

Achieving High Field Strength at High Frequency in a EC/95/54 150mm Stripline

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Abstract

The construction of a standard 150mm high 50Ω stripline is proved to affect the impedance discontinuities, examined using time domain reflectometry. Improvements to the structure are made which significantly reduce these discontinuities resulting in a 50Ω stripline that can generate fields of 100V/m at frequencies up to 1GHz with a power amplifier of 100W. The improvements have also improved field contour within the stripline, which is expected to reduce test variability.

Background

The 150mm high 50Ω stripline is specified in European Council directive EC/95/54^[1] and International Standard ISO 11452-5^[2] for use in radiated susceptibility testing of automotive electronic sub-assemblies (ESA's). The structure is popular for use up to frequencies of 500MHz due to the relatively low input power required to generate high electric fields (typically less than 10W can generate over 100V/m) with relatively high field contour uniformity.

The design of the 150mm stripline (figure 1) provides a uniform field ($\pm 2\text{dB}$) up to the cut-off frequency of the first dominant TE₁₀ mode, given by the equation;

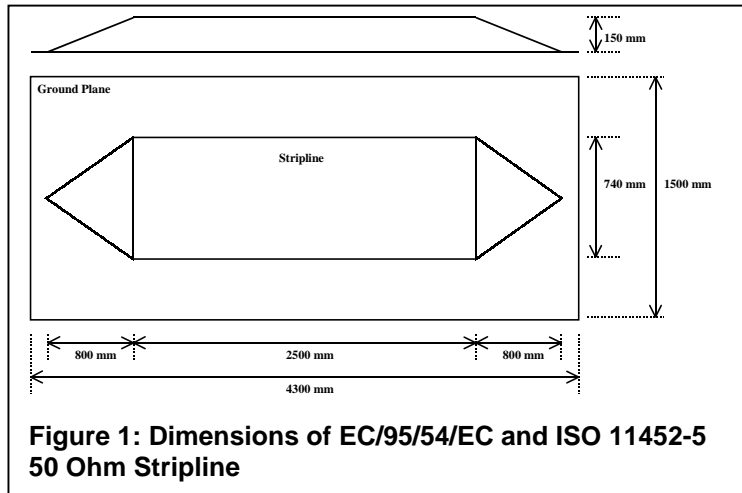
$$f_{c10} = \frac{c}{\lambda_{c10}} = \frac{c}{2w}$$

Where w is the width of the stripline, hence for the EC/95/54 and ISO 11452-5 design ($w=0.74\text{m}$) the cut off frequency for single mode operation is approximately 202MHz. Above this frequency the stripline operates as a multimode waveguide^[3], hence high field and good contour are still possible, but not guaranteed by the design.

The field generated within the stripline can be found by calculation when operating below the TE₁₀ cut-off frequency. Knowing the applied forward power (P), the impedance of the stripline ($Z=50\Omega$) and the height of the stripline ($h=0.15\text{m}$) the field (E) is given by;

$$|E| = \frac{\sqrt{PZ}}{h}$$

The field required by EC/95/54 is 60V/m (25% over the 48V/m reference level), hence up to 200MHz this can be achieved in a 150mm 50Ω stripline with just over 1W of forward power (1.04W). The maximum limit in ISO 11452-5 of 200V/m can be generated from only 18W. It is common to use 50 or 100W power amplifiers with a 150mm stripline as these can generate the required field strength to meet both EC and ISO standards at a 'reasonable' cost (a 100W-rated amplifier is used with the stripline examined here).



The ISO 11452-5 standard only includes measurement up to 200MHz, which is within the range of single mode operation of the 150mm stripline. EC/95/54, however, does include immunity tests up to 1GHz with no upper frequency specification for the stripline. The only stipulation on field is that the centre of the stripline is used as the calibration point. Measurement at this point, at each frequency, establishes the forward power needed to generate the target field strength. Although no explicit mention of field contour is made for ESA testing, the vehicle test specification gives a maximum field contour of $\pm 50\%$ over a displacement of 0.5m from antenna centre, and so it was considered reasonable to adopt similar limits for ESA testing.

Initial Tests

An assessment of the ability of the stripline structure (as supplied) to generate a field of 100V/m up to frequencies of 1GHz was performed by measuring the field generated using a 1W amplifier and calculating for the available 100W.

As well as assessing the field at the centre, the field across the stripline (field contour) was also tested using the EC/95/54 calibration procedure. The procedure uses the central field curve (figure 2) and controls the power amplifier output to generate the required field strength in the stripline, with a field of 100V/m being used to assess the contour. Field strength was recorded using an isotropic field probe at intervals of 0.5m along the length and 0.25m across the width, giving a 15 point 2-dimensional grid.

