Improvement of Power Capability and Field Uniformity with Tapered Coaxial Matching Units in Strip Line for Measuring Electromagnetic Immunity of Vehicular Components

Yeon-Choon Chung, Tae-Won Kang, and Dong-Chul Park

Abstract

The design process and construction method of a strip line is described for measuring radiated susceptibility of vehicular components having electrical cables more than 2 m in length. The characteristic impedance of the strip line was determined 90 Ω to obtain the field uniformity of $\leq \pm 3$ dB in the frequency range from 100 kHz to 500 MHz. Tapered coaxial lines were used instead of the traditional lumped circuit elements for the impedance matching units, therefore, the strip line has high power capability. Using these techniques, the field uniformity and power capability of a strip line could be considerably improved.

I. Introduction

Electromagnetic interference problems by the unwanted emissions from a ignition system have been recognized as early issues. The unwanted emissions are generated during operation from the many intravehicular sources; a generator, wiper and fan motors, the relays of a regulator, etc., as well as a ignition system [1]. The conducted or radiated emissions generated from any type of sources can interfere with radio reception and the normal function of the intravehicular components. Therefore, many countries enforce the electromagnetic susceptibility regulations as well as electromagnetic emission regulations for the vehicular components.

Radiated susceptibility phenomena are usually due to the coupling of the high-intensity interference field from the intravehicular sources to the electrical cable connected to the sensitive equipments. Therefore, the electromagnetic immunity requirement to the radiated field must be satisfied for the safety-critical equipments having a long electrical cable, such as control units of diesel fuel injection, ABS(Anti-Brake System) and other power train controls. There are SAE J1113-23, ACEA 72/245, DIN 40839 Teil 4 as the related standards[2~4].

This paper discusses that the power capability and field uniformity of a strip line can be improved by using the tapered coaxial line as an impedance matching unit. It has a great advantage to obtain very high intensity field by the high power injected to the line, because the impedance matching unit is made with a tapered coaxial line instead of the traditional lumped circuit elements having the limitation of input power. Using this strip line, we can generate the electric field of ≥ 300 V/m with the field uniformity of $\leq \pm 3$ dB in the frequency range from 100 kHz to 500 MHz, therefore, it can be used for the electromagnetic immunity test of the vehicular components to the radiated field.

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II. Design and Construction of a Strip Line

1. Applications and Characteristics of a Strip Line

A strip line has been extensively used for measuring the electromagnetic immunity of audio/video equipments and vehicular electronic components. It is a non-shielded version of a TEM cell consisting of a conducting strip separated from the ground plate by a dielectric air. Therefore, it is used in exactly the same manner as the coaxial TEM cell and has most of the same limitations. However, since it has a grounded conductor only at the bottom and not on the sides and top of the line, the overall physical size reduces.

The advantages of strip lines for immunity testing are low cost, high field intensity, exposure of EUT together with the wire harness and peripheral devices simultaneously to the interfering field, as well as good accessibility to the test area. However, some disadvantages limit the applicability of strip lines: limited frequency range, leaking hazardous field, fixed field polarization requiring the rotation of the EUT, and the fact that it should be operated inside an anechoic chamber [5].

At least 1.5 m of the wire harness feeding the EUT is to be exposed to the generated uniform fields inside of a strip line. Because the wire harness is typically arranged longitudinally along the length of the strip line, both the E and H fields are coupled into the wire harness, as shown in Fig. 1. Coupling will occur via the differential mode (coupling between the different wires in the cable) since the wires are at different heights above the ground plane of a strip line. Common mode coupling also occurs due to capacitance (stray or through components in the EUT) of the EUT to the ground plane. This coupling will provide information on the EUT behavior representative of the vehicle environment.

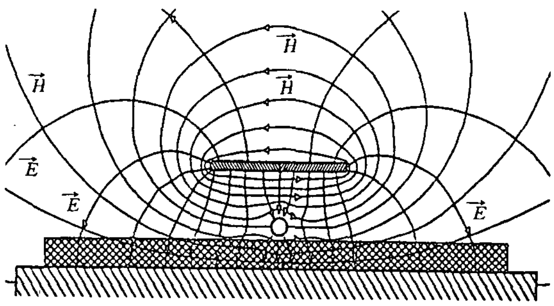

Fig. 1. Electromagnetic fields distribution in a strip line.

