Development of SATB Based on LIEH Shaped Patch Antenna for Digital Beamforming System

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Abstract: - This paper presents the design and development of the smart antenna system testbed (SATB). The SATB is developed based on using the novel L-probe fed inverted hybrid E-H (LIEH) microstrip patch element design arranged into 4×1 uniform linear array antenna. This paper reports the development of a software reconfigurable testbed for the implementation and evaluation of digital beamforming algorithm for smart antenna systems. The novel SATB developed based on modular design employing two novel designs of LIEH array antenna and software reconfigurable digital beamforming system (DBS). The modular concept of the system provides the capability to test the antenna hardware, beamforming unit, and beamforming algorithm in an independent manner, thus allowing the smart antenna system to be developed and tested in parallel, hence reduce the design time. The digital beamforming system was developed using a high performance TMS320C6711™ floating-point DSP board and a 4-channel RF front-end receiver developed in-house. The over all peak side lobe level is achieved around at -10 dB for the different scanning angle. The antenna is used for a scan range as far as ±30°.

Key-Words: - SATB, LIEH, TMS320C6711™, Prototype, Beamforming Algorithm,

1. Introduction

Smart antenna is regarded as one of the key components in the 3G wireless network to meet the demand for increased capacity and broadband multimedia services at high data rates. Smart antenna systems consist of multiple antenna elements at the transmitting and/or receiving end of the communication link, in which the radio link signals are processed adaptively in order to exploit the spatial dimension of the mobile radio channel.

Smart antenna technology dramatically improves the interference-suppression capability and greatly increases frequency reuse, resulting in increased capacity. Smart antenna with its beamforming capability optimizes the signal to noise performance or power consumption at both ends of the links. Advancement in powerful low cost digital signal processor (DSP), general-purpose processors, field programmable gate array (FPGA), application specific integrated circuits (ASIC), as well as innovative software-based signal processing techniques (algorithms) or software defined radio (SDR) has allowed the development of smart antenna system to progress rapidly and make the smart antennas practical for cellular communications systems [1].

The beamforming is a key technology in smart antenna system which is a process in which each user's signal is multiplied with a complex weight vectors that adjust the magnitude and phase of the signal from each antenna element [2]-[5]. Hence the array forms a transmit beam in the desired direction and minimizes the output in the interferer directions. A beamformer appropriately combines the signals received by different elements of an antenna array to form a single output. Classically, this is achieved by minimizing the mean square error (MSE) between the desired output and the actual array output. This principle has its roots in the traditional beamforming employed in sonar and radar systems [6]-[13].

Investigating the performance of highly sophisticated wireless systems, in particular the smart antenna systems, is a difficult task. In most cases, this can only be performed via simulation, which means modeling complex behavior by simpler mathematical descriptions. Software simulation, for example Matlab software with its highly accurate double-precision numerical environment, is on the one hand a perfect tool for the investigation of algorithms. On the other hand many imperfections of the real-world are neglected [14]. A testbed is generally used for research which is a vehicle for further development, for verification of algorithms, or ideas under real-world or real-time conditions. This results in the requirement for scalability, modularity, and extendibility [14]. The advantage of testbed is to reduce the investment risk of the new product in case the new technology would hide unforeseen challenges.

Recently, there has been a great effort to build the SATB to meet the ever demanding channel capacity for the future generation broadband mobile 3G communication systems [15]-[17]. There are testbeds reported in the literature focusing on various wireless technologies. The TSUNAMI project [18] in Europe was aimed at promoting research and development in adaptive antennas. The testbed reported by Virginia Tech lab [19] is a 2×2 broadband MIMO. Iospan Wireless Inc. and Stanford University also reported in [14] a smart antenna testbed one in down link and another in uplink. These smart antenna testbeds are designed based on narrowband antennas employing conventional dipole, slots, TEM horns, reflectors antenna, etc. that made the antennas bulky and heavy. Aesthetic appearances of these structures are adversely affected by big bulky antennas. Microstrip technology meet the requirement of a compact and low profile system due to its light weight, low production cost, ease of fabrication and conformability with RF circuitry [20],[21]. However conventional microstrip antenna or array suffers from very narrow bandwidth. This set the design challenges, of developing a broadband microstrip antenna that can cover the 3G radio band.

