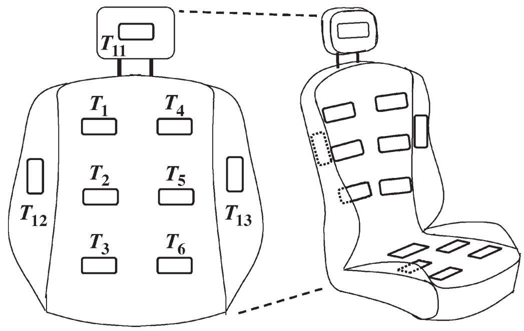

Fig. 12. Pictorial view of an automobile seat equipped with proposed capacitive sensing electrodes. Two additional electrodes T_{12} and T_{13} are introduced in the backrest area of the seat. This provides collateral information that is particularly useful for controlling the firing of window curtain air bags. Typical change in capacitances recorded from the prototype for a test case is shown in Fig. 13.

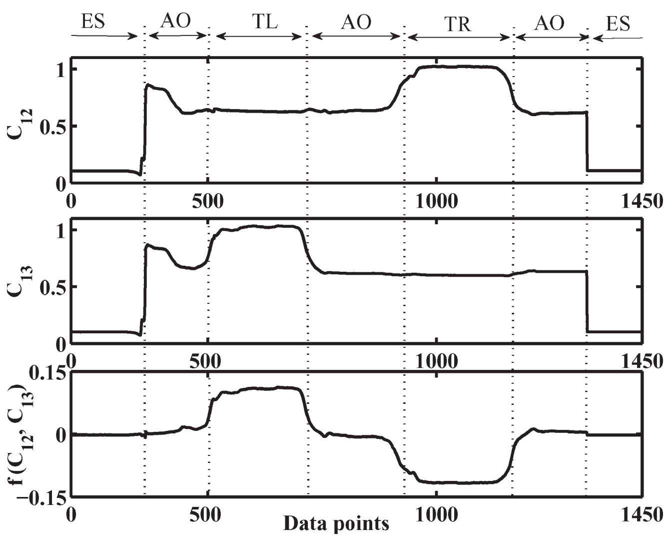

Fig. 13. Change in capacitances were recorded and plotted for ES, AO, TL, AO, TR, AO, and ES in order. C_{12} and C_{13} are the capacitances between receiver R and transmitter T_{12} and T_{13}, respectively. A function $f(C_{12}, C_{13}) = (C_{13} - C_{12})/(C_{13} + C_{12})$ is computed and plotted. The polarity and magnitude of $f(C_{12}, C_{13})$ give an indication of the degree of TL or TR status of the passenger.

The shoulder and head positions of the occupant in the backrest area of the seat are very important as far as the operation of window curtain air bags is concerned. It will be dangerous to deploy window curtain air bags when the passenger is very close to it. In such a condition, the deployment force should be controlled and kept low to avoid possible harmful effects. Thus, the current posture of the passenger, particularly the highly TR and TL conditions, is valuable to meet this demand. The TR and TL conditions can reliably be sensed by introducing two new transmitting electrodes T_{12} and T_{13} as shown in Fig. 12 in the right and left side extensions (wings) of the backrest area of the seat. Let C_{12} and C_{13} be the capacitances between receiver R and transmitters T_{12} and T_{13}, respectively. Whenever the occupant is in position TL or TR, according to the degree of inclination, the occupant's body will get close to the corresponding transmitter segment, and hence, the associated capacitance C_{12} or C_{13} will be increased. This feature has been incorporated in the prototype system and tested. Fig. 13 shows typical variations in capacitances observed during a test cycle for the conditions of ES, AO, TL, AO, TR, AO, and ES in order. A function $f(C_{12}, C_{13}) = (C_{13} - C_{12})/(C_{13} + C_{12})$ is computed and plotted. The polarity and magnitude of $f(C_{12}, C_{13})$ give an indication of the degree of status TL or TR of the passenger. In such an electrode system, the number of transmitting electrodes in the backrest area can be minimized by replacing T_1 and T_4 by an electrode of the same size in the middle of the current positions of T_1 and T_4. The same procedure can be applied to the electrodes T_2 and T_5, as well as T_3 and T_6. In the modified system, the backrest area will only have a single column (instead of two) of three electrodes along with the side electrodes T_{12} and T_{13}.

IV. Conclusion

A simple and cost-effective seat occupancy detection scheme suitable for smart air-bag systems has been developed based on a capacitive sensing principle. The system successfully senses the presence of an occupant. It also detects out-of-position condition of a seat occupant. In the proposed system, the whole measurement is made by using a single receiving electrode and, hence, provides a less-complex measurement method for the occupant sensing system. A prototype has been developed, and its performance for various possible conditions of seat occupancy has been evaluated, proving the practicality of the proposed scheme. The developed system takes up to 200 μs to complete a full set of measurements and, hence, guarantees a dynamic operation of the air-bag system. The measurement principle is based on a carrier-frequency method and uses a lock-in-amplifier technique to obtain the final capacitance values. This technique provides a precise measurement of capacitances and, hence, gives details about the occupancy, even in the presence of external electromagnetic interference.

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