ESD to the Display Inducing Currents measured using a Substitution PC Board

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Abstract—**ESD to a display may upset or damage the display or the touch circuit. The ESD may have a visible spark carrying current to the frame of the mobile device, to the connecting flex cable, or into the display by penetrating the glue between the glass layers. It may also be a sparkless ESD that causes corona charging on the surface of the glass having currents as high as 10 A. A measurement technique is presented that allows measurement of the currents on all traces, including ground of flex cables that connect from the display to the main board of a mobile device. The main board is substituted by a PCB that has the same connections to the body of the mobile device and the same shape, i.e., the same electromagnetic affects. However, all connections to the display are terminated in resistive structures that allow measuring the currents in the flex cable individually. Besides measuring ESD currents, the substitution board offers various other applications with respect to the coupling and propagation of self-interference causing signals or EMI problems.**

Keywords: flex cable, LCD; mobile device; sparkless ESD; substitution board; touch-screen.

I. INTRODUCTION

Electrostatic discharge (ESD) to portable electronic devices can cause hard and soft errors [1]-[3]. Typically in system level ESD testing, the ESD generator is discharged into the exposed metal parts of the DUT. The ESD generator voltage is incremented in steps and system level errors such as perturbation of the display, loss of touch functionality, system reset, etc. are monitored. Various measurement and modeling techniques have been used to study the effect of ESD discharge directly to different areas of the mobile device such as the main board reference ground, clock traces, power pins, metal chassis of the phone, and the LCD display [4]-[8]. The main limitation is that one notices a disturbance or damage to the ICs that connect to the display, but the currents that caused these effects are not known.

Sparkless ESD on the glass surface is the most likely ESD discharge to displays as cell phone design often provides sufficient isolation at the edges such that a discharge into the phone is not possible. These sparkless discharges [9] into an electronic product may also lead to various types of upsets and damages to ICs via induced current flow using any of the multiple coupling paths within the device, as shown in Fig. 1. Sparkless ESD to glass surfaces was studied in [9] and a method to visualize the surface charges using dust figures on the glass after a discharge event was analyzed in [10]. A discharge event on the glass may cause current coupling to the touch screen matrix and then to the traces of the touch controller IC on the flex cable. Similarly, current coupling to the LCD may induce currents to the LCD driver IC. The severity and type of upset/damage depends on the magnitude of the current flow to the sensitive ICs.

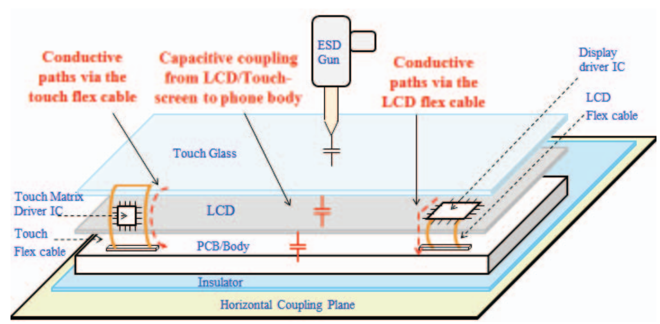


Fig. 1. Various possible coupling paths within a mobile device for sparkless discharge to the glass.

The measurement technique presented in this paper allows measuring the induced currents at the flex cable connectors on the substitution board due to an ESD discharge on the mobile phone screen/glass. These current values can help to understand the risk of damage to the driver IC or the display IC or disturbances of the data transfer. In some cases, ICs are mounted on the glass or the flex cable. In these cases the method will only measure the current that flows out of these ICs into the flex cable, as the measurement is done on the main board of the phone.

