tower top to the processor on the ground is very low and can be accomplished easily using a low speed ethernet connection. In fact, our calibration algorithms allow 16 transmit or receive channels to be calibrated (both magnitude and phase) and verified using as few as 76 data points. For this research prototype, a single board ethernet based acquisition system purchased from Intelligent Instrumentation was used. It is controlled by an 8086 microprocessor and can be completely controlled via TCP/IP commands which of course are platform independent.

Figure 1 illustrates a block diagram of the tower top electronics. The input RF signal comes from a multicoupler that is connected to each of the 16 TX/RX modules via a 20 dB directional coupler. A sequence of synchronization pulses is generated by the beamforming computer and sent up the tower via RS-422. These pulses acts as the sampling trigger for the tower top 16 bit A/D converter. Upon reception, the tower top electronics timing board generates a rising edge 20 µs into the time slot, thus telling the calibration system when to sample the detection system output. A sequence of measurements is required to calibration the entire array. These are specified in a "calibration experiment" that is communicated from a calibration computer located anywhere on the network to the beamforming computer located at the base of the tower. In turn, the beamforming computer sets up a sequence of amplitude and phase settings in the IF portion of the transmit chain.

Figure 2 illustrates the system timing. The hardware can function with time slots as narrow as 40 µs. The sampling edge occurs at roughly 20 µs and is set by a timer in the tower top hardware. It is also worth noting that a high isolation RF switch is part of the front end hardware for the purpose of making sure that high level transmissions during adjacent time slots do not overdrive the calibration detection system. Additionally, this switch allows carefully generated RF pulses to be sent down the antenna receive chain for uplink system calibration.

III. Measurement Results

The performance of the remote detection system was measured carefully in a laboratory prior to system

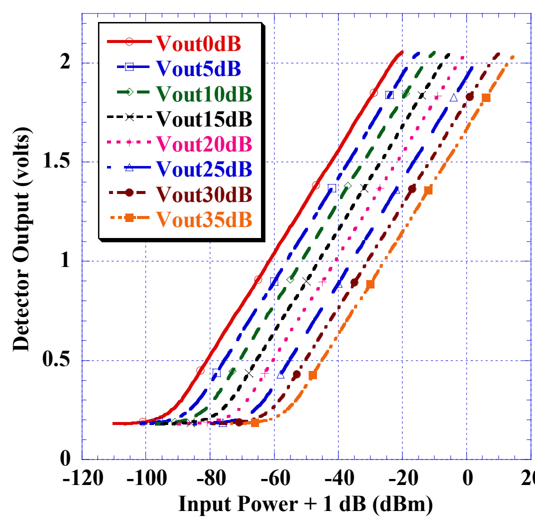

Fig. 3. Calibration Box Transfer Function

integration. Figure 3 illustrates the transfer function of the detection system for different front end attenuator settings. These attenuator settings are remotely controlled through the internet. This plot illustrates the extremely log linear performance of the detection system. Correlation coefficients of better than 0.9999 were obtained over the log linear region of Figure 3. This is critical to alleviate the need for calibration iterations and complicated lookup tables.

Although discussion of calibration algorithms is beyond the scope of this paper, calibration measurements for this system will be illustrated to demonstrate the performance of the prescribed hardware system. Figures 4 and 5 show measured calibration coefficients for 16 transmit channels

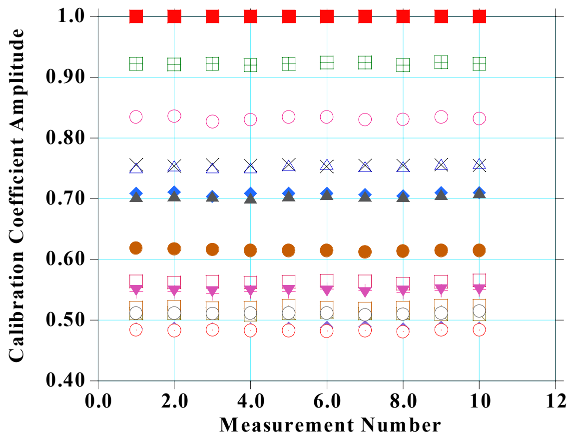

Fig. 4. Amplitude Calibration Coefficient Measurements

as a function of time. Note the stability of these measurements is very good over the 20 minute measurement period. The measurement point is at the output of the multicoupler illustrated earlier in figure 1.

