IMPACT OF MESHED GROUND PLANES ON THE ELECTROMAGNETIC BEHAVIOUR OF PRINTED CIRCUIT BOARDS

Martin Salter [1], Nick Ridler [1], Matthew Harper [1], Tian Hong Loh [1], David Hindley [1], Ralph Green [2], Percy Phelps [2], Mark Walker [2]

[1] National Physical Laboratory (NPL), Hampton Road, Teddington, Middx, UK, TW11 0LW
[2] EADS Astrium, Anchorage Road, Portsmouth, Hampshire, UK, PO3 5PU

ABSTRACT

In this paper, the high frequency electromagnetic performance of Printed Circuit Boards (PCBs) with meshed ground planes is compared with that of PCBs with solid (unmeshed) ground planes. This is done by means of Radio Frequency (RF) testing and electromagnetic modelling of some specially designed PCB test structures. Four types of PCB were designed and three versions of each type were manufactured with different grades of ground plane (solid ground, fine mesh ground and coarse mesh ground) making a total of twelve PCB test structures. The RF testing included frequency-domain tests carried out using 2-port and 4-port Vector Network analysers (VNAs), time-domain tests carried out using an oscilloscope and pulse generator and free-field radiated emission tests carried out in both an anechoic chamber and in a reverberation chamber. The electromagnetic modelling was carried out using CST Microwave Studio. It is found that the meshed plane PCBs exhibit more electromagnetic loss than the solid plane PCBs and that this loss is not due to radiation and so it is must be occurring inside the PCBs.

1. INTRODUCTION

The use of meshed ground planes and power planes in printed circuit boards (PCBs) has certain potential mechanical advantages over the use of solid (unmeshed) planes. For example, the use of meshed planes potentially results in (i) reduced overall mass of the PCB, (ii) improved manufacturability of the PCB e.g. meshed planes aid with the drying out of the PCB during manufacture, (iii) increased bonding strength for multilayer PCBs resulting in physically more robust PCBs for which delamination is less likely and (iv) increased flexibility of flexible PCBs.

In this paper the high frequency electromagnetic performance - i.e. the radio frequency (RF) performance - of meshed plane PCBs is compared with that of solid plane PCBs. This comparison is carried out by means of RF testing and electromagnetic modelling of some specially designed PCB test structures. In particular, the impact of meshed ground planes on the following electromagnetic characteristics of PCBs is investigated: (i) transmission loss through the PCB, (ii) crosstalk between neighbouring transmission lines on the PCB and (iii) radiated emissions from the PCB. These factors are amongst those which affect the signal integrity of high speed digital signals propagating on PCBs.

The outline of the paper is as follows. Section 2 describes the design and manufacture of the PCB test structures. Section 3 describes the RF tests performed on the test structures and presents some of the results obtained. Section 4 describes the electromagnetic modelling of the test structures and presents a comparison between results of the modelling and measurements on the test structures. Finally Section 5 gives recommendations for further study and Section 6 provides conclusions.

2. PCB TEST STRUCTURES

Four types of PCB were designed and manufactured in order to investigate the effect of meshed ground planes, namely: (1) a simple tri-plate transmission line or through line, (2) a 20 dB tri-plate coupler, (3) two isolated tri-plate lines and (4) two orthogonal isolated tri-plate lines. PCB types 2 and 3 are illustrated in Figs. 1-2. Note that these both have two transmission lines. In PCB type 2, the two lines are placed side by side to form a coupler whereas in PCB type 3 the two lines are stacked vertically with a ground plane between them to provide some isolation between the two lines. PCB type 1 is similar to type 2 except that it consists of only one transmission line. PCB type 4 is similar to type 3 except that the two vertically stacked transmission lines are arranged to cross at right angles. Each PCB type was manufactured with three different grades of ground-plane: (i) solid ground planes (no mesh), (ii) fine mesh ground planes (250 μm spacing mesh) and (iii) coarse mesh ground planes (500 μm spacing mesh). The mesh plane format is shown in Fig. 3. There were thus a total of twelve PCB test structures altogether which are listed in Tab. 1.

