TOWER-TOP ANTENNA ARRAY CALIBRATION SCHEME FORNEXT GENERATION NETWORKS

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Abstract- Recently, there has been increased interest in moving the RF electronics in base stations from the bottom of the tower to the top, yielding improved power efficiencies and reductions in infrastructural costs. Tower-top systems have faced resistance in the past due to such issues as increased weight, size, and poor potential reliability. However, modern advances in reducing the size and complexity of RF subsystems have made the tower-top model more viable. Tower-top relocation, however, faces many significant engineering challenges. Two such challenges are the calibration of the tower-top array and ensuring adequate reliability. We present a tower-top smart antenna calibration scheme designed for high-reliability tower-top operation. Our calibration scheme is based upon an array of coupled reference elements which sense the array's output. We outline the theoretical limits of the accuracy of this calibration, using simple feedback-based calibration algorithms, and present their predicted performance based on initial prototyping of a precision coupler circuit for a 2 ×2 array. As the basis for future study a more sophisticated algorithm for array calibration is also presented whose performance improves with array size.
Keywords: Tower-Top Antenna, Array Calibration Scheme, Next Generation Networks.

1 INTRODUCTION

Antennas arrays have been commercially deployed in recent years in arrange of applications such as mobile telephony, in order to provide directivity of coverage and increase system capacity. To achieve this, the gain and phase relationship between the elements of the antenna array must be known. Im-balances in these relationships can arise from thermal effects, antenna mutual coupling, component aging, and finite manufacturing tolerance. To overcome these issues, calibration is required. Traditionally, calibration would have been undertaken at the manufacturer, address static effects arising from the manufacturing tolerances. However, imbalances due to dynamic effects require continual or dynamic calibration. Array calibration of cellular systems has been the subject of much interest over the last decade, and although many calibration processes already exist, the issue of array calibration has, until now, been studied in a "tower-bottom" smart antenna context. Industry acceptance of smart antennas has been slow, princi- pally due to their expense, complexity, and stringent reliability requirements. Therefore, alternative technologies have been used to increase network performance, such as cell splitting and tower-bottom hardware upgrade. To address the key impediments to industry acceptance of complexity and expense, we have been studying the feasibility of a self-contained, self-calibrating "tower-top" base transceiver station (BTS). This system sees the RF and mixed signal components of the base station relocated next to the antennas. This provides potential capital and operational savings from the perspective of the network operator due to the elimination of the feeder cables and machined duplexer filter. Furthermore, the self-contained calibration electronics simplify the issue of phasing the tower-top array from the perspective of the network provider. Recent base station architectures have seen some departure from the conventional tower-bottom BTS and tower-top antenna model. First, amongst these was the deployment of tower-top duplexer low-noise amplifiers (TT-LNA),demonstrating a tacit willingness on the part of the network operator to relocate equipment to the tower-top if performance gains proved adequate and sufficient reliability could be achieved. This willingness can be seen with the

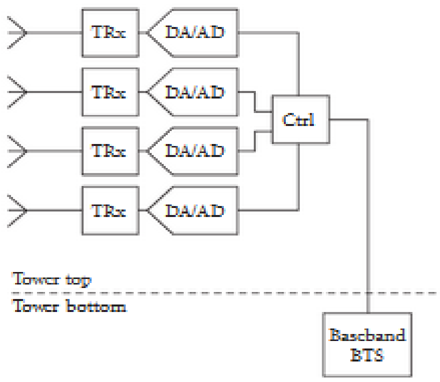

Figure 1 The hardware division between tower top and bottom for the tower-top BTS

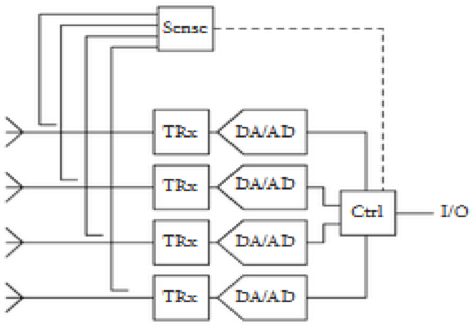

Figure 2 A simplified block schematic diagram of a typical array calibration system

exploration of novel base station architectures, with examples such as reduced RF feeder structures utilising novel switching methodologies, and the development of base station hotelling with remote RF heads. Such approaches aim to reduce capital infrastructure costs, and also site rental or acquisition costs. In this paper, we present our progress toward a reliable, self-contained, low-cost calibration system for a tower-top cellular BTS. The paper initially presents a novel scheme for the calibration of an arbitray-sized rectilinear array us- ing a structure of interlaced reference elements.

