Separation of the Common-Mode- and Differential-Mode-Conducted EMI Noise

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***Abstract*—A device is developed to decipher common-mode and differential-mode noise from a conducted EMI noise measurement. This device is a useful tool for noise diagnosis and line filter design.**

I. Introduction

Electromagnetic interference (EMI) emission is always a great concern for power electronics circuit designers. One of the difficulties in dealing with EMI is the lack of diagnostic tools. When the noise emission of a piece of equipment fails to pass regulation, it is often not easy to trace the origin of the noise sources. In a conducted emission test, for example, emission measured is a mixture of both differential-mode (DM) and common-mode (CM) noise. These two modes come from different sources and must be dealt with separately in the line filter. Therefore, it is advantageous to be able to discern the two modes of noise source in order to design a good line filter.

Techniques have been reported for separate measurement of the two modes of noise present in a mixture of noises. Nave introduced a differential-mode rejection network (DMRN), but it can be used only for measuring CM noise [1]. A differential amplifier can be used to measure DM noise, but the bandwidth of the amplifier is not nearly enough for the frequency of interest (10–30 MHz), unless an expensive, high-performance unit is used. Current probes can also be used to measure both modes of noise current, but accuracy of measurement is poor [2]. Furthermore, for FCC and VDE specifications, the noise voltage is the concern, and converting noise current to noise voltage is not a straightforward procedure.

In the present paper, a new noise separator will be presented, which can be used to separate both CM and DM noise from a mixture of noises. In the paper, the basic principles of the noise separator will be described.

The construction of the hardware and the actual performance also will be reported.

II. Conducted EMI Test and Noise Types

Fig. 1 shows a diagram for the measurement of conducted EMI emission. The box LISN is a line impedance stabilizing network used in standard measurements to isolate the line impedance from affecting measurement results. The noise voltage measured across the 50-ohm resistor, R_L, is, by definition, the emission of the line side. It is required that a 50-ohm resistance be connected between points $(A, 0)$ and between points $(B, 0)$. The 50-ohm resistance between points $(A, 0)$ is the input impedance of the spectrum analyzer. The same condition applies to the neutral side noise measurement when the pointer is switched to point B. The emission must meet government specification (i.e., FCC or VDE), which is expressed in spectrum requirement. The noise voltage measured is a mixture of CM and DM noise as described in the following paragraph.

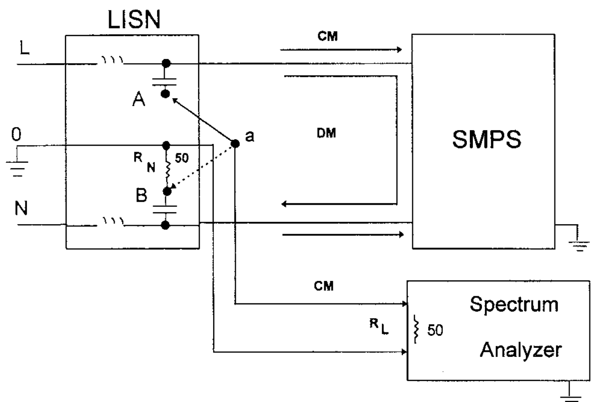

Fig. 1. Conducted EMI test setup.

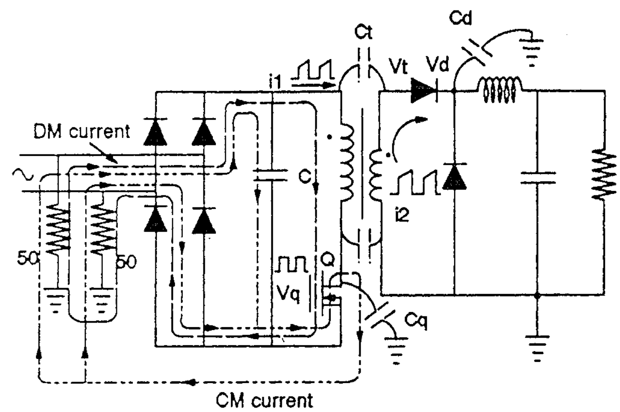

Fig. 2. Noise source and coupling paths in a forward converter.