The resulting central field curve shows that below 600MHz, field strengths above 200V/m can be relatively easily generated with the 100W amplifier (details below 500MHz are not shown here). Above 600MHz (figure 2) the curve has several local minima where the achievable field strength is low (approximately 625Hz, 730MHz and 850MHz). At these frequencies the stripline cannot produce a field greater than 60V/m. As an internal target, we had hoped to be able to meet 100V/m at all frequencies.

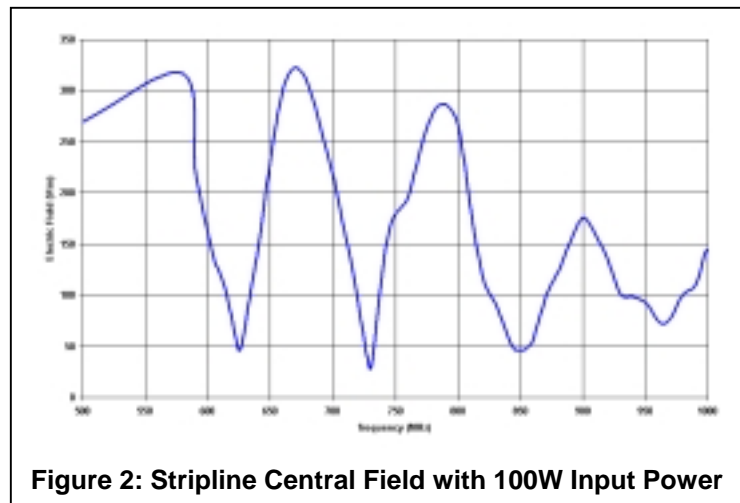


Figure 2: Stripline Central Field with 100W Input Power

The contour plot (figure 3, shown in 1 dimension along the centre) illustrates that the central reference point generally experiences a lower field than other areas. As the large number of contour lines illustrate, there is a lack of uniformity within the stripline, and so

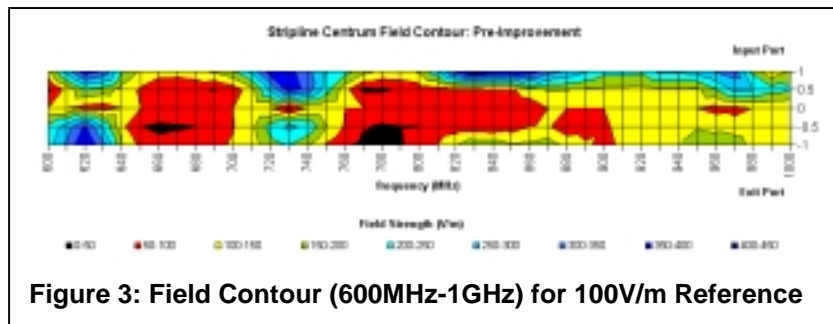


Figure 3: Field Contour (600MHz-1GHz) for 100V/m Reference

ESA's under test will be exposed to a wide field variation and test failures could occur due to excessively high field rather than out-of-specification product immunity performance.

Time Domain Reflectometry

A time domain reflectometry (TDR) technique was used to assess the possible cause of the contour discontinuities. Rapid rise-time pulses were applied to the stripline and the reflection of the pulse was measured on a time-based system to determine location of the reflection within the stripline. The main impedance discontinuities causing reflections appeared to originate from the input and output ports and the transition from the flat central section to the ramped triangular end structure.

Structural Discontinuities

The structure was examined at the locations indicated by the TDR results. The end support structures were constructed from blocks of paxolin. Although having a low dielectric constant ($\epsilon_r=4.5 - 6.0$), at high frequencies this impedance discontinuity (increased capacitance per unit length) reflects some of the applied power back to the amplifier. The paxolin was removed and reduced into columns (4 across each end, figure 4), so reducing the local impedance variation, hence reducing reflected power and increasing the power delivered to the stripline (i.e., an increase of the field generated for a given forward power).



Figure 4: Stripline Modified Supports

The input and output ports showed no obvious constructional or physical signs to suggest the cause of the TDR reflections, however, adding capacitance in the form of dielectric material at the N-type connector joint did significantly improve the TDR response (suggesting an excess of inductance per unit length). The end pieces of the stripline join to N-type connectors by means of triangular copper end plates bolted to the stripline end plate. Over time, these had become slightly distorted due to the forces acting upon them. New end pieces were made and bolted in 9 places, rather than 6 previously used, to improve the intermetallic contact. The re-manufacture of the end plates made only minor improvements in the TDR response.