2 RECTILINEAR ARRAY CALIBRATION

i) Array calibration-To yield a cost-effective solution for the cellular BTS market, we have been studying the tower-top transceiver configuration shown in Figure 1. This configuration has numerous advantages over the tower-bottom system but, most notably, considerably lower hardware cost than a conventional tower-bottom BTS may be achieved. We define two varieties of array calibration. The first, radiative calibration, employs free space as the calibration path between antennas. The second, where calibration is performed by means of a wired or transmission line path and any radiation from the array in the process of calibration is ancillary, is refered to as “nonradiative” calibration. The setup of Figure 2 is typically of a nonradiative calibration process. This process is based upon a closed feedback loop between the radiative elements of the array and a sensor. This sensor provides error information on the array output and generates an error signal. This error signal is fed back to correctively weight the array element’s input (transmit calibration) or output (receive calibration). It is important to observe that this method of calibration does not correct for errors induced by antenna mutual coupling. Note that in our calibration scheme, a twofold approach will be taken to compensate for mutual coupling. The first is to minimise mutual coupling by screening neighbouring antennas and perhaps using electromagnetic (EM) bandgap materials to reduce surface wave propagation to distant antennas in large arrays. The second is the use of EM modelling-based mitigation such as that demonstrated by Dandekar et al. Further discussion of mutual coupling compensation is beyond the scope of this paper. While wideband calibration is of increasing interest, it remains difficult to implement. On the other hand, narrow- band calibration schemes are more likely to be practicallyimplemented. The calibration approach presented here is directed towards narrowband calibration. However, the methodology supports wideband calibration through sampling at different frequencies.

ii) Calibration of a 2×2array- Our calibration process employs the same nonradiative calibration principle as shown in Figure 2. The basic building block, however, upon which our calibration system is based is shown in Figure 3. This features four radiative array transceiver elements, each of which is coupled by transmission line to a central, nonradiative reference element. In the case of transmit calibration (although by reciprocity receive calibration is also possible), the transmit signal is sent as a digital baseband signal to the tower-top and is split (individually addressed) to each transmitter for SISO (MIMO) operation. This functionality is subsumed into the control (Ctrl) unit of Figure 3. Remaining with our transmit calibration example, the reference element sequentially receives the signals in turn from the feed point of each of the radiative array elements. This enables the measurement of their phase and amplitude relative to some reference signal. This information on the

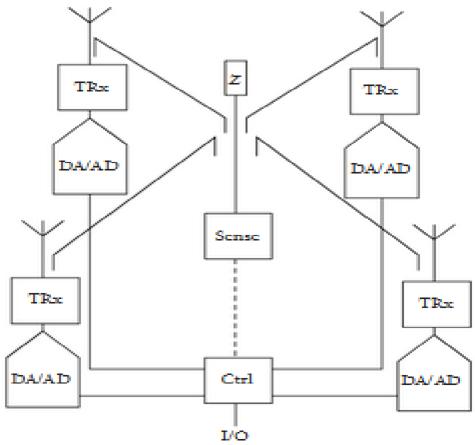

Figure 3 A central, nonradiative reference sensor element coupled to four radiative array transceiver elements.

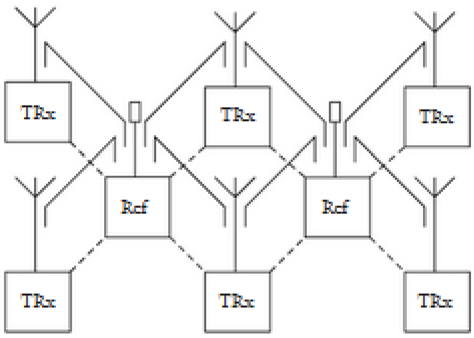

Figure 4 A pair of reference elements, used to calibrate a 2×3array

relative phase and amplitude imbalance between the feed points of each of the transceivers is used to create an error signal. This error signal is fed back and used to weight the input signal to the transceiver element effecting calibration. Repeating this procedure for the two remaining elements calibrates our simple 2×2 array. This baseband feedback system is to be implemented in the digital domain, at the tower-top.

The functionality of this system and the attendant computing power, energy, and cost requirements of this system are currently under investigation.

iii) Calibration of an n×narray- By repeating this basic 2 ×2 pattern with a central reference element, it becomes possible to calibrate larger arrays. Figure 4 shows the extension of this basic calibration principle to a 2 ×3array.