A substitution board is designed and fabricated to replace the main board of a mobile phone. Well shielded 0.8 mm diameter semi-rigid coaxial cables are used to probe the terminated flex traces individually on the substitution board. It must be noted that using multiple coaxial cables for probing also changes the electromagnetic behavior of the device being tested. These cables offer a path to ground. If ferrite clamps are not used on the coax cables, the cables act like a single ground connection similar to a short USB cable that would connect to a well-grounded system. The distribution of currents on the various I/O lines, flex cable shield, ground and power pins is obtained by this measurement technique. A contact mode discharge into a small copper patch on the glass was selected as the excitation because it approximates the sparkless discharges to the display from a current point of view. In contrast to a real arc it still is a linear system, as no arcing is involved in contact mode. We assume that the currents are strong enough to turn on all ESD protection within the ICs that are placed on the glass, such that only their dynamic resistance is visible. Testing at different voltages has verified the assumption of linear behavior.

II. DEVICE UNDER TEST: MOBILE PHONE

A four-layer PCB was designed for a mobile phone to demonstrate the substitution board methodology for measuring individual currents. The features of the phone that influence the electromagnetic behaviour of the phone (such as the main board ground structure, main board-to-phone body contact points, flex cable connector ground contacts, etc.) are identified and reproduced on the substitution board.

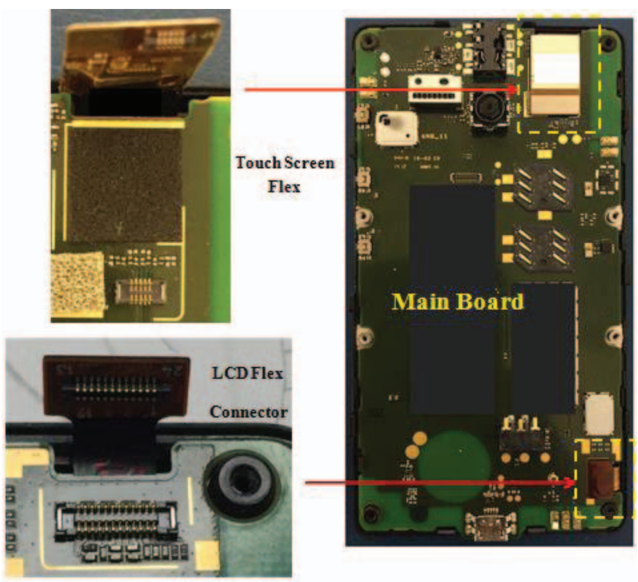


Fig. 2. Photos of the main board of the mobile phone that show the location and details of the touch screen and LCD flex cable connectors.

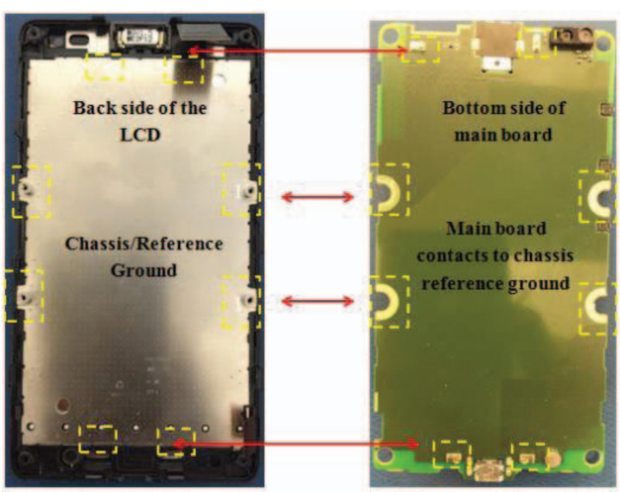


Fig. 3. Photos of the back side of the original main board that show the ground contacts of the main board to the chassis reference ground.

The details of the main board, its connections to the LCD and touch flex cables via board-to-board connectors, are shown in Fig. 2. The main board ground structure and its contact points to the mobile phone's reference ground are shown in Fig. 3.