2. *Design and Construction of a Strip Line*

The longer parallel section of a strip line provides the less influences on the electromagnetic field generated inside the parallel section by the higher modes at the inclined sections. It is determined 2.0 m to expose at least 1.5 m length of the wire harness. The ratio of the width W to height h determines the characteristic impedance of the strip line by the following equation [2]:

$$Z_o = \frac{120\pi}{(\frac{W}{h}) + 2.42 - 0.44(\frac{h}{W}) + (1 - \frac{h}{W})^6} \quad \text{for } W/h > 1 \qquad (1)$$

where W= the width of a strip line active conductor(m),
h = the height of a strip line active conductor from the ground plate(m).

The field strength generated between an active conductor and a ground plate is determined by the characteristic impedance, the delivered net power, and the height of a strip line active conductor from the ground plate:

$$E(V/m) = \frac{\sqrt{P_{net} \times Z_o}}{h} \qquad (2)$$

where P_{net} = the delivered net power to a strip line(W).

First, the height of a strip line has to be determined by considering the available maximum size of a wire harness to be tested, and it is reasonable to be three times of the maximum size (35 mm) of a wire harness to be tested to obtain the uniform exposed field. Therefore, the height of a strip-line is to be at least 115 mm. If the height is to be raised, the more input power is required to obtain the same exposed field strength. Therefore, the height of 155 mm with 40 mm margin was finally determined.

Secondly, if we choose 50 Ω to be the characteristic impedance of the line, it is easy to drive a strip line with 50 Ω system, and additional impedance matching network is not required. But the characteristic impedance 50 Ω of a strip line may need the narrower width or lower height of a strip line which do not satisfy the required field uniformity. In this case, the wire harness under test will occupy more part of the test volume, and the exposed field will be distorted, and the input impedance will be changed. Therefore, the characteristic impedance of 90 Ω was finally determined to have the optimum dimensions and field uniformity.

From the above considerations, the ratio of the width W to height h, $t=h/W$ can be calculated from (1). The optimum value of t is 0.506 and the width is accordingly 306 mm. Fig. 2 shows the physical dimensions of the designed strip line section. And the next step to design an impedance matching network (50 Ω to 90 Ω) is now required.

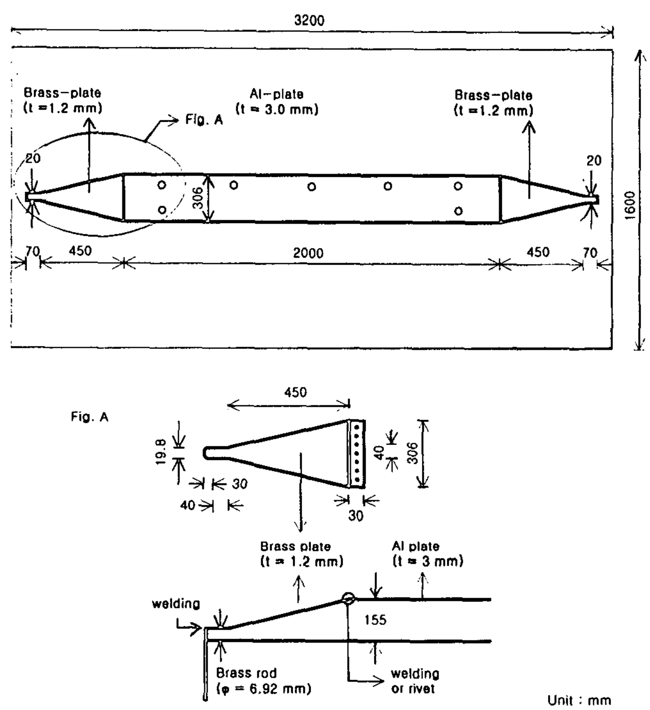

Fig. 2. Physical dimensions of strip sections.