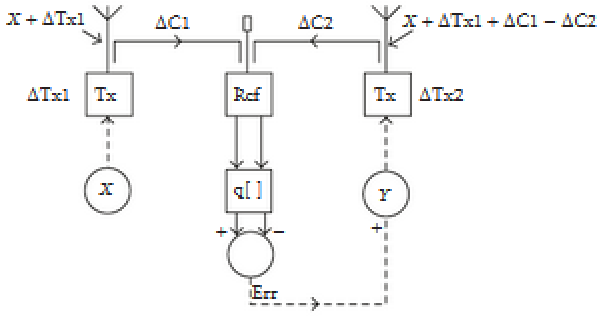

Figure 5 Propagation of error between calibrating elements

To calibrate a large, n×n, antenna array, it is easy to see how this tessellation of array transceivers and reference elements could be extended arbitrarily to make any rectilinear array geometry.

3 CALIBRATION COUPLER

i) 2×2array calibration coupler- The phase and amplitude balance of the six-port coupler structure at the feed point of every transceiver and reference element in Figure 4 is crucial to the performance of our calibration scheme. This six-port coupler structure is shown schematically in Figure 10. In the case of the reference element, the output (port B) is terminated in a matched load (antenna) and the input connected to the reference element hardware (port A). Ports C−F of the coupler feed adjacent transceiver or reference elements. Similarly, for the radiative transceiver element, port B is connected to the antenna element and port A the transceiver RF hardware. For the individual coupler shown in using conventional low-cost, stripline, board fabrication techniques, phase balance of 0.2 dB and 0.9°is possible. By interconnecting five of these couplers, then the basic 2 ×2 array plus single reference sensor element building block of our scheme is formed. It is this pair of precision six-port directional couplers whose combined error will form the individual calibration paths between transceiver and reference element. A schematic representation of the 2 ×2 array coupler is shown in Figure 6. This forms the feed-point coupler struc- ture of Figure 4, with the central coupler (port 1) connected to the reference element and the load (port 2). Each peripheral couplers is connected to a radiative transceiver element

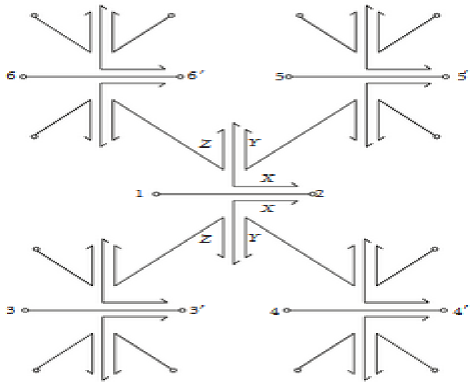

Figure 6 Five precision couplers configured for 2 ×2arraycalibration

(ports 3–6). By tiling identical couplers at half integer wave length spacing, our objective was to produce a coupler network with very high phase and amplitude balance.

ii) Theoretical coupler performance- The simulation results for our coupler design, using ADS momentum. Insertion loss at the design frequency of 2.46 GHz is predicted as 0.7 dB. The inter transceiver isolation is high a minimum of 70.4 dB between transceivers. In the design of the coupler structure, trade off exists between insertion loss and transceiver isolation. By reducing the coupling factor between the antenna feeder transmission line and the coupled calibration, higher efficiency may be attained. However, weaker calibration coupling than −40 dBm is undesirable from the perspective of calibration reference ele-ment efficiency and measurement reliability. This necessitates stronger coupling between the calibration couplers this stronger coupling in the second coupler stage will reduce transceiver isolation. It is for this reason that −20 dB couplers are employed in all instances (X,Y, and Z).