The multilayer PCB test structures were manufactured by Systronic (Paris, France). The PCB material used was Polyimide. A micro-sectional constructional analysis showed that the boards were manufactured in close agreement with the original design expectation to within a dimensional tolerance of about 5%. The test structures were fitted with precision microwave end launch coaxial connectors to provide an interface to the test equipment. The three versions of PCB type 1 consist of a single transmission line and so have two connectors (i.e. two ports) whereas all the other test structures consist of two transmission lines and so have four connectors (i.e. four ports). The connector launch areas were fitted with RF shields to minimise radiation from the connectors. A photograph of one of the assembled test structures is shown in Fig. 4.

3. RF TESTING OF THE PCB TEST STRUCTURES

The RF tests carried out on the PCB test structures can be classified as follows:

- Frequency-domain tests;
- Time-domain tests; and
- Free-field radiated emission tests.

These three classes of tests will now be described separately.

3.1 Frequency-domain tests

In the frequency-domain tests, a VNA was used to measure the complex-valued transmission and reflection coefficients i.e. the scattering parameters (*S*-parameters) of the test structures. Both 2-port and 4-port VNAs were used for these frequency-domain tests. Measurements were made up to 20 GHz although the transmission characteristics of the PCB were found to degrade significantly above about 8 GHz. The *S*-parameters contain information on the transmission loss through the PCB test structures and the crosstalk between neighbouring lines on the PCB test structures.

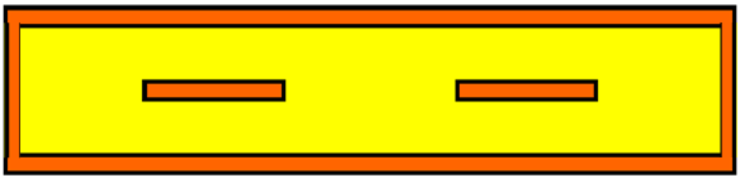


Figure 1(a). PCB type 2 – tri-plate coupler: cross-section

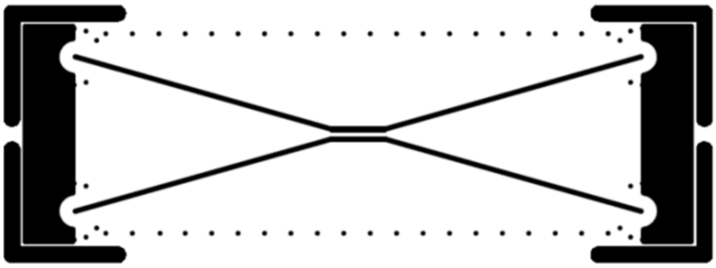


Figure 1(b). PCB type 2 – tri-plate coupler: top view

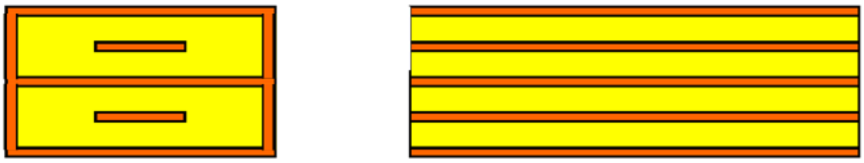


Figure 2(a). PCB type 3 – tri-plate isolated lines: cross-section (left) and longitudinal section (right)