The connectors had a central pin spill protruding by approximately 5mm above the N-type connector ground, this was reduced to 'near zero' height and soldered to the triangular end plate. Reducing the spill height produced one of the most significant improvements in the TDR response and coupled with the reduction in end support capacitance gave a low reflection.

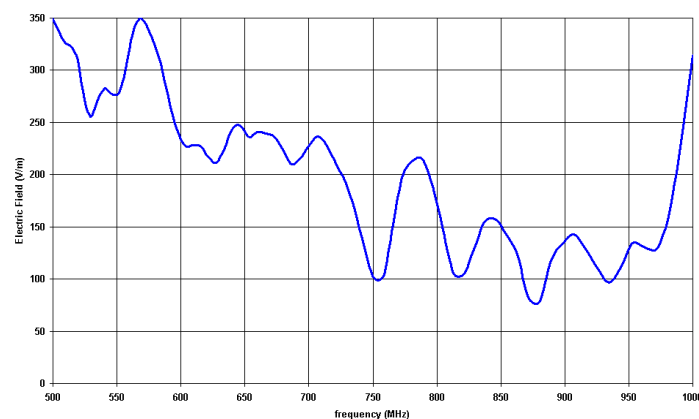


Figure 5: Stripline Central Field with 100W Input Power

Improved Structure Field Response

The field strength tests were repeated once the structural improvements had been completed. The results show that the stripline is now capable of generating 100V/m at its centre using the 100W amplifier at high frequencies, with a single minimum at 870MHz (figure 5). In practice the 870MHz minimum is not a problem as the 100W rated amplifier used has 15W of headroom at its' top end (115W) which is sufficient to give 100V/m over the complete 20MHz-1GHz frequency range of EC/95/54.

The field contour is improved at higher frequencies (figure 6), exhibiting significantly fewer contours below the reference value of 100V/m. Again using the 15W additional headroom, the stripline would be within the limits allowed for antenna contour as specified in EC/95/54 for vehicle level testing ($\pm 50\%$ over $\pm 0.5\text{m}$ from the centre).

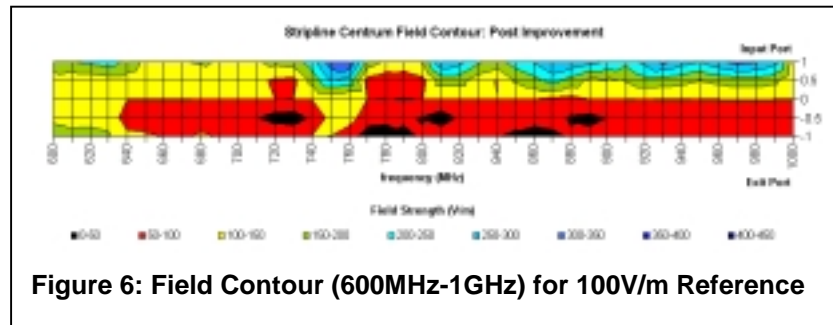


Figure 6: Field Contour (600MHz-1GHz) for 100V/m Reference

The field contour improvement should help with test variability as well as meeting EC/95/54 implied requirements. There is a major benefit in reducing sensitivity to test harness position in a stripline, as poor contour can lead to slight changes in positioning exposing the harness to significant difference in applied field.

Conclusion

The construction of the 150mm stripline structure is the primary factor affecting its ability to match to 50Ω at frequencies above the dominant cut-off frequency. Carefully minimising the extent of the dielectric discontinuities in the structure allows the stripline to be readily utilised up to frequencies of 1GHz, generating 100V/m with a 100W-rated power amplifier. The improved structure also reduces field contour significantly and can meet the vehicle test contour requirements of EC/95/54.

The improved structure, therefore, allows the 150mm stripline to be used for radiated susceptibility testing over the full frequency range of EC/95/54, reducing test time and eliminating the requirement to employ multiple test techniques^[4] for this test standard.

References

1. European Directive 95/54/EC, "...relating to the suppression of radio interference produced by spark ignition engines fitted to motor vehicles."
2. ISO 11452-5 (1995), Road vehicles – Electrical disturbances by narrowband radiated electromagnetic energy – Component test methods – Part 5: Stripline.
3. Engineering Electromagnetics, Kenneth Demarest, Prentice-Hall, 1998, ISBN 0138897832.
4. Comparison of Automotive Unit EMC Test Techniques, Peter Miller and Martin O'Hara, Electromagnetic Compatibility for Automotive Electronics, IEE Colloquia 99/134, 28 September 1999.