III. DESIGNED AND FABRICATED SUBSTITUTION BOARD

Based on the dimensions and ESD current flow relevant features of the mobile phone, a four-layer substitution board was designed and fabricated to replace the actual main board of the mobile phone. Fig. 4 shows the layout of the top layer of the substitution board. The board has the following main features:

- Similar dimensions and thickness as that of the actual main board.
- Similar ground structure and contact points to phone body as that of the actual main board.
- 24-pin flex connector receptacle for connection to the LCD flex cable.
- 10-pin flex connector receptacle for connection to the touchscreen flex cable.
- Pads for semi-rigid coax cable probing for all flex connector pins including ground connections.
- Pads for resistive terminations for all flex connector pins including ground connections.
- The ability to measure the current on the flex shield which is normally connected via a gasket to the main PCB ground.

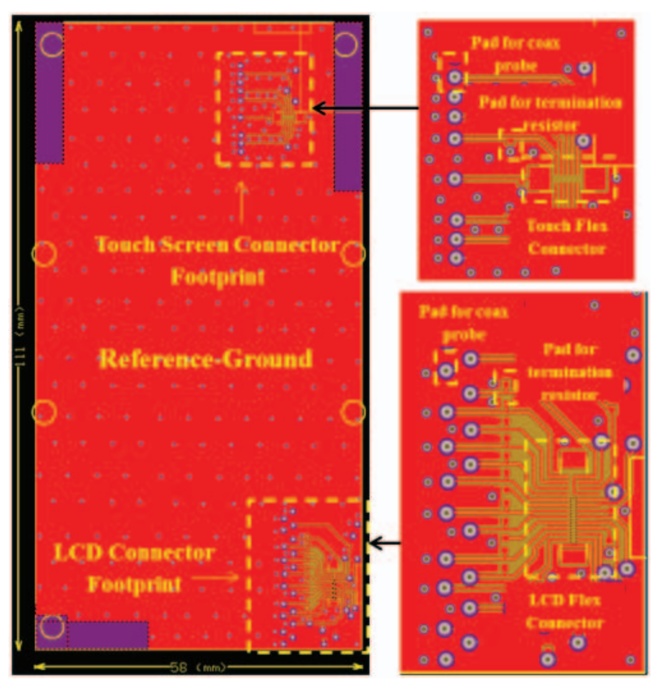


Fig. 4. The layout of the designed four-layer substitution board and zoom-in of the LCD connector layout to show the traces to each pin, including ground, pads for resistive termination and for coaxial cable probing.

IV. PROBING CIRCUIT & MEASUREMENT SETUP

Direct probing of the individual traces of the original main board and display flex cables was difficult because of the multilayer board design and thin flex traces. However, the substitution board allowed multiple probing coax cables. The currents in the individual traces of the flex cables were measured using well-shielded 0.8 mm diameter semi-rigid coaxial cables that are soldered on the pads that connect to the flex connector footprint via short (< 1 cm) transmission lines. The currents were measured in two different termination schemes depending on the assumption of the state of the ESD protection diodes on the main board ICs. The signal and I/O lines were loaded with the 50 ohm coax cables when the ESD protection was assumed to be turned off (scenario I). When the ESD protection was assumed to be turned on, the signal lines were terminated with a 1 ohm resistance (scenario II). In both the scenarios, each of the flex cable ground pins/connections was terminated with a 1 ohm resistance. The termination values were chosen as a compromise between the actual loading of the traces, and the ability to measure the currents well. The probing circuit diagram for scenario I and the termination circuit diagram showing all the signal and ground connections of the LCD and touchscreen flex connector are shown in Fig. 5 and Fig.6, respectively.