It must be possible to inject a very high input power to the strip line for measuring electromagnetic immunity of vehicular components. Lumped circuit elements are generally used to fabricate a impedance matching unit. But those elements have frequency characteristics below tens of MHz. Although some electrical components have frequency characteristics up to several GHz, they are not to be used due to low power capability. It is very difficult to find the lumped circuit elements of a high power capability and constant frequency characteristics up to 1 GHz with low cost. Because of these reasons, EMC Automation Co. makes the strip line with 50 Ω characteristic impedance for the vehicular testing, but the field uniformity characteristic is not good. And Rohde & Schwarz Co. makes the strip line with 150Ω characteristic impedance for the electromagnetic immunity testing of audio/video products, but it has a limited power capability.

We considered the tapered coaxial line as an impedance matching unit, therefore, it has high power capability which is dependent on the power capability of a coaxial termination only. And it also has relatively good frequency characteristics in the frequency range of interest. The characteristic impedance of the coaxial line in Fig. 3 is as follows:

$$Z(\Omega) = \frac{377}{2\pi}\ln\left(\frac{d_1}{d_2}\right) \tag{3}$$

where, d_1 = the inner diameter of a outer conductor,
d_2 = the outer diameter of a inner conductor

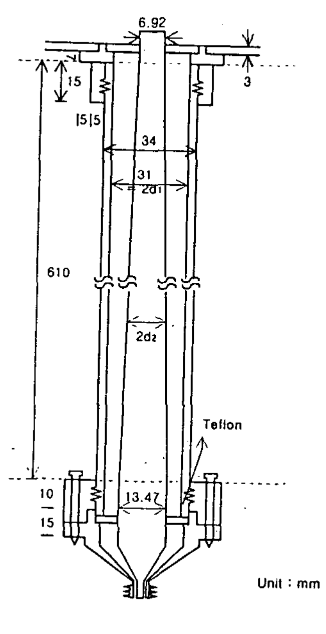

Fig. 3. Impedance matching unit with a tapered coaxial structure.

The outer conductor of the tapered coaxial line is fabricated with a commercially available SUS(stainless steel) pipe of the 31 mm diameter, the inner conductor is made by fabricating the tapered diameter of a brass rod from 13.47 mm to 6.92 mm, as shown in Fig. 3. This structure can transform the characteristic impedance from 50Ω to 90Ω, and vice versa. And the overall length of the tapered coaxial line is determined to be 690 mm by considering the height of the ground plane in the strip line from the floor of test laboratory to be 900 mm which is the conventional height of a working table.

III. Evaluation of the Strip Line

1. Input Impedance

The input impedance of the designed strip line with the tapered coaxial matching line was measured in the frequency range of 1 MHz to 500 MHz by a HP 8753C network analyzer. Fig. 4 shows the measurement result. From the result, it is found that the input VSWR is 3.10 at 20.7 MHz, 2.77 at 58.4 MHz, 2.50 at 97.1 MHz, 2.08 at 135.7 MHz, 1.49 at 179.2 MHz, and 1.51 at 342.9 MHz. The behaviors at lower frequencies are something like the resonance phenomena, and it is due to the limited length of the impedance matching unit to 690 mm. Therefore, the required field strength cannot be obtained at a one time by the constant input power, but this problem can be solved by controlling the input power through monitoring the net delivered power to the line. The fine control of input power must be required near those frequencies.

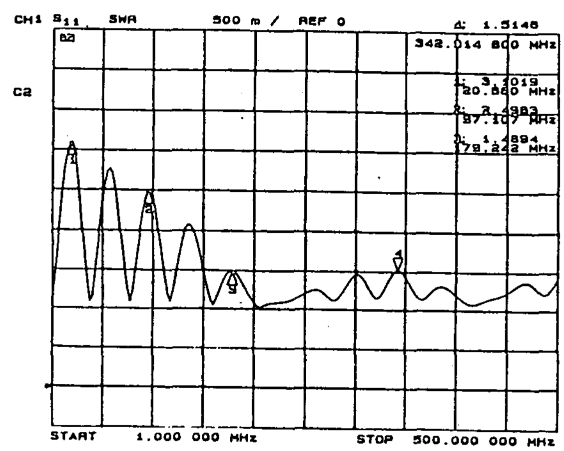

Fig. 4. Input impedance characteristics of the designed strip line with the tapered coaxial matching units.