2. System Architecture

The SATB is developed based on modular concept employing two novel designs of four element microstrip patch antenna array and DSP-based digital beamforming system (DBS), which allows the exploitation of digital beamforming. The testbed is designed as a receiver unit. A block diagram of SATB receiver system architecture is shown in Fig. 1. The testbed receiver system composed of antenna system, radio unit and digital signal processing base band section.

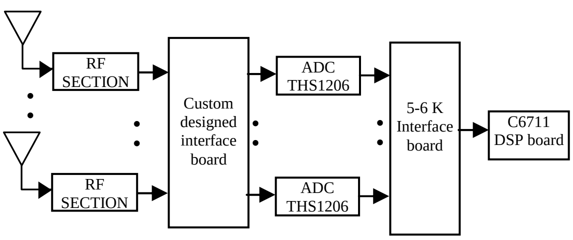

Fig. 1 Block diagram of SATB receiver

The radiating element, the LIEH shaped microstrip patch antenna (MPA) is arranged in a 4×1 linear array configuration. The LIEH array antenna is constructed using two dielectric layer arrangement where a thick air-filled substrate was sandwiched between top-loaded dielectric substrate or superstrate with inverting radiating patch and an aluminium ground plane [22]. The array antenna is designed based on LIEH shaped microstrip patch which used contemporary design techniques namely, the L-probe feeding, inverted patch and slotted patch techniques to meet the design requirement. The geometry of the 4×1 uniform linear LIEH array antenna is shown in Fig. 2.

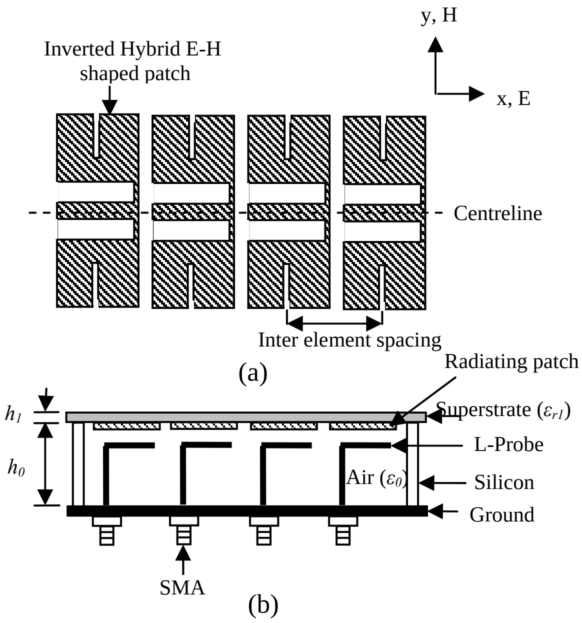

Fig. 2 (a) Top view (b) side view of the 4×1 LIEH patch elements

One of the fastest floating-point platforms available, the Texas Instruments TMS320C67 DSP capable of 900 MFLOPS, was selected as the computational platform for the DBS. The radio frequency (RF) receiver front ends accommodate a multi channel two-stage down conversion between the RF section and the baseband section. Center frequency of 2040 MHz is used in the custom designed front-ends due to the propagation similarities compared to the worldwide 3G radio band and the availability of standard components at this frequency. The DBS front-end is composed of four parallel RF channels which filtered, amplified, and downconverted the incoming signal from the antenna into eight complex baseband signals (*I*&*Q*) using the *I*&*Q* demodulators. These signals are fed to the analog to digital conversion (ADC) board for data conversion.