Fig. 2 shows the noise-frequency equivalent circuit of Fig. 1. A forward converter is used to illustrate the noise sources. The DM noise is caused by the unfiltered portion of the transistor pulsation current flowing through the 50-ohm resistor. The other noise source is CM noise source

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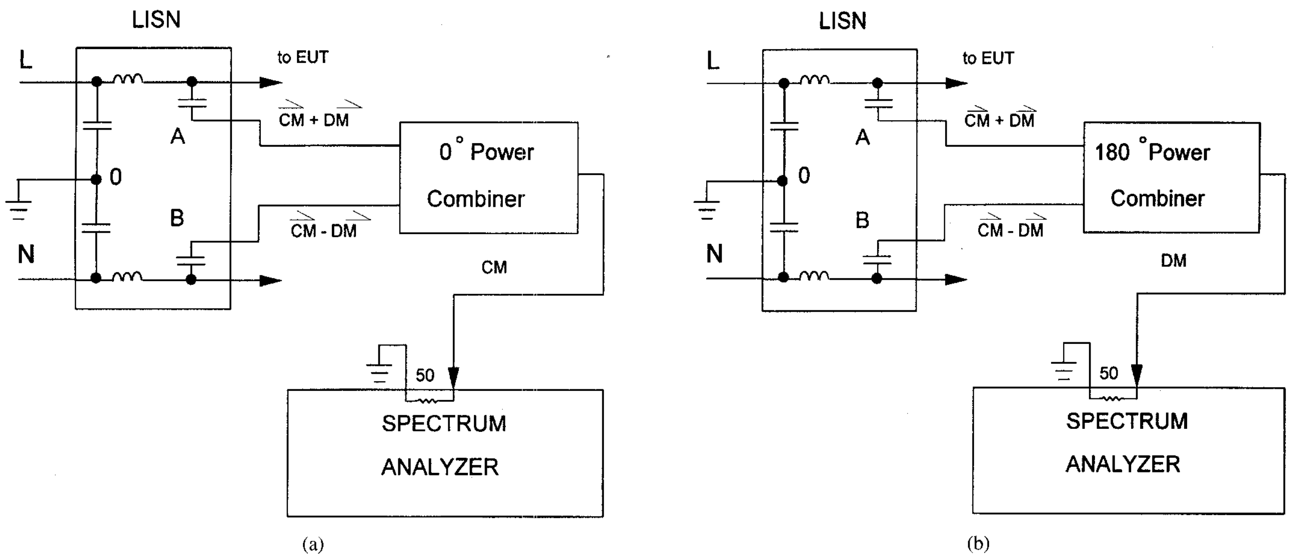


Fig. 3. (a) DM rejecter. (b) CM rejecter.