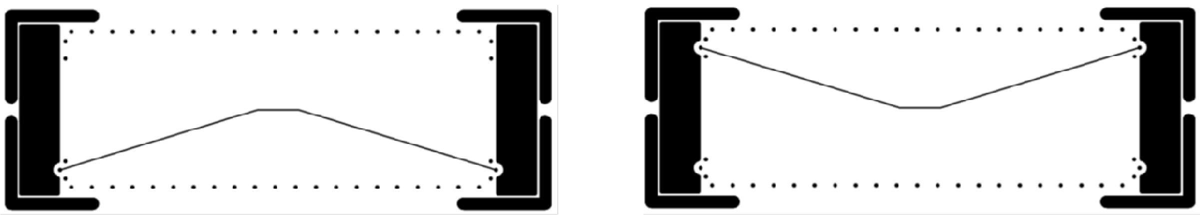


Figure 2(b). PCB type 3 – tri-plate isolated lines: lower layer pattern (left) and upper layer pattern (right)

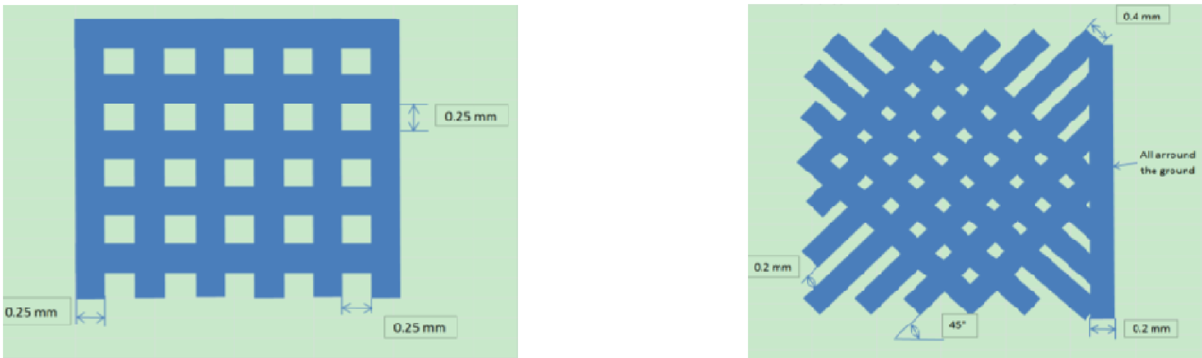


Figure 3. Mesh plane format: outer ground plane (left) and inner ground plane (right). The mesh dimensions given are for a fine mesh – for a coarse mesh these dimensions are doubled.

Table 1. Twelve PCB test structures formed from four PCB types and three ground plane grades (“A-1”, “B-1” etc. are labels used to identify the test structures)

PCB type	Ground plane grade		
	Solid	Fine mesh	Coarse mesh
(1) Through line	A-1	B-1	C-1
(2) Tri-plate coupler	D-1	E-1	F-1
(3) Tri-plate isolated lines	S-1	T-1	U-1
(4) Tri-plate orthogonal isolated lines	W-1	X-1	Y-1

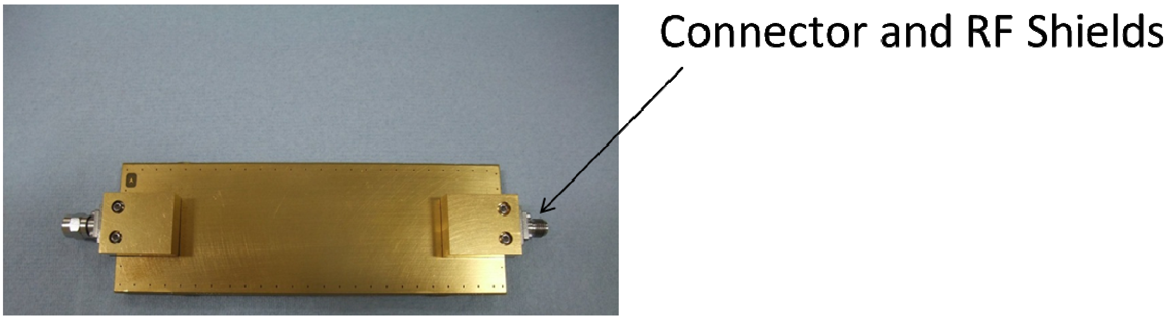


Figure 4. An assembled test structure showing the end launch connectors and RF shields. This is PCB type 1 with solid ground planes i.e. test structure “A-1”.