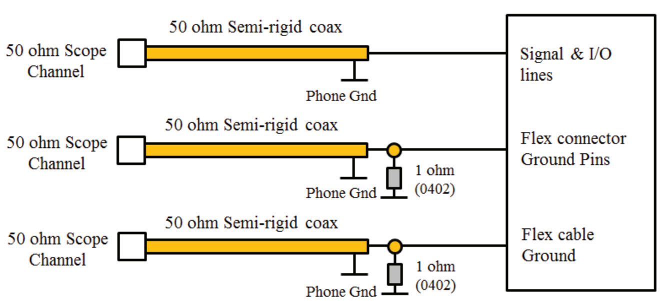
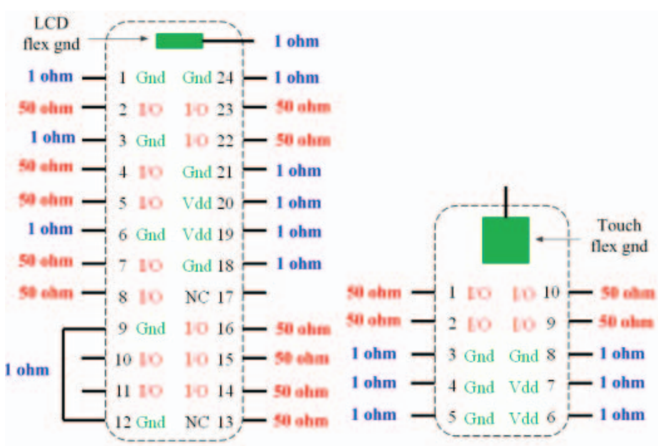


Fig. 5. Probing circuit for the signal lines and the ground connections for the touch-screen connector and LCD flex connector in scenario I.



(a) (b)

Fig. 6. Termination circuit diagram for: (a) LCD flex connector; (b) Touchscreen flex connector in scenario I.

A photo of the substitution board mounted into the mobile phone's body including the soldered semi-rigid coaxial cables and the connection of the touchscreen flex cable ground to the substitution board ground via a gasket is shown in Fig. 7.

The measurement set-up used for measuring the currents in the individual lines of the flex cable connectors on the substitution board for a discharge to a copper patch on the glass is shown in Fig. 8. The photo of the measurement set-up is shown in Fig. 9. The mobile phone with the substitution board and soldered semi-rigid coaxial cables is placed, with the display facing upwards, on a reference metal plate using a 1 cm thick Styrofoam spacer. Since the substitution PCB is well grounded by multiple coax cables, the height of the phone above the reference ground is not relevant. The currents were measured for discharges to a 2 cm x 2 cm copper patch on the glass in contact mode for three positive discharge voltages: 1 KV, 2 KV and 3 KV. The different voltages were selected to test the assumption of linearity which is based on the assumption that all ESD protection within the IC on the glass was turned on. As mentioned in the article, the discharge scenario is similar to sparkless discharges to the display [9]. Since there are 29 total coaxial probe outputs, the probe outputs were measured in sets of three. For each set of measurement, three probe outputs were connected to 50 ohm oscilloscope channels using an 8.7 V overvoltage protection device on each channel to limit the maximum voltage on the channel to 8.7 V. The rest of the coax outputs were terminated with 50 ohm each.

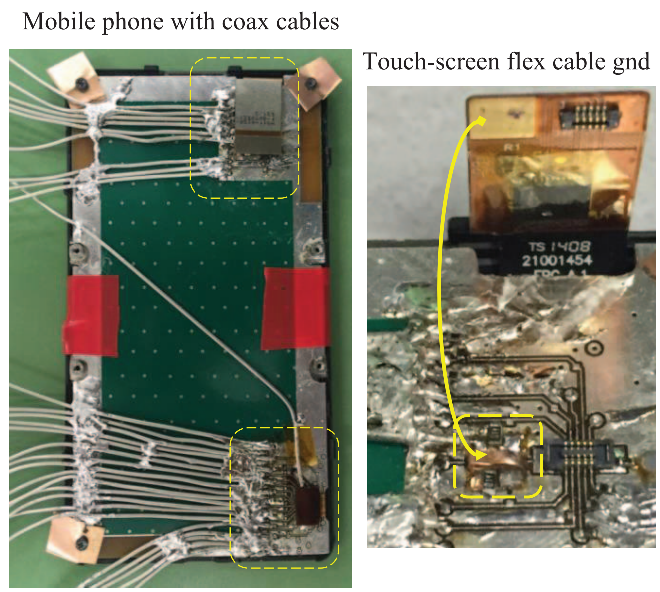


Fig. 7. Photo of the substitution board with the soldered coax cables and the touchscreen flex cable ground connection via a gasket.