The ADC is performed with the multi-channel Texas Instruments (TI) THS1206M EVM, which is mated to the Texas Instruments C67 DSP board through TI 5-6K Interface board. Since an 8-channel ADC board was not available on a single board, two 4-channel TI THS1206M EVM boards were placed on top of another. The ADC board has been modified for stacking the two ADC board to get eight baseband channels. Two custom designed boards were developed to interface with ADC board. A high resolution ADC and Nyquist sampling technique are employed to solve signal digitization error.

Fig.3 shows the developed SATB system. The developed SATB is composed of 4×1 LIEH array antenna, four RF branches, eight channel ADC, TMS320C6711 DSP board and Pentium host PC. The DBS of SATB consists of four layer rake. The dimension of each layer is 24 inch × 14 inch and mounted on an aluminium metal plate above the perspex for grounding and mechanical support. The bottom three layers are used to accommodate all the components and the top layer for the screening purpose only. The power connections are run beside the board from the DC power supply.

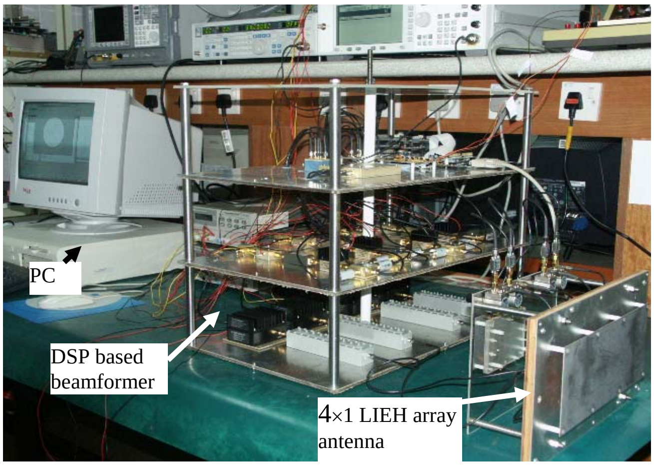

Fig. 3 Constructed SATB receiver system

The SATB receiver system implemented the digital beamforming which is based on the constant modulus algorithm (CMA) algorithm. The DSP with its beamforming algorithms generates the required weight vector based on the angle of arrival of the intended user. The CMA algorithm is simpler to implement and does not require any synchronization and reference signal. The beamforming algorithm is implemented on C67 floating point DSP for the low cost non-coherent testbed system. It does not waste the bandwidth for the training signal. A host PC is used to collect data in real time and offline processing. The data collected by the host PC is passed to the MATLAB environment for post processing and display.

3. Results

A testbed is setup to in the microwave lab to evaluate system performance. The digital beamforming (DBF) measurement result is presented in this section. A single-tone test is performed for the evaluation of the SATB testbed performance. An Agilent 54622 D mixed signal digital oscilloscope is used after the LPF to observe the demodulated baseband signal waveform. Fig. 4 shows the experimental set up for the evaluation of beamforming algorithm.

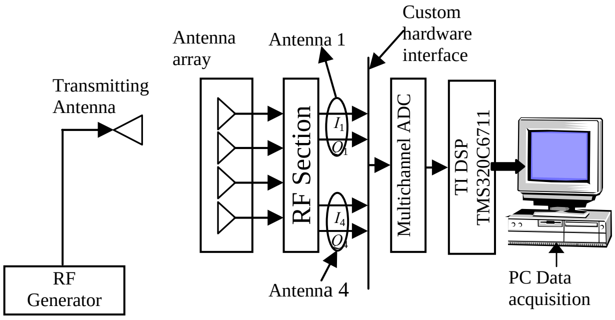

Fig. 4 SATB receiver testbed experimental setup

A continuous wave of 2040.010 MHz RF signal is transmitted by transmitting antenna. The signal is received by the 4×1 LIEH array at the front end of SATB receiver and supplied to all RF chains by a multichannel signal splitter. The RF tone is downconverted into a 10 kHz baseband signal with a LO set at 1972 MHz. The *I* and *Q* signal for different channels are recorded using Agilent 54622 D digital oscilloscope from the LPF before they are sending down to the ADC board. Figure 5 shows *I* signal for channel 1 and channel 2.