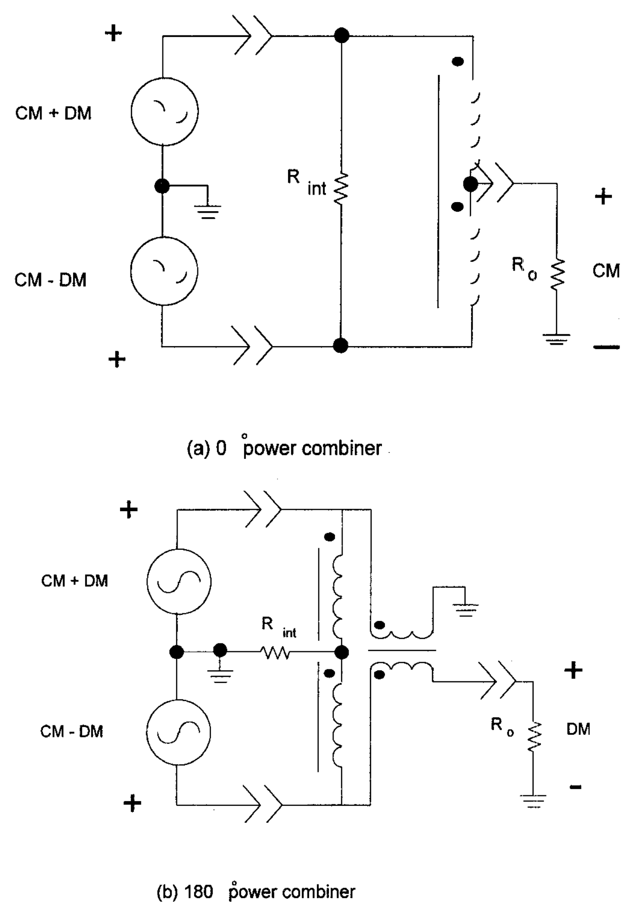


Fig. 4. Power combiner.

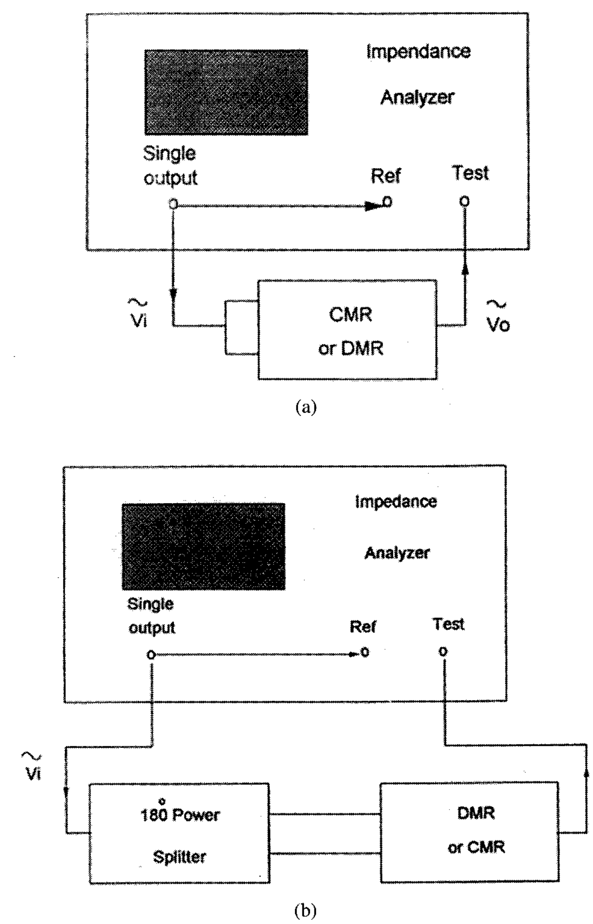


Fig. 5. (a) Measurement of attenuation of CM signal for CMR. (b) Measurement of attenuation of CM signal for DMR.

caused mainly by the displacement current flowing through the 50-ohm resistor. The displacement current is coupled through parasitic capacitors C_d, C_q, and C_t. C_d and C_q are the parasitic capacitances between semiconductor devices and chassis, and C_t is the transformer interwinding capacitance. The CM noise current flows through the two 50 ohm resistors in parallel, i.e., through both line and neutral to ground, while