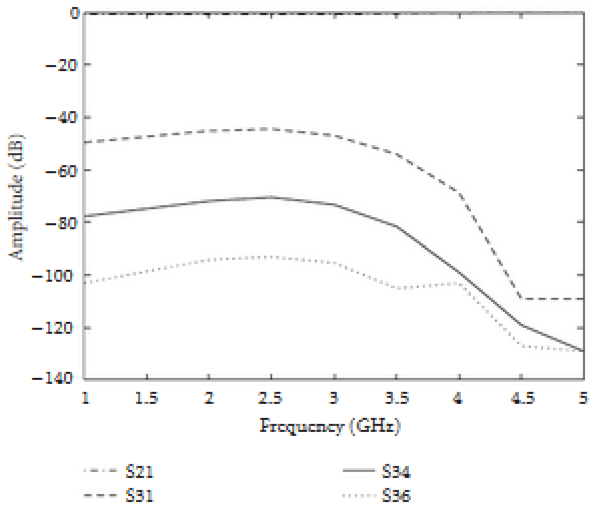

Figure 7 The theoretically predicted response of the ideal 2 ×2 coupler

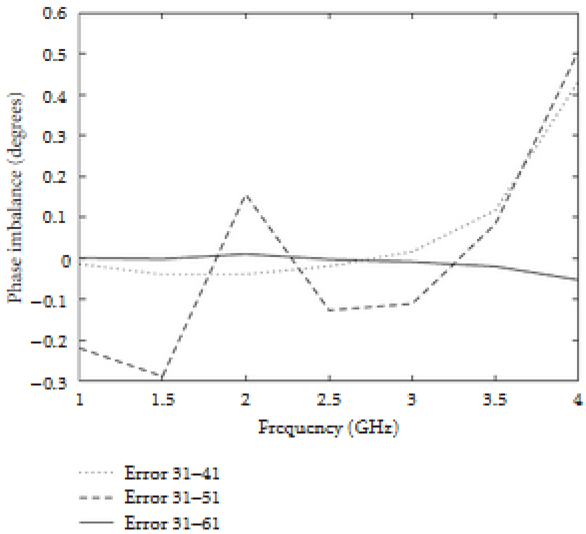

Figure 8 The predicted phase imbalance of an ideal 2 ×2 coupler

A, D(X,Z) type error and an A,C(X,Y)type error. This has the overall effect of reducing error. Were there to be a diagonal bias toward the distribution of error, then the error would accumulate. Also visible in these results is a greater phase and amplitude balance between the symmetrically identical coupler pairs. For example, the phase and amplitude imbalance between ports 3 and 6 is very high. This leads to efforts to increase symmetry in the design, particularly the grounding via screens.

iii) Measured coupler performance- Our design for Figure 6 was manufactured on a low-cost FR-4 substrate using a stripline design produced in Eagle

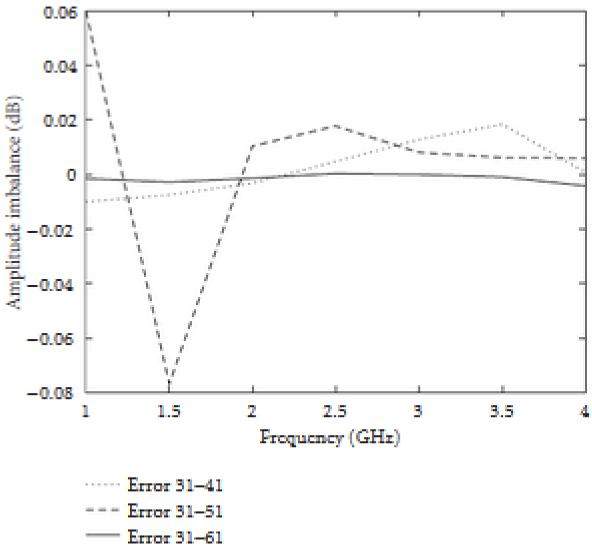

Figure 9 The predicted amplitude imbalance of an ideal 2 ×2 coupler

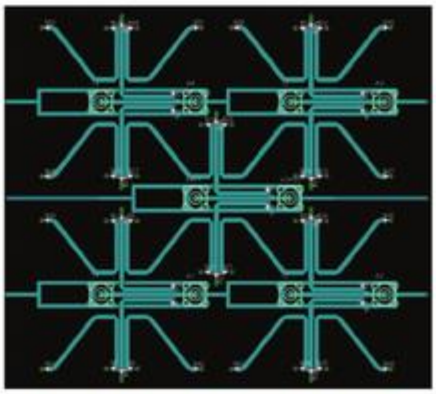

Figure 10 The PCB layout of the centre stripline controlled impedance conductor layer

see Figure 10. Additional grounding strips, connected by blind vias to the top and bottom ground layers, are visible which provide isolation between the individual couplers. A photograph of the finished 2 ×2couplermanufacturedby ECS circuits. Each of the coupler arms is terminated in low-quality surface mount 47 Ωresistors

4 CONCLUSION

In this paper, we have presented a new scheme for tower-top array calibration, using a series of nonradiative, interlinear reference elements to sense the output of the array. The accuracy of this calibration scheme is a function of the array size, the calibration path taken in calibrating the array, and the coupler performance. Where the measurement accuracy is unlimited, then the accuracy of this calibration is dependent upon the number of couplers in a given calibration path. The basic building block of this calibration scheme is the 2×2 array calibration coupler. We have shown that using low-cost fabrication techniques and low-quality FR-4 substrate, a broadband coupler network with rms phase balance of 1.1175°and amplitude balance of 0.3295 dB is realisable. Based upon this coupler hardware, we have shown that phase calibration accurate enough for cellular smart antenna applications is possible. Although amplitude accuracy is still outside our initial target, work is ongoing on improving the precision coupler network and on the development of calibration algorithms to further reduce this requirement. Finally, we presented examples of one such algorithm whose performance, unlike that of the conventional feedback algorithms, improves with array size. Moreover, this calibration algorithm, which is based upon exploiting randomness within the array, outperforms conventional calibration for large arrays. Future work will focus on use of simulated annealing and hybrid calibration algorithms to increase calibration accuracy.

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