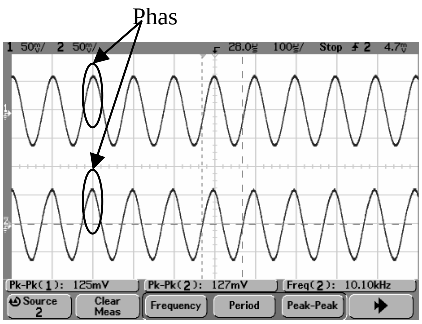

Fig. 5 Channel 1 *I* & Channel 2 *I* signal

As can be seen from this figure, *I* signal from channel 1 and channel 2 are well aligned in same phase and the amplitude of the signal is 125 mV and 127 mV respectively. The well-aligned phase front demonstrates a good broad side reception. The baseband signal is recorded as 10.10 kHz.

There is no disruption observed in the signal.

The following results are carried out to demonstrate the SATB as a beamforming system. The resulted weight vectors are used in MATLAB to plot the antenna response pattern. The data is taken for a different angle of 0º, 30ºand -30º to plot the beampattern. The *I* & *Q* baseband signals are digitized through ADCs and processed by DSP. The architecture is designed to retain all the amplitude and phase information for each antenna element through down conversion and signal recovery, so that, DBF algorithms can be applied. Once each channel's data has been recovered, the DBF algorithm is calculating the weight vectors to form the antenna pattern. The DBF allows the antenna's radiation pattern to be scanned over a wide range of angles without using the associated expensive RF attenuator and phase shifter hardware. Complex weighting coefficients are multiplied with each channel's data to synthesize the pattern at the desired position.

Fig. 6 demonstrates the baseband DBF radiation pattern at 0º 30ºand -30º. The 3 dB beamwidth is observed close to 25º. The sidelobe levels are distributed unequally.

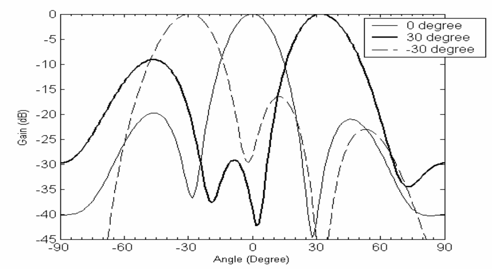

Figure 6 Baseband digital beamforming radiation pattern at the angles -30°, 0°, and 30°

The first side lobe level is -20 dB at -50º at 0º scanning angle. The peak side lobe level is -10 dB at -40º for the scanning angle of 30º. For the scanning angle of -30º, the peak side lobe level is -15 dB at 10º correspondingly. The antenna is used for a scan range as far as ± 30°. Beyond this range, the array degrades the antenna pattern due to the mutual coupling.

4. Conclusion

This paper presented the design and development of a SATB capable of performing digital beamforming that employed LIEH array antenna and DBS. The SATB has been designed in a modular manner, which simplifies the design, reduces the development time, eases hardware update and facilitates testing the various modules (e.g., antenna hardware, beamforming unit and beamforming algorithms) in an independent manner. This paper also presented the antenna beampattern of different scanning angle. The capability of digital beamforming has been demonstrated successfully on the SATB. A DSP-based DBS system provided reconfigurability, rapid prototyping and low cost implementation. The novel low cost SATB with its modular design and software reconfigurable approach provided a full 3G band with small footprint and less weight. The low cost implementation of the testbed system has proven to be a small budget educational tool to enable researcher to understand practical implementation issues regarding smart antenna system.

5. Acknowledgments

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