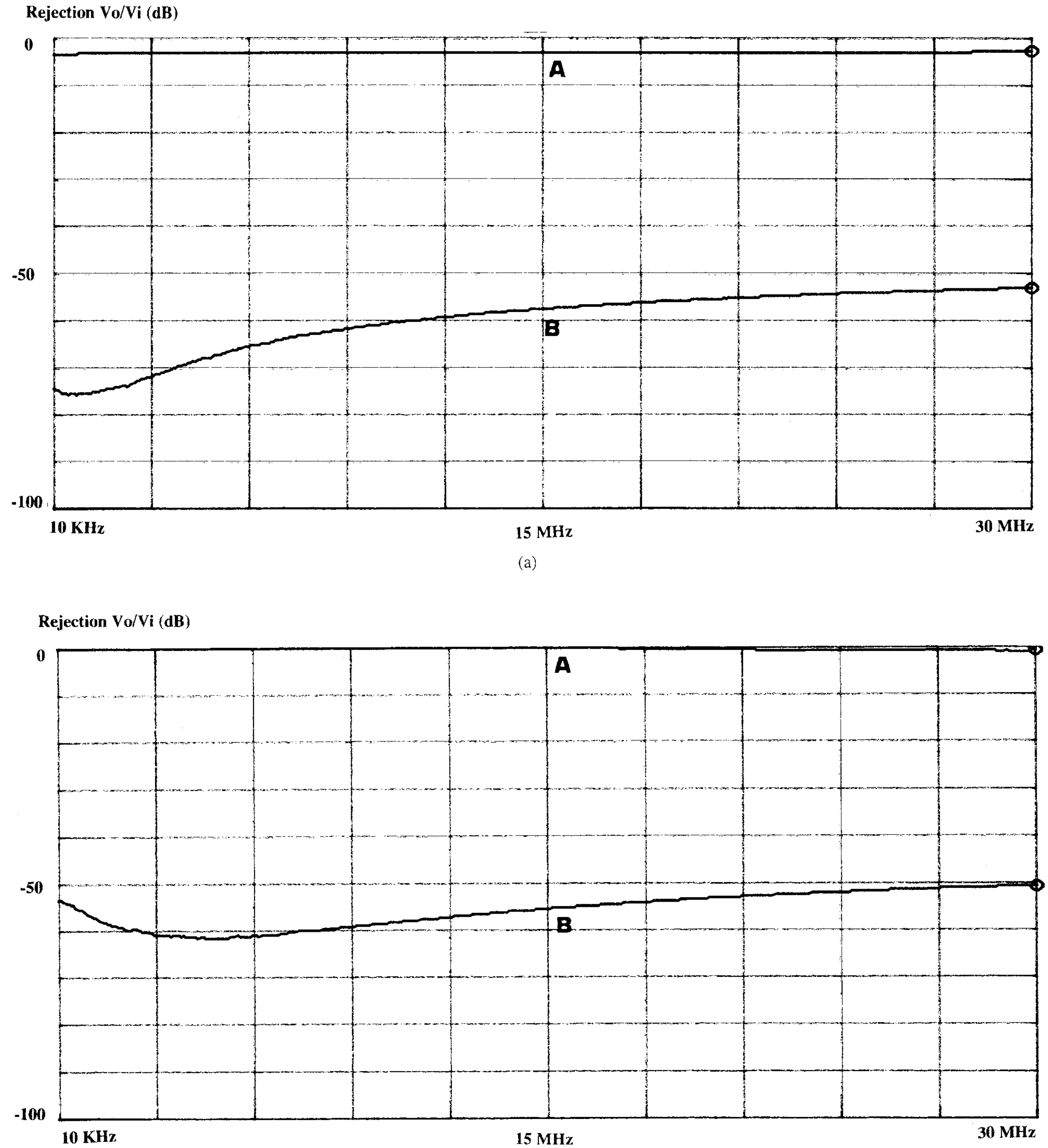
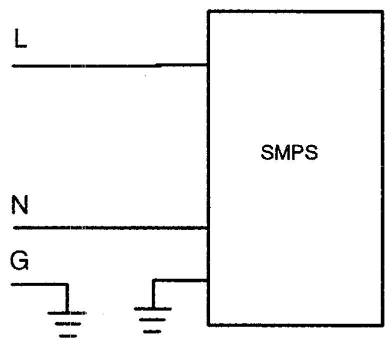


Fig. 6. (a) CM rejection of a CMR. (b) DM rejection of a DMR.

