Current Density Measurements in Conductive Polymer Coated Surfaces

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Abstract: A series of measurements mapping out the current density distributions in conductive polymer coated PC boards have been performed. For these measurements, a device called EMSCAN™, a planar array of 1280 virtually infinitesimal magnetic dipoles, was used. This device allows the user to scan for current hot spots on PCBs. It has been extremely useful in troubleshooting production boards and pre-production boards for Electromagnetic compatibility for automotive applications. A comparison between three types of boards was made: a standard board clad with copper, a board clad with conductive polymer, and a board clad with ferrite impregnated polymer. Each board was fabricated with a centered trace that was then terminated with a 50 ohm resistor to a ground plane on the reverse side of the board. A signal generator was connected to the input side of the trace and the trace was driven with sinusoidal signals ranging from 25 MHz-325 MHz. The use of conductive polymer coatings would be of benefit in automotive EMC applications where the relatively low cost, versus multi-layer PCB solutions, makes the polymer an attractive alternative. The question that needs answering is: How much benefit can be expected? This paper attempts a partial answer.

Measurement Procedure

Before beginning the trace measurements, a series of ambient measurements were made.

Three instances are shown:

1) Spectrum analyzer input open. This was used as a basis.

2) EMSCAN connected to the analyzer, no test board and no signal present.

3) EMSCAN connected to the analyzer with a board resting on the EMSCAN surface and the board cabled to the RF source, but no signal present.

In Figure 1, we see that the ambient levels peak in two regions, at 50-100 MHz and at 275-325 MHz. The lower frequency peak was seen to be an effect of the cabling that was attached to the test board resting on the EMSCAN surface. The higher frequency peak was something else.

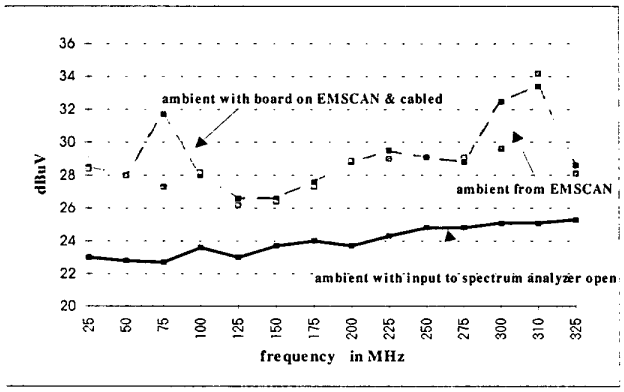

Figure 1
Ambient measurements

This higher frequency peak was also seen when no test board and cabling were present. It was seen that the ambient distribution across the EMSCAN surface had organization to it. Figure 2 shows what should be seen when doing an ambient scan.

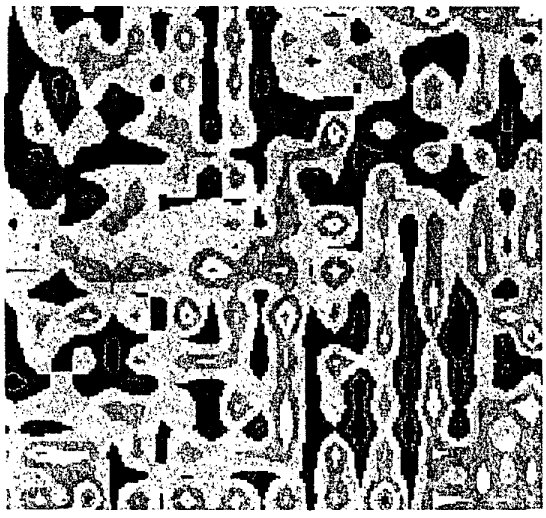

Figure 2
ambient scan at 200 MHz

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In Figure 2 the noise distribution is random in appearance. The levels measured varied by 2 dB across the measured area.
Figure 3 shows the situation at 310 MHz.