The discharge current into the patch was also measured simultaneously using an F65 current clamp, as shown in Fig. 10. The discharge current into the patch in each set of measurement was practically identical. The current clamp output was connected to the oscilloscope channel using a 20 dB attenuator and an overvoltage protection circuit clamping at 8.7 V.

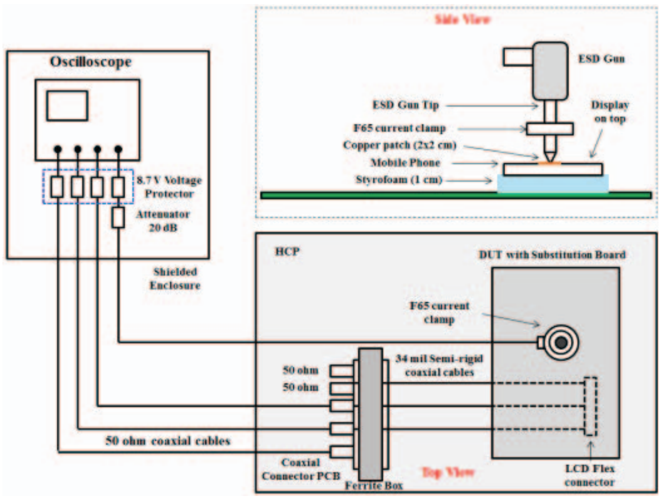


Fig. 8. The measurement set-up for the current measurement on individual lines of the flex cables.

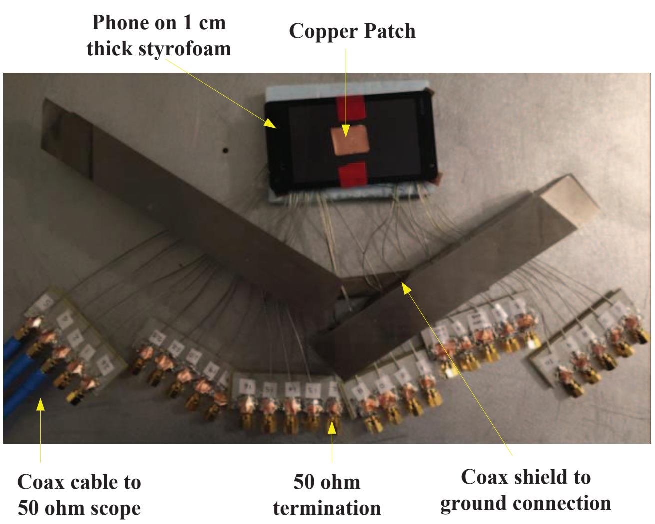


Fig. 9. Photo of the measurement set-up.

V. RESULTS AND ANALYSIS

The main goal of the current measurements was to understand the relative distribution of currents within the mobile phone and on the various signals and ground connections of the flex cable for a discharge to the glass. The measured peak current magnitudes for scenario I and II on each of the different pins of the LCD and touchscreen flex cable connectors for all three discharge voltages are plotted in Fig. 11-Fig. 12 and Fig. 13-Fig. 14, respectively. As an example, the measured current waveforms for a set of measurements, in scenario I (50 Ohm termination for I/O), at the LCD and touchscreen flex cable connector for +1 KV discharge is shown in Fig. 17. The peak current plots in Fig. 11-Fig. 13 show that the currents in the LCD and touchscreen flex cable ground structures are more than 10 times larger than the currents that flow in the I/O lines while they are about 2-4 times larger for the case when each of the signal lines are terminated with a 1 ohm resistance.