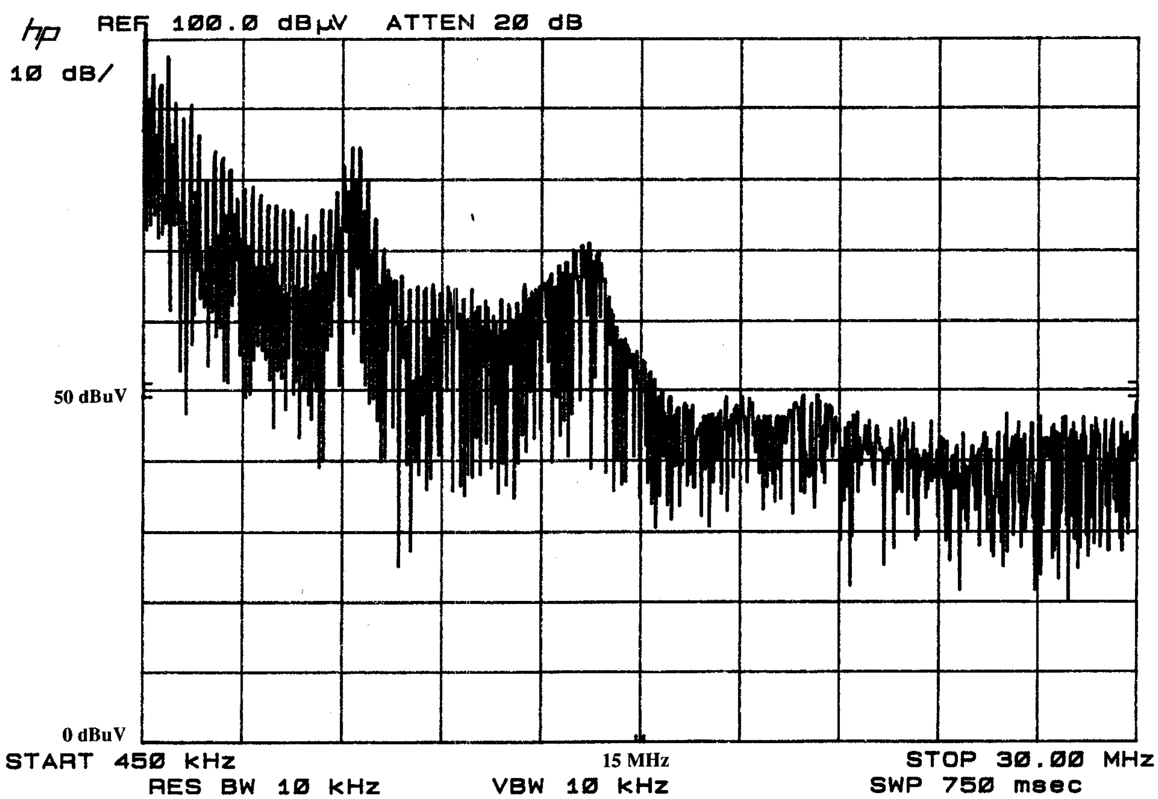
the DM current flows through the two 50-ohm resistors in series. It is therefore expected that the EMI measured voltages on the line and the neutral are different. One is CM + DM, and the other is CM − DM.

III. Noise Separator

The basic concept of a noise separator is very simple. Fig. 3 shows the diagrams depicting this concept, in which the two signals (A and B) derived from the LISN, consist of both CM and DM noises. However, one of the signals is the vector sum of the two modes of noise ($\vec{CM}+\vec{DM}$), and the other signal is the vector difference of the two modes of noise ($\vec{CM}-\vec{CM}$). It is assumed that the CM current is evenly divided between the two input terminals, which is often true except in extreme cases. The block "0^0 power combiner" is a device that cancels out the DM component and lets through the CM component, as shown in Fig. 3(a). The block "180^0 power combiner" cancels out the CM component and lets through the DM component,



(a)



(b)

Fig. 7. (a) Diagram. (b) Total noise.