Some results obtained for PCB type 2 (tri-plate coupler) are plotted in Figs. 5-6. From these results and other similar frequency-domain tests carried out on the PCB test structures, the following conclusions are drawn: (i) there is a consistent drop-out in the transmission through the test structures at around 8 GHz which could, for example, be due to PCB vias or connector launches; (ii) the PCBs with meshed planes are more lossy than those with solid planes and (iii) there is little difference in transmission between coarse- and fine-meshed ground planes.

Other frequency-domain tests carried out on the PCB test structures included: (i) the use of time-domain gating applied to electrically ‘remove’ the mismatch effect of the connectors on transmission measurements and (ii) the measurement of mixed-mode *S*-parameters [1] of the 4-port test structures (i.e. PCB types 2, 3 and 4) treated as differential structures. The mixed mode *S*-parameters include transmission and reflection coefficients for the differential mode, for the common mode and for conversion between the two modes.

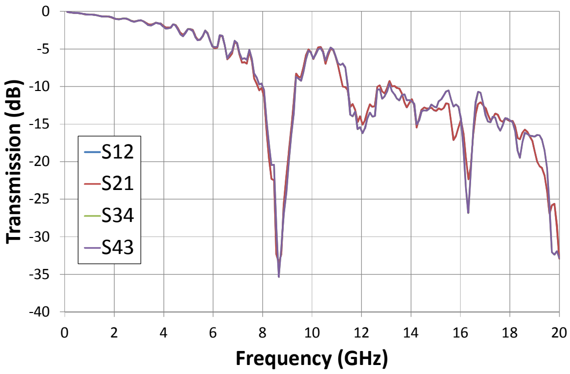


Figure 5. Magnitude (dB) of transmission coefficients of test structure “D-1” i.e. a tri-plate coupler with solid ground planes. S12 and S21 are the transmission coefficients of one of the two lines of the coupler whilst S34 and S43 are the transmission coefficients of the other line.

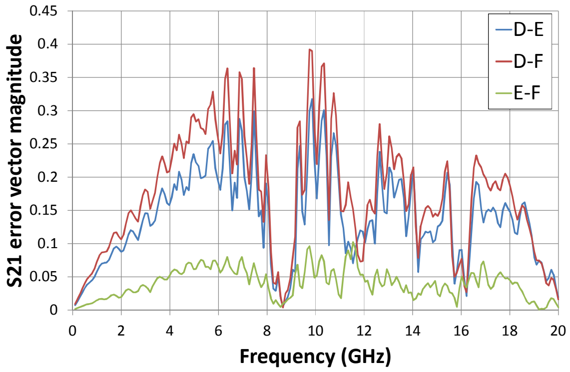


Figure 6. Linear magnitude of the differences in transmission coefficient S21 between tri-plate couplers with solid (D), fine mesh (E) and coarse mesh (F) ground planes.

3.2 Time-domain tests

In the time-domain tests, an oscilloscope and Time-Domain Reflectometer (TDR) unit were used to measure the PCB test structures as shown in Fig. 7. The TDR unit generates either a step or an inpulse which is then measured on the oscilloscope.