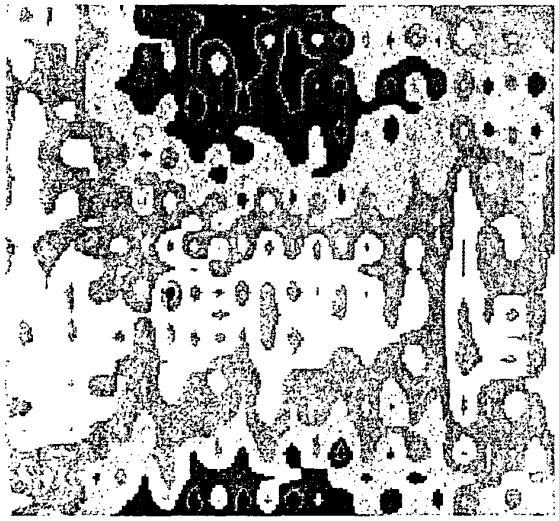

Figure 3
Ambient scan at 310 MHz.

At 310 MHz, the noise levels varied by 5 dB across the measured area. In addition, it is apparent that the noise currents have more structure than at other frequencies. The first eigenfrequency of the structure occurs in this range.
Figure 4 shows a representation of the test board.

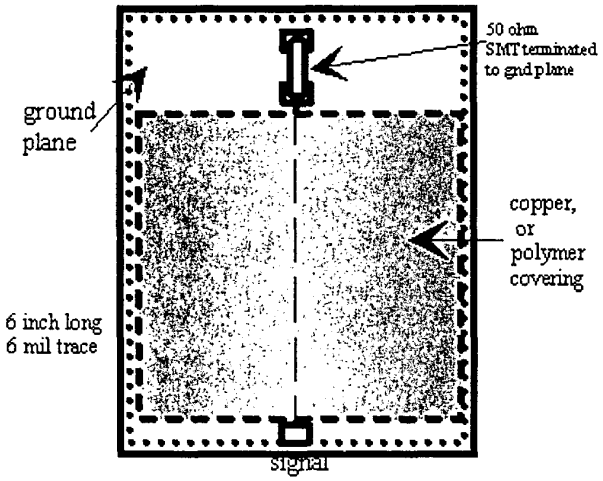

Figure 4

The output of the signal generator was set to 100 mV for each frequency of excitation. Figure 4 shows the results for the measured maximum levels along the traces.

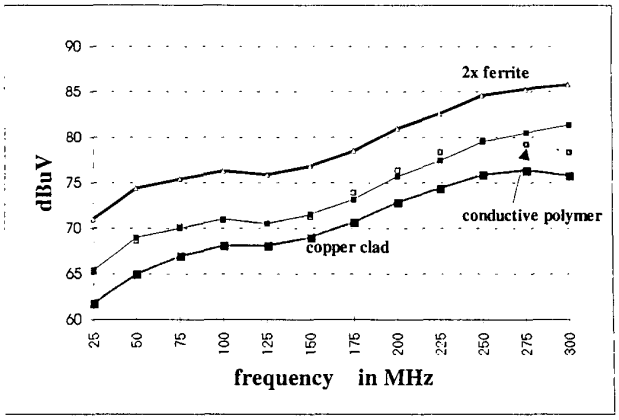

Figure 4
measured maximum levels
along trace

As Figure 4 shows, The induced field levels along the traces increased as the frequency increased. In addition, the copper showed the lowest induced field level, the ferrite showed the highest, and the conductive polymer fell in-between. Since the current is somewhat constrained in the path that it can take, it should not be surprising that the ferrite board showed the higher field levels due to its higher intrinsic impedance.
Figure 5 shows the measured minimum field levels in the entire measured region.