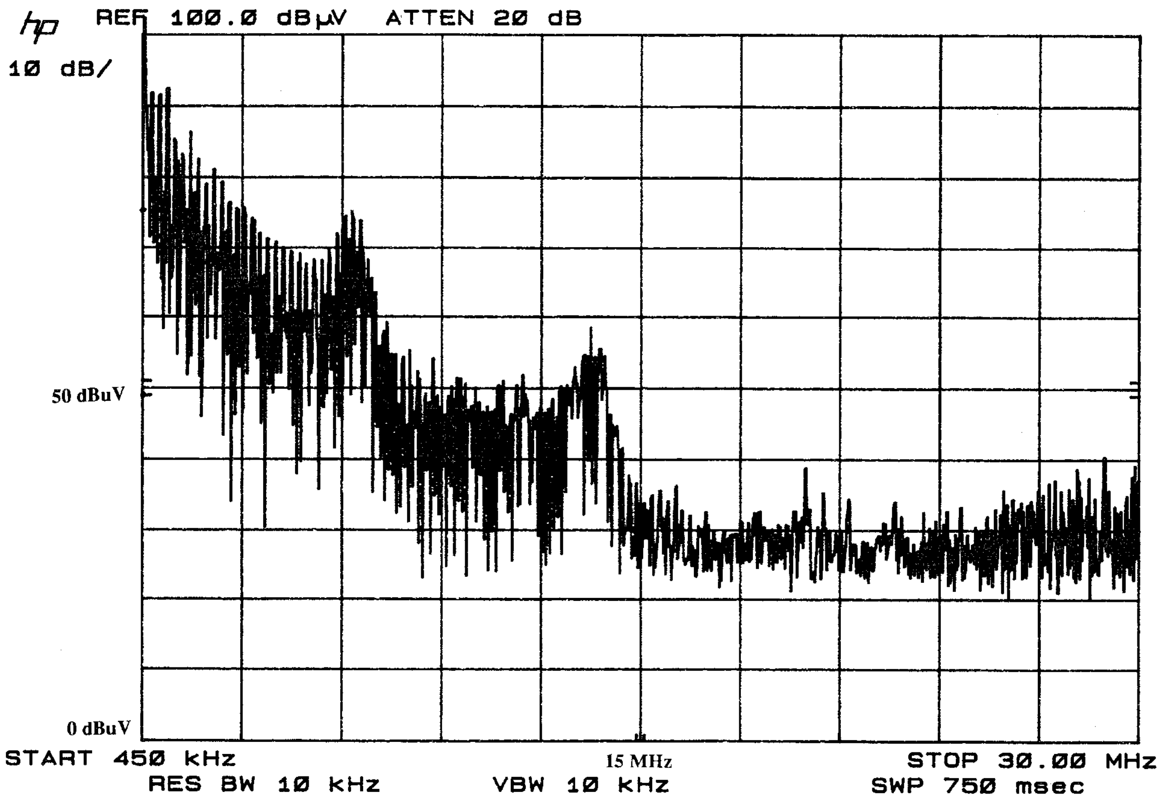
as shown in Fig. 3(b). A description of the power combiner will be given in later sections.

The challenge of implementing the basic concept described above is to maintain the accuracy for the frequency ranging from 10 to 30 MHz. A small error of phase or magnitude introduced in the process of summing or the phase subtracting leads to large percentage of error for the separator. A device that meets such accuracy requirements is the power combiner.

A. Power Combiner

A power combiner is physically the same as a power splitter but used in reverse. A power splitter is a commonly used RF device for splitting an input signal into two signals with equal amplitudes and a specified phase angle. When used in reverse, a splitter becomes a combiner. There are two types of combiners used in the noise separator, a 0^0 combiner and a 180^0 combiner. The output of a 0^0 power combiner is the sum of the two input signals, and the output of a 180^0 combiner is the difference of the two input signals. Both inputs are of equal amplitudes. Fig. 4 shows the circuit diagram of a 180^0 combiner.