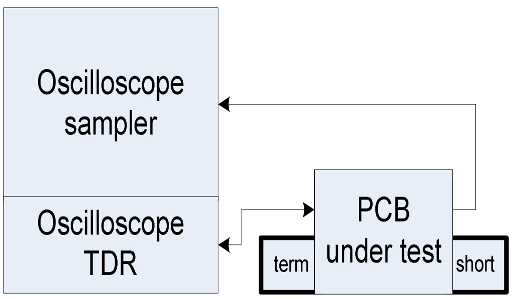


Figure 7. Oscilloscope and TDR pulse generator used for the time-domain tests

The following time-domain tests were performed on the PCB test structures: (A) the Root-Impulse-Energy (RIE) method [2] was used to assess the loss of each mesh-plane with respect to the equivalent solid-plane loss; (B) for each of the test structures, an effective response value was obtained for the impulse response (impulse width) and the step response (step rise time); (C) for each of the test structures, the step response was examined for waveform deformations and (D) for PCB types 2, 3 and 4, the Time-Domain Transmitted (TDT) response in the ‘coupled’ line was examined to look for crosstalk between the two lines.

The results of the effective response test (test B) for PCB type 1 (through line) are shown in Tab. 2. The uncertainty in these results is estimated to be ±2.5 ps. The results for the TDT response in the coupled line (test D) for PCB type 3 (tri-plate isolated lines) are plotted in Fig. 8 for the three grades of ground plane (solid, fine mesh and coarse mesh).

The following conclusions are drawn from the results of the time-domain tests: (i) no significant change in broadband loss was detected between solid and meshed ground planes using the RIE method, (ii) some pulse-broadening was observed in the impulse responses (as shown in Tab. 2), (iii) very little change to the step response pulse structure was detected and (iv) some crosstalk was detected for coarse meshes on the ‘coupler’ circuits (as shown in Fig. 8).

Table. 2. Effective Response Tests –PCB type 1

Ground plane	Impulse response (ps)	Step response (ps)
Solid	51.0	81.0
Fine mesh	54.8	81.0
Coarse mesh	55.7	81.0

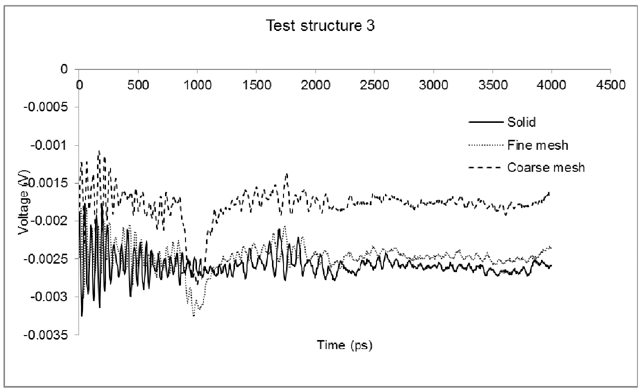
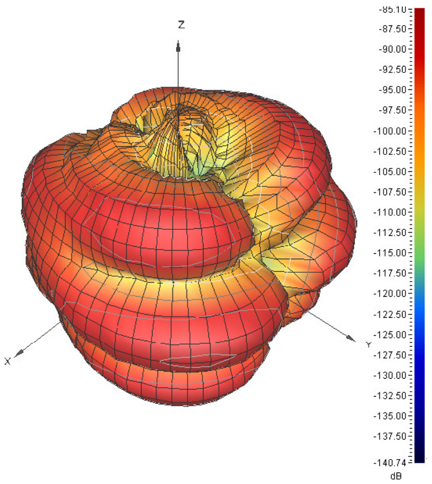


Figure 8. TDT response in the coupled line for PCB type 3.

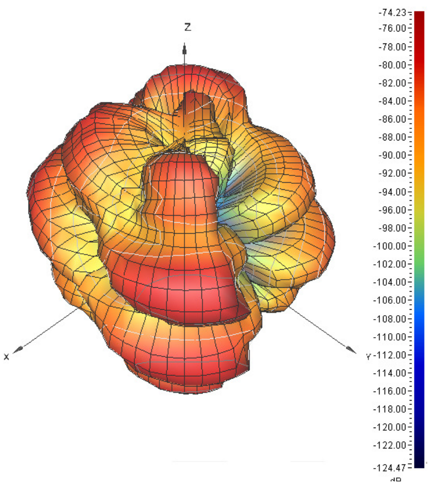
3.3 Free-field radiated emission tests

The three-dimensional (3D) radiation patterns of the PCB test structures were measured in an anechoic chamber and the total radiated power from the test structures was measured in the anechoic chamber and also in a reverberation chamber. For example, the measured radiation patterns of test structure 1 (through line) for different grade ground planes are shown in Fig. 9.