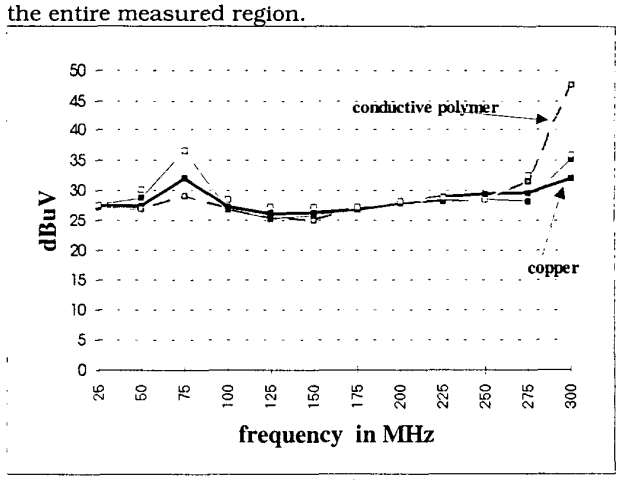

Figure 5
measured minimum levels
in entire scan area

Again we see the peak in the range 50-100 MHz, and this is an artifact of the cabling. It is interesting that the polymer material peaks up significantly higher than the copper at the high end of the range
Figure 6 shows a comparison of the measured median values of the field levels induced throughout the entire board surface.

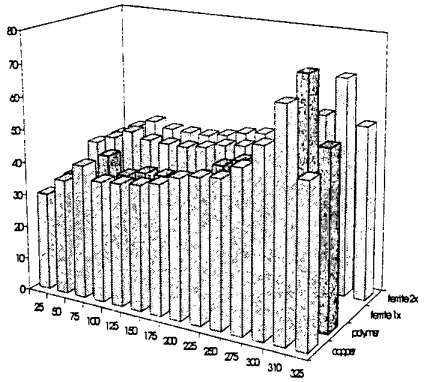

Figure 6
calculated median value of
the induced levels throughout scan area

The sharp resonance at 310 MHz needs further investigation because it is where the EMSCAN device itself appears to resonate. This may limit very high frequency work to less than 300 MHz.
We can see from these distributions that there are not very significant differences between the copper clad board and the conductive polymer board in terms of the overall induced levels in a coated board.

Figure 7 shows the calculated standard deviations for the boards.

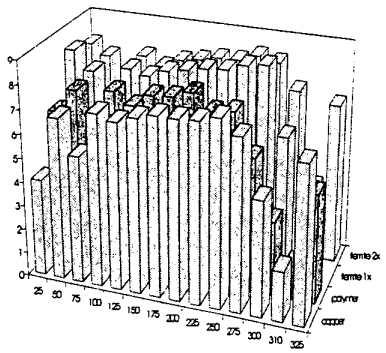

Figure 7
calculated standard deviation
in the scan area

For the next series of measurements, the traces were disconnected and the ground plane backing the boards was driven with the signal generator. We wanted to see if the different coatings had any effect on the distributions of currents in an excited copper plane. Figure 8 shows the results for the maximum measured levels in the entire scan area.

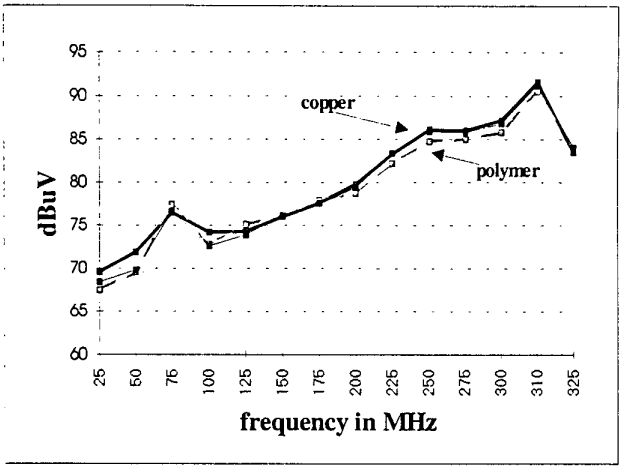

Figure 8
maximum measured levels

Interestingly, the EMSCAN peak at 310 is more pronounced when you're driving a large surface, like the copper ground plane, versus driving a trace that is essentially 1-dimensional.