The design and the fabrication technique of a combiner are closely related to those of a wide-band transformer. The accuracy of combining must be maintained over a larger frequency range. Besides the accuracy, a combiner should also provide proper input impedance to avoid disturbing the



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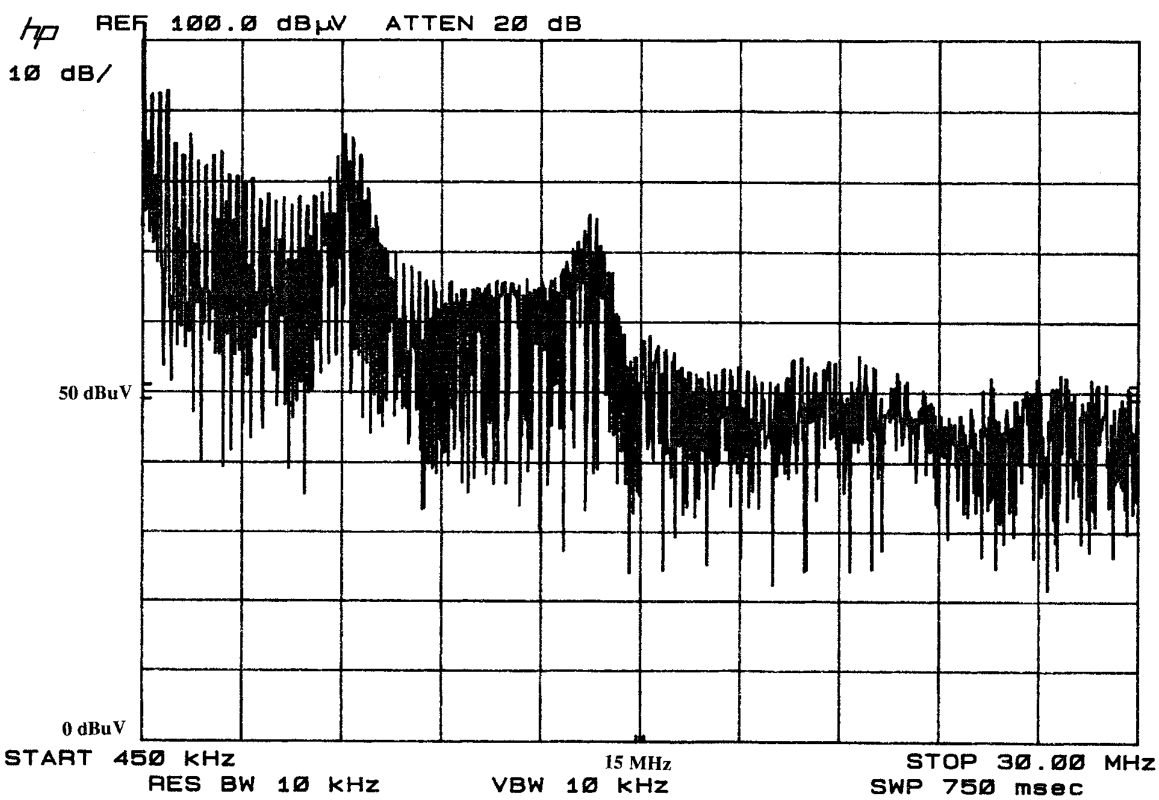
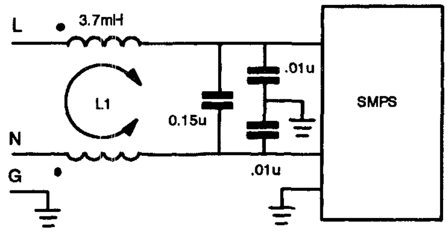