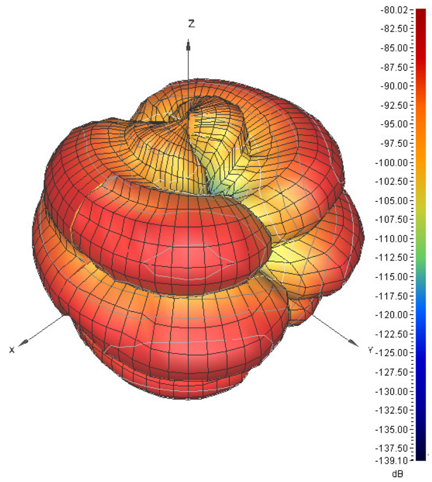
The following conclusions are drawn from the results of the free-field tests: (i) the 3D radiation patterns for the three different ground planes are different, (ii) however, there does not seem to be significant radiated power from any of these grades of ground plane and (iii) differences in radiated power from the three ground planes are close to zero.



(a)



(b)



(c)

Figure 9. Measured 3D radiation patterns of PCB type 1 (through line) at 5 GHz for different grades of ground planes: solid ground (a), fine mesh ground (b) and coarse mesh ground (c).

4. Electromagnetic modelling of the PCB test structures

CST Microwave Studio [3] was used to perform electromagnetic modelling of the PCB test structures. The electromagnetic models included the end launch connectors and their shields as well as the transmission lines, the vias and, the solid and meshed ground planes on the PCBs. The electromagnetic models were used to compute the *S*-parameters, the pulse response, the 3D radiation pattern and the total radiated power from the test structures which could then be compared with measured values. For example, Fig. 10 compares measured and simulated S-parameters and Fig. 11 compares measured and simulated 3D radiation patterns.

The following conclusions are drawn from the results of the numerical electromagnetic modelling: (i) generally good agreement is obtained between the numerical models and measurements, (ii) the numerical models can be used to predict trends (e.g. the ‘dip’ in transmission at 8 GHz), (iii) some subtle variations in the measurements do not show up in the numerical model (iv) improving the computational grid (i.e. making it finer) could improve the numerical model performance and (v) the numerical models still worked for low level signals (e.g. in predicting the 3D radiation patterns).

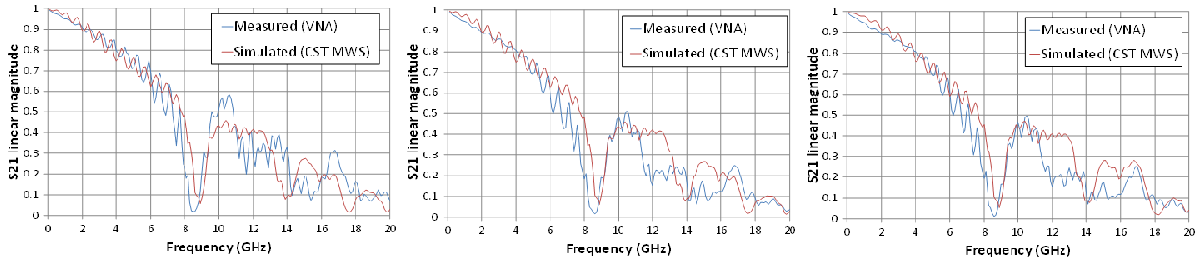


Figure 10. Comparison of measured and simulated S-parameters for PCB type 1 (through line) with solid ground plane (left), fine mesh ground plane (centre) and coarse mesh ground plane (right).