Figure 9 shows the measured minimum levels in the same scan area.

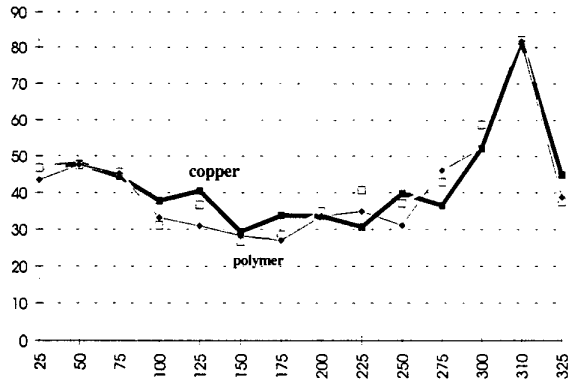

Figure 9
minimum measured levels

The following figures show the distributions of measured levels at 3 frequencies: 50 MHz, 200 MHz, 300 MHz.
These are the actual levels measured using EMSCAN, approximately 700 probes active. The first series of plots show the data in 3D Excel format in order to show the amplitudes more clearly. The second series of plots shows the actual 2D surface scans from EMSCAN.
Note that the minimum z value corresponds to the average ambient value.

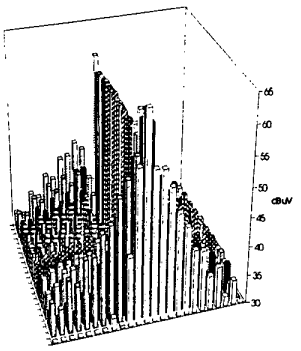

Figure 10
copper @ 50 MHz

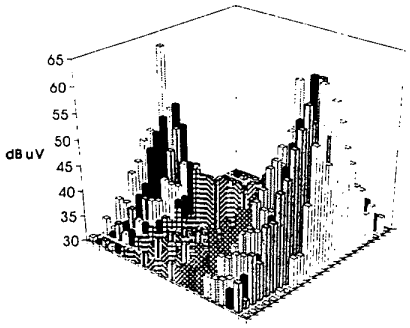

Figure 11
polymer @ 50 MHz

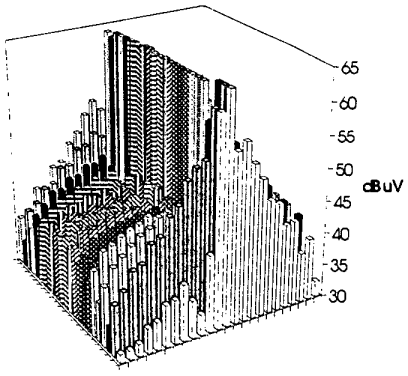

Figure 12
ferrite 2x @ 50 MHz

It is interesting to note that the copper board shows the current distribution along the trace quite clearly, but the polymer shows high distribution only at the excitation point and the 50 ohm load. The polymer is evidently shielding, as it should, but not completely since you can still see the trace image. The ferrite, as expected, shows no shielding. In addition, the ferrite board shows higher induced levels outside the trace image than do the copper and polymer boards, on the order of 10 dB.