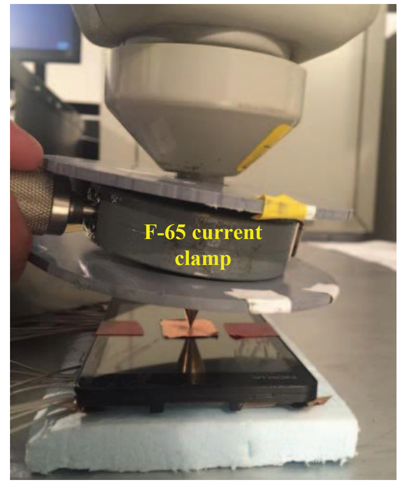


Fig. 10. The measurement set-up for the current measurement.

Fig. 14 shows that most (1 A) of the peak patch current flows in the I/O (pin-9) on the touch flex connector when the patch is in the center of the glass. To investigate the dependence of the peak current on touch pin-9, the peak currents were measured for different positions of the patch, as shown in Fig. 15, effectively scanning the discharge location on the glass. The plot of the peak currents on touch pin-9 for different discharge positions on the glass, Fig. 16, indicates strong dependency of the peak current on the discharge location. The peak current magnitudes on the I/O lines might also cause various upset events in the actual system. Correlation of the currents measured using the substitution board to the upsets events on the actual mobile phone was not part of this study. However, the authors hope that the substitution board methodology can be used for such an investigation.

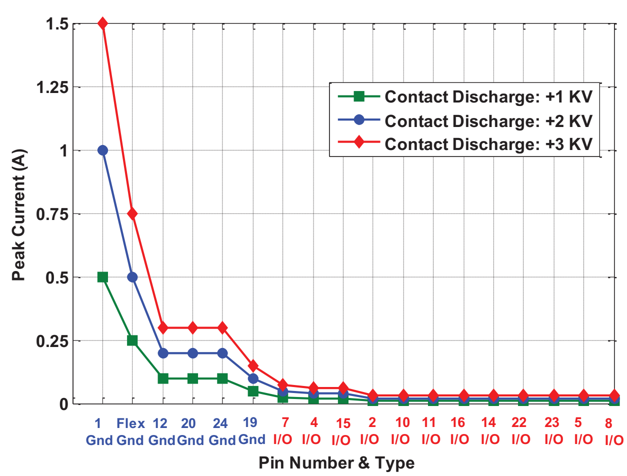


Fig. 11. The peak current magnitudes for the probed pins of the LCD connector in scenario I.

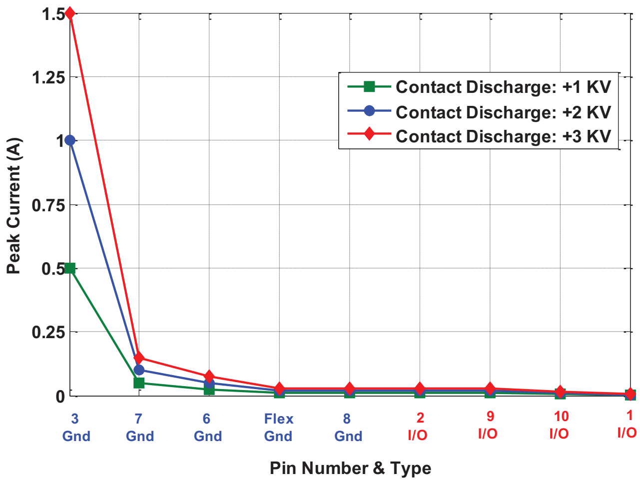


Fig. 12. The peak current magnitudes for the probed pins of the touch-screen connector in scenario I.

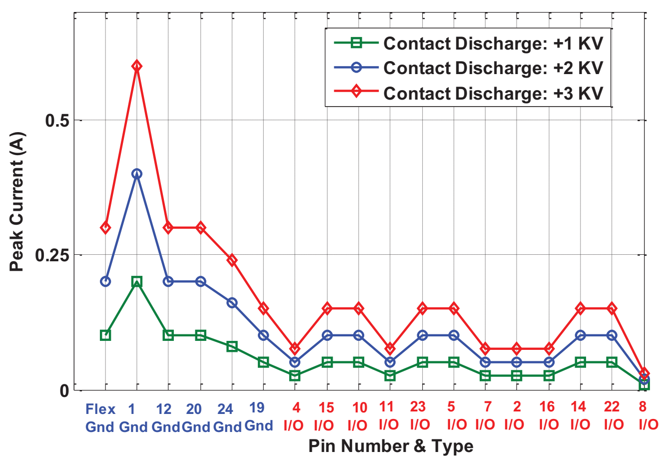


Fig. 13. The peak current magnitudes for the probed pins of the LCD connector in scenario II.

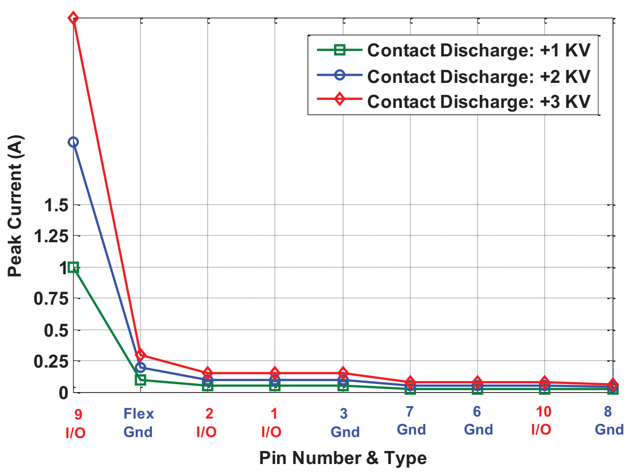


Fig. 14. The peak current magnitudes for the probed pins of the touch-screen connector in scenario II.

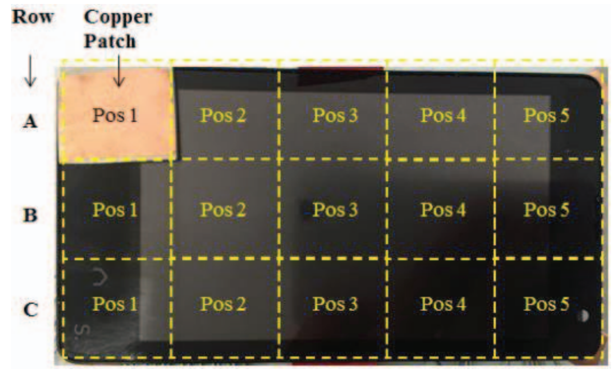


Fig. 15. The peak current magnitudes for the probed pins of the touch-screen connector in scenario II.

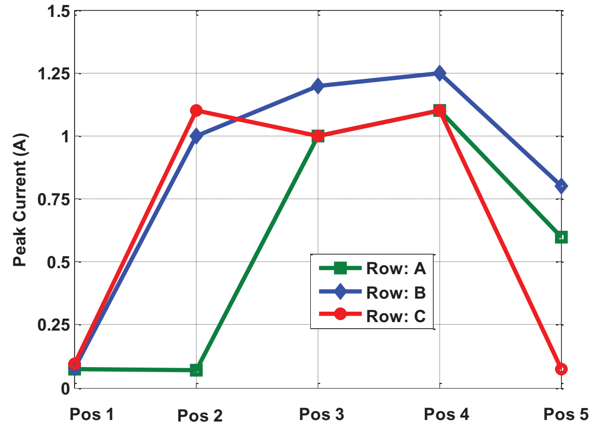


Fig. 16. The peak current magnitudes for the probed pins of the touch-screen connector in scenario II.

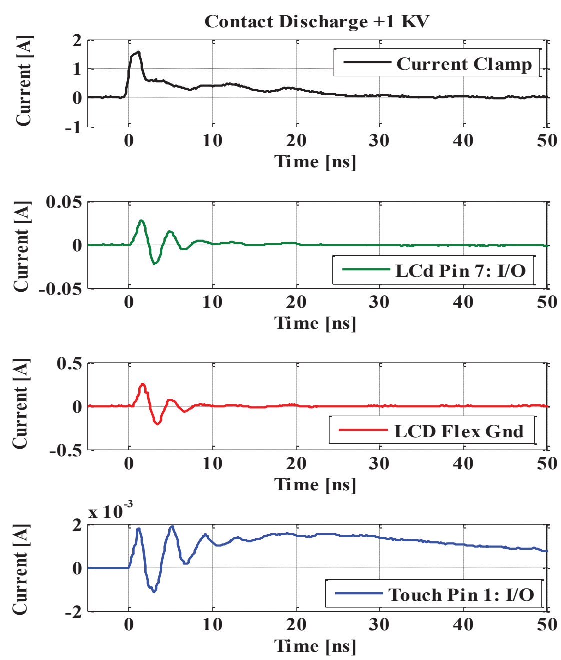


Fig. 17. Example measured discharge current and the currents on few pins on the LCD and touchscreen flex cable connector for +1 KV discharge voltage.

From the current comparisons, for scenario I and scenario II (Fig. 11 – Fig. 14), it can be inferred that the ESD protection turn on can significantly change the current paths within the phone and the current distribution between the I/O and ground pins. To obtain an approximate distribution of currents that flow into the flex cable and to the body of the phone via capacitive coupling after a discharge to the glass, all the measured currents on both the LCD and touchscreen flex cables were summed up and compared with the discharge current into the copper patch. The comparison between the patch current and summation of individual currents and the summation of the absolute magnitude of individual currents for scenario-I is shown in Fig. 18. The peak current magnitude of the discharge current is about 1.6 A and that of the summed-up currents is 1.2 A in scenario I.

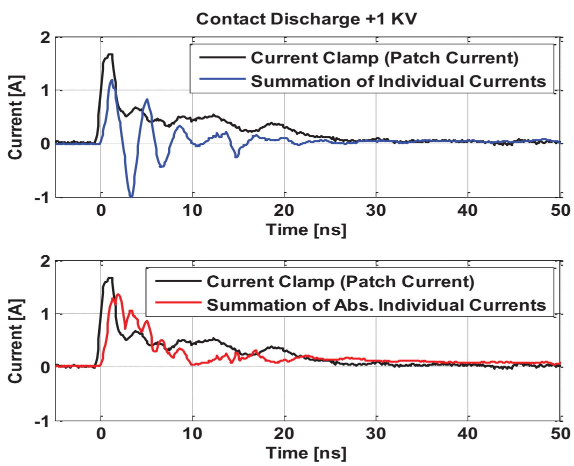


Fig. 18. The comparison between the patch current and summation of individual for scenario I.

VI. CONCLUSION

A measurement technique is presented that allows measuring the induced currents at the LCD and touchscreen flex cable connectors on a substitution board due to an ESD to the glass/screen of a mobile device. The design of a substitution board based on the EMC relevant features of the mobile device and the measurement set-up for measuring the currents on various I/O and ground connections individually was demonstrated. The use of multiple coaxial cables that are well connected to the reference plane presents a similar scenario as that of a mobile device connected by a single wide, short USB or charging cable. The resistive terminations for different lines are chosen so as to emulate the impedance of the actual main board terminations as close as possible. Here, one can change the values depending on the assumed status of the ESD protection at the IC I/Os. Preliminary measurements using the substitution board indicated that a large part of the discharge current flows to the PCB via the flex cables and a smaller part via capacitive coupling to the phone body. The current distribution may be different for different products. In addition, observations of the measured peak current magnitudes at various flex connector pins show that the turn on of the ESD protection circuits at the ICs I/O can significantly change the current paths within the phone. These ratios may be influenced by the status of the ESD protection circuits at the ICs I/O. The current values measured using the substitution board can help to understand damage to the driver IC or the display IC or disturbances of the data transfer and can be used to correlate the current magnitudes to system level effects. The applicability of the substitution board methodology is not limited to mobile devices and can be applied to other electronic products as well.

Besides measuring ESD currents the substitution board offers various other applications with respect to the coupling and propagation of self-interference causing signals or EMI problems.

VII. ACKNOWLEDGEMENT

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