2. Uniformity of the Exposed Field

The electromagnetic field of constant strength is generated between the active conductor and the ground plate of a strip line, and distorted by the strip line structure and the impedance characteristics of a terminating load. Non-uniform field can affect test results, therefore, the uniformity of the exposed field must be checked. The evaluation system is constructed to measure the uniformity of the generated field using an SMY01 signal generator, a NRV-Z51 / NRVD dual power meter of Rohde & Schwarz Co., 25A250 / 10W1000A power amplifiers, a DC3001 dual directional coupler(coupling factor: 40 dB) of Amplifier Research Co., and a HI-4400 broadband E-field intensity meter of Holaday Co., it is shown in Fig. 5.

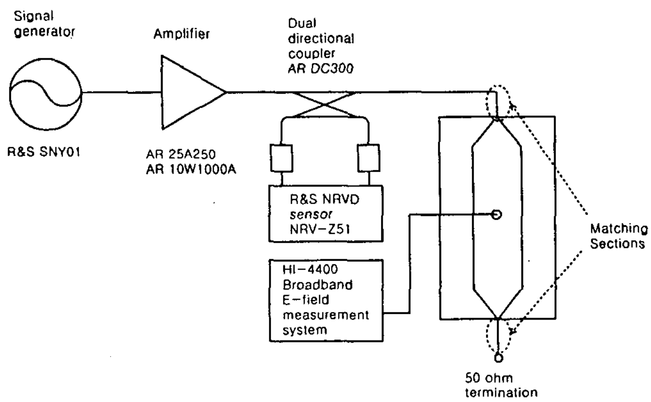

Fig. 5. Block diagram of the field uniformity measurement system.

Using the dual power meter, we first determine the net delivered power required to obtain the constant field strength(100 V/m) at the center of the strip line. The required power is maintained constant as a reference during the evaluation. The variations of field strength were measured at 51 test points by moving an isotropic probe in the step of 10 cm in the longitudinal direction and 15.5 cm in the direction normal to the longitudinal direction. Test results were obtained for the 51 test points at 21 frequencies of the frequency range from 100 kHz to 500 MHz, all of the field strength data were within ±3 dB compared with the field strength of the center point [6]. Fig. 6 shows some of measurement results. It is found that the variation of the field strength is more rolling along the length of the line as the frequency increases.