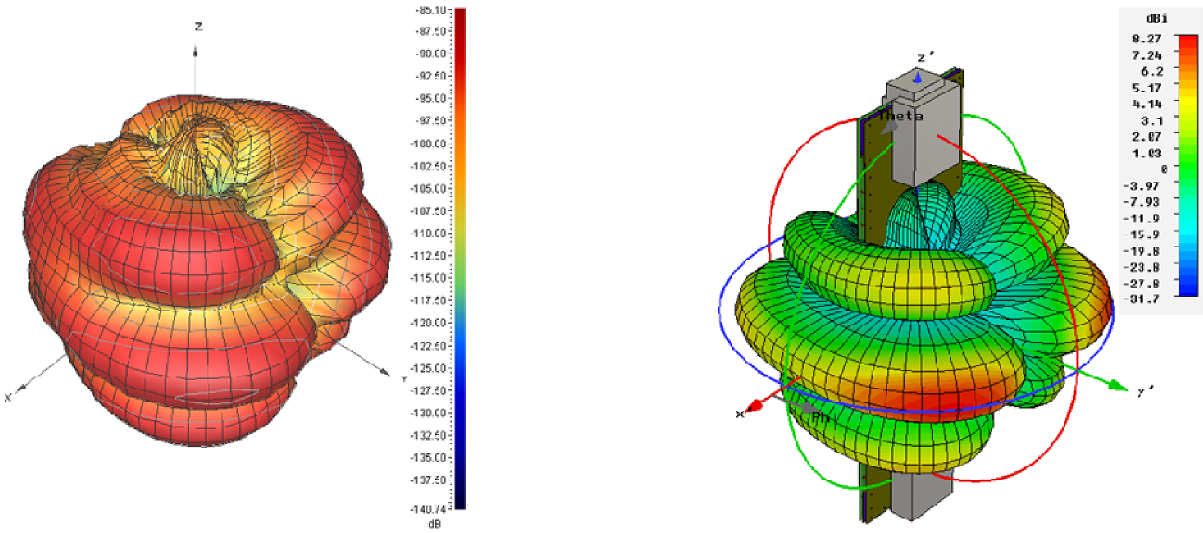


Figure 11. Comparison of measured (left) and simulated (right) 3D radiation Patterns for PCB type 1 (through line) with a solid ground plane at 5 GHz

5. Recommendations for further study

The results of this work suggest that the following further work could be useful:

- An extension of the study to include larger mesh sizes;
- The use of modified PCB test structures to allow operation up to much higher frequencies;
- An investigation into the performance of mesh planes with flexible substrates (the test structures investigated here were rigid);
- An investigation into the current carrying capability of mesh planes;
- The development of standardised test method(s) for meshed PCBs.

6. Conclusions

Based on a detailed analysis of the results obtained from this study, it was found that:

- Meshed-plane PCBs exhibit more electromagnetic loss than solid-plane PCBs;
- The increased loss is not due to radiation and so it must be occurring inside the PCBs;
- The increased loss is due to the degradation in performance of the PCB transmission lines (mesh-planes make less effective ‘grounds’);
- Since performance of the two mesh-planes (fine mesh and coarse mesh) was similar, larger mesh sizes may be acceptable for some applications;
- Further study is recommended (e.g. for larger meshes and higher frequency applications, etc).

7. Acknowledgement

The work presented in this paper was funded by the European Space Agency (ESA – ESTEC) under Contract No 4000101718/NL/SFe.

8. References

1. D E Bockelman and W R Eisenstadt, "Combined differential and common-mode scattering parameters: theory and simulation", IEEE Trans MTT, Vol. 43, No. 7, July 1995, pp 1530-1539.

2. IPC-TM-650 TEST METHODS MANUAL, 2.5.5.12, "Test Methods to Determine the Amount of Signal Loss on Printed Boards", 07/12, Revision A, http://www.ipc.org/TM/2-5_2-5-5-12A.pdf

3. www.cst.com