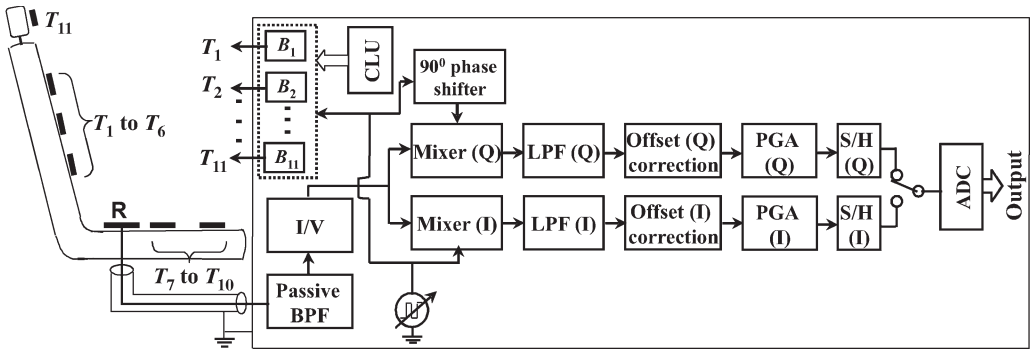

Fig. 8. Carrier-frequency-based measurement system using I/Q demodulation technique [18] with an array of transmitter electrodes and a common receiver electrode for the proposed seat occupancy sensing system. The buffer units $B_1 - B_{11}$ drive the transmitter segments. These buffers are enabled and disabled by the CLU in the sensor IC according to a user-defined sequence.

in the sensor IC is programmed to enable the buffer unit B_1 alone first to excite T_1 with the carrier signal. During this period, all other transmitter electrodes are at ground potential. Once the sensor IC completes the measurement between T_1 and R, buffers $B_2, \ldots, B_{11}$ will be enabled in a similar fashion in an ascending order, and corresponding measurements will be made by the IC. This way, the carrier signal is applied to each transmitting electrode in a sequential manner. As shown in Fig. 8, when a transmitter electrode is excited, the displacement current that flows from the transmitter to the receiver enters into a current-to-voltage converter. The output of the current-to-voltage converter is mixed with the carrier signal for the in-phase (I) channel. A 90° phase-shifted carrier is used for the quadrature phase (Q) channel. The outputs from the I and Q channel mixers are low-pass filtered, and the offsets in both the channels are removed before feeding it into corresponding programmable gain amplifiers (PGAs). Second-order RC low-pass filters with a 3-dB cutoff frequency of typically 150 kHz (depends on factors such as temperature and process variations) are used for low-pass filtering. The outputs from the I and Q channel PGAs are fed to a successive-approximation-register-type analog-to-digital converter, which provides the digital output. The output of the I channel is proportional to the conductance between the corresponding transmitter and receiver electrodes while the Q channel provides an output which is proportional to the capacitance between the electrodes [13], [18], [19]. The capacitance values are used to obtain the presence, position, and type of the occupant while the dielectric properties of objects present between the transmitter and receiver can be obtained using the conductance and capacitance values. Electromagnetic compatibility features of this measurement technique have been presented in [13].

III. Experimental Setup and Results

A prototype capacitive sensing system has been developed and installed on an automobile seat. Transmitting electrodes, 10 cm in length and 5 cm in width, were fabricated by using 100-μm-thick copper plates. The receiver electrode was made identical to the transmitter segment. Transmitter and receiver electrodes were stitched to a cotton cloth material and placed on the sitting and backrest areas of the seat as shown in Fig. 9. A prototype capacitance measurement system has been developed by using a capacitance-to-digital converter IC implemented

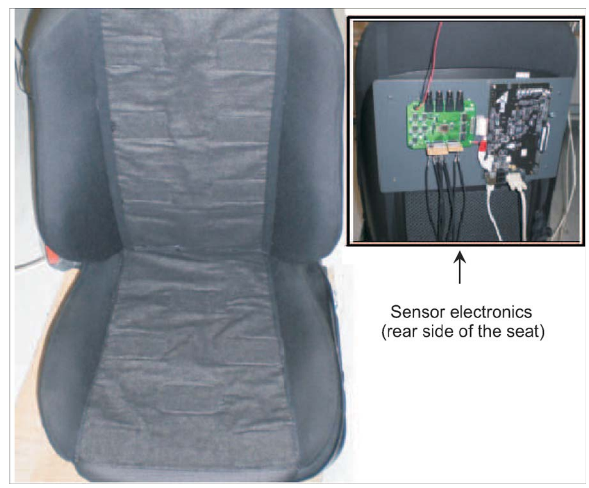

Fig. 9. Automobile seat equipped with prototype capacitive sensing system. Electrodes are stitched to a cotton cloth material and placed in the seat. Associated sensor electronics is fitted in the rear of the seat.

in 0.25-μm CMOS technology [18], [19]. The principle of operation of the sensor IC is explained in Section II-A.

The frequency of the carrier signal used in the prototype system is 5 MHz. For carrier frequencies above 10 MHz, we observed a number of resonance conditions. For carrier frequencies in the range of several kilohertz, the analog low-pass filtering is not efficient due to the comparatively large bandwidth of the low-pass filter of the mixers. The measurement system consists of the sensor IC and a μCLinux Board with a digital signal processor (DSP). A Blackfin processor is used to define initialization parameters for the sensor IC to acquire data from the sensor IC and the data transmission to the host computer. The measured data are then processed in the host computer. Communication between the DSP board and the host computer is accomplished via an Ethernet connection and a transmission control protocol/IP protocol stack. The time required to measure the capacitance between a transmitter and receiver R is about 18 μs. Thus, a system with 11 electrodes takes roughly 198 μs to complete the measurement process. The time required for final decision making depends on the performance of the microprocessor and the complexity of the classification algorithm. For the developed prototype, a simple classification based on predefined threshold levels is used. This algorithm can be implemented in the μCLinux Board, and it can