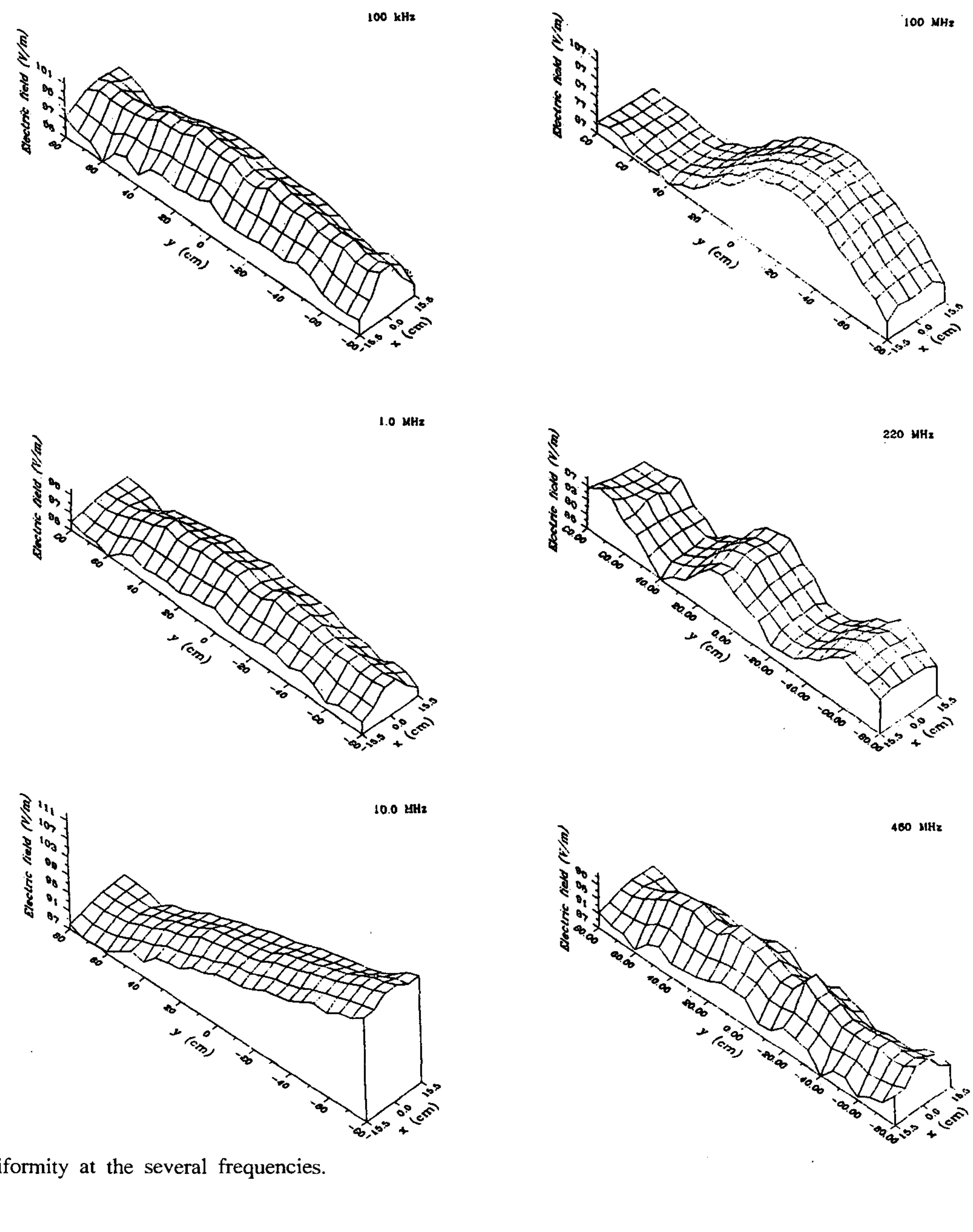

Fig. 6. Field uniformity at the several frequencies.

IV. Conclusions

The design process and construction method of a strip line for the electromagnetic immunity testing were described. The characteristic impedance of the strip line was determined 90 Ω by considering the field uniformity requirement and the maximum size of a wire harness under test. This impedance provides good uniformity in the exposed fields due to the broader width and raised height of the active conductor compared with the traditional 50 Ω strip line. Field uniformity was evaluated for the 51 test points at 21 frequencies of the frequency range from 100 kHz to 500 MHz, it was confirmed that all of the field strength data were within ± 3 dB compared with the field strength of the center point.

Impedance matching units of the designed strip line were made using the tapered coaxial line. Therefore, its power capability is determined only by the power capability of a terminating load. High power can be injected to the strip line through the tapered coaxial matching line, and then high intensity field is generated inside the strip line.

It is concluded that the designed strip line having 90 Ω characteristic impedance and the tapered coaxial impedance matching units can be used for measuring the electromagnetic immunity of vehicular components with electrical cables having more than 2 m in length. Further study will be done to improve input impedance characteristics at the low frequency range by using the technique applied at the high power balun and to analyze the field uniformity by the numerical simulation technique.

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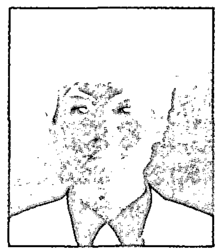

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