Another way to illustrate calibration performance is to effectively generate a beam by stepping a progressive phase front across all of the elements while measuring the

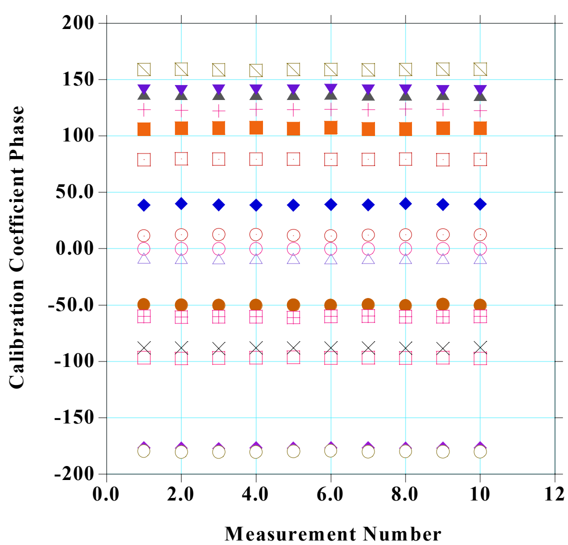

Fig. 5. Phase Calibration Coefficient Measurements

signal at the multicoupler output. This is a very good metric for calibration since cancellation of signals for all 16 elements simultaneously can only be achieved with accurate phase and amplitude calibration across the entire array. Figure 6 is an illustration of such a measurement. This data was taken using the base station prototype illustrated in figure 7. Since the multicoupler in the system acts as a voltage summer, it is clear that the output

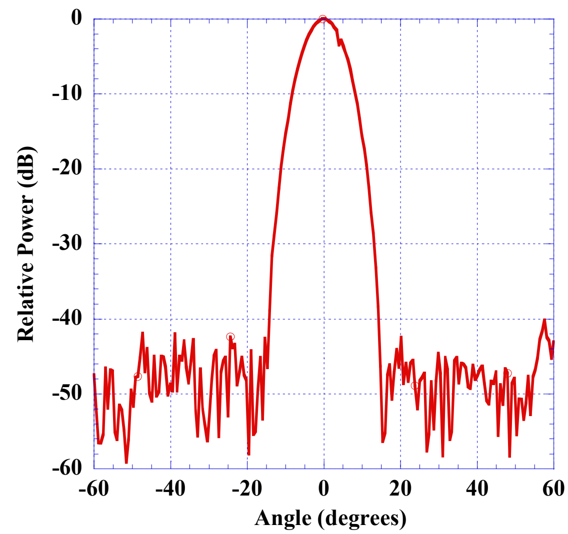

Fig. 6. Internally Measured Swept Beam

power can be expressed as

$$P(\theta) = \left|\alpha \sum_{i=0}^{15} a_n e^{j2\pi(\sin\theta)ns}\right|^2 ,$$

where α=scale factor, s=element spacing in wavelengths (0.55), a_n=weights for a 50 dB N=7 Taylor distribution, and θ= the angle off boresight. The effective swept beam has noise sidelobes at about 44 dB below the main beam. Following the derivation in Mailloux [12], one can estimate the expected standard deviation of the phase and amplitude errors for the 16 elements as a function of the average residual sidelobe level as

$$\frac{\frac{1}{2}10^{SLL_{dB}/10}}{\left(\frac{\sum |a_n|^2}{\left|\sum a_n\right|^2}\right)} = \sigma_a^2 + \sigma_\phi^2 .$$

The variance for the average amplitude and phase errors are σ_a^2 and σ_ϕ^2 respectively, and SLL_{dB} is the measured residual sidelobe level relative to the peak in dB. This derivation assumes that the phase and amplitude errors are small and that the noise sidelobes are dominant over the design sidelobes. In the case that the noise sidelobes are not dominant, the phase and amplitude errors will be smaller than predicted, so this is a conservative estimate. In the case of the data illustrated in Figure 6, if we assume that the phase and amplitude errors are equal, an average amplitude error of 1.45 % and phase error of 0.83 degrees are predicted.

The described calibration system was integrated into our advanced wireless access smart array platform and elevated to a height of 115 feet. Figure 7 is an illustration of the antenna on the top of Crawford Hill. This platform has a tower top positioner allowing us to point the array at various transmitters and receivers for experimentation.

Fig. 7. Advanced Wireless Access Smart Antenna Basestation on top of Crawford Hill

V. CONCLUSION

A new type of TDMA calibration system has been demonstrated that can provide very accurate phase and amplitude measurements during prescribed time slots. The required tower top hardware takes advantage of a high dynamic range sampled logarithmic receiver architecture. Required sampling rates are very modest resulting in low cost tower top hardware, a low required data transfer rate, and internet controllability. Calibration algorithms can be run from any machine on the network, where measurement latency does not have an impact on the performance of the algorithm. This approach offers an attractive alternative to running expensive 100 foot RF monitoring cables.

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