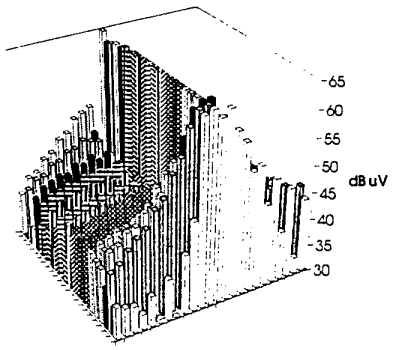

Figure 13
copper @ 200 MHz

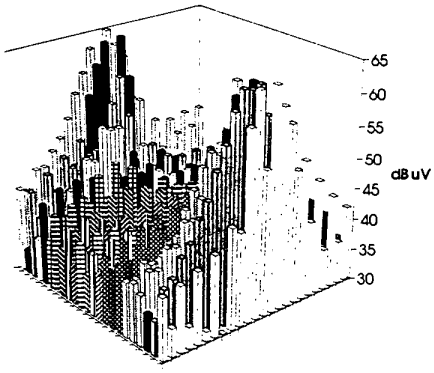

Figure 14
polymer @ 200 MHz

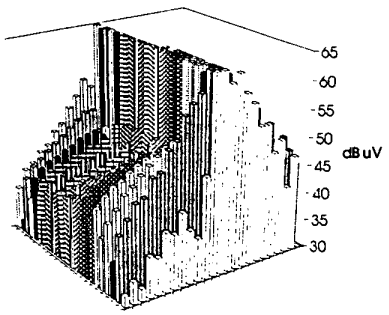

Figure 15 ferrite at 200 MHz

Again, note that the polymer has a different distribution than does the copper, but the trace image is no longer evident at 200 MHz, as it was at 50 MHz. Also, the copper, polymer and ferrite have similar induced levels outside the trace image.

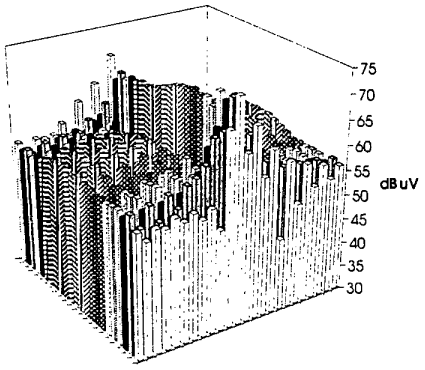

Figure 16
copper @ 300 MHz

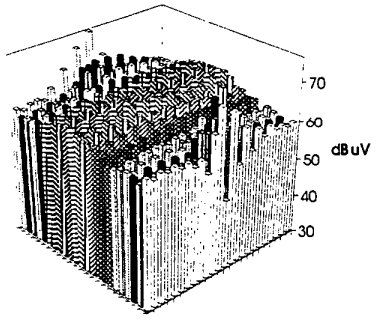

Figure 17
polymer @ 300 MHz

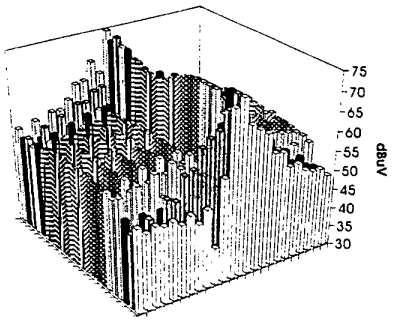

Figure 18
ferrite 2x @ 300 MHz

At 300 MHz, the polymer shows an overall higher distribution of current outside the trace image than does the copper. This broad excitation of the copper ground plane will be more evident in the following plots. We now look at the EMSCAN 2D scans.

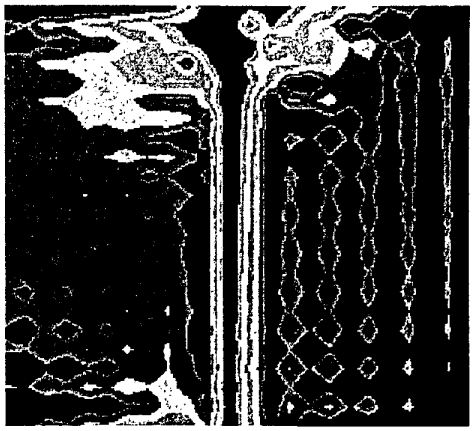

Fig 19 copper EMSCAN @ 50 MHz

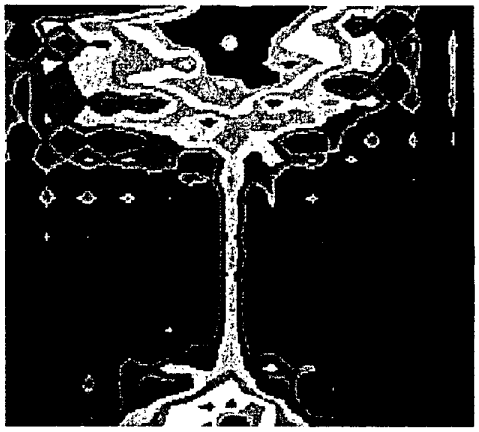

Fig 20 polymer EMSCAN @ 50 MHz

The current density along the trace is lower for the polymer than it is for the copper. In addition, we see higher excitation levels outside the trace boundaries in the polymer than we do in the copper.

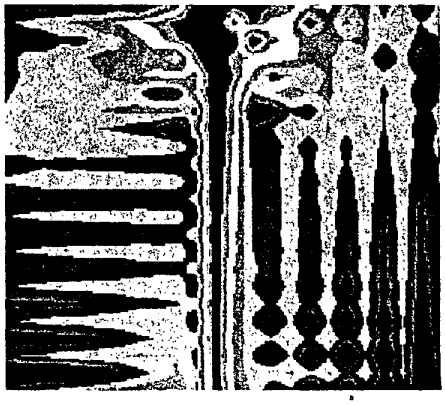

Fig 21 copper EMSCAN @ 200 MHz

Fig 22 polymer EMSCAN @ 200 MHz

At 200 MHz we see the same pattern correspondence as we did at 50 MHz.

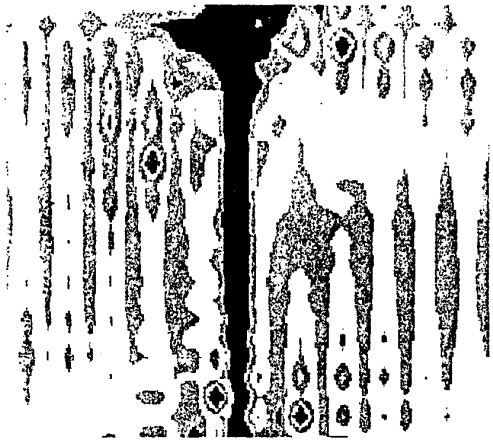

Fig 23 copper EMSCAN @ 300 MHz

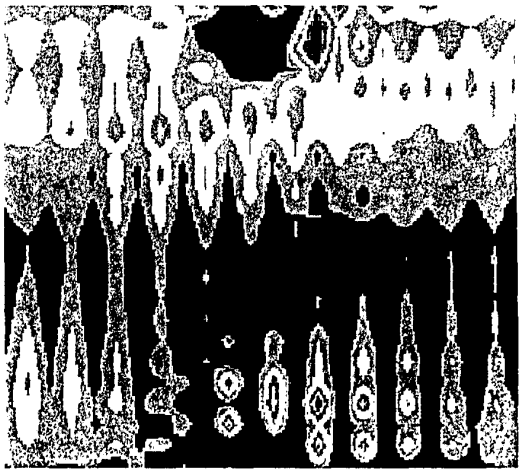

Fig 24 polymer EMSCAN @ 300 MHz

At 300 MHz, we see that the polymer clad board has excited an antenna type pattern in the structure. The current is no longer primarily along the trace but rather is orthogonal to the trace. In the copper, the current is still primarily along the trace. Overall, the induced levels outside the trace image are 10 dB higher in the polymer clad board than in the copper board.

Summary

The conductive polymer material looks like a promising technology for automotive applications. It can be applied to specific areas where current densities are highest and require higher local capacitance than a 2-layer, or even a 4-layer, board can provide. These preliminary measurements have shown, though, that the polymer might have detrimental higher frequency properties. These need further investigation. In addition, a series of measurements is to be performed that will compare the surface impedance as a function of frequency for both the polymer clad boards and plain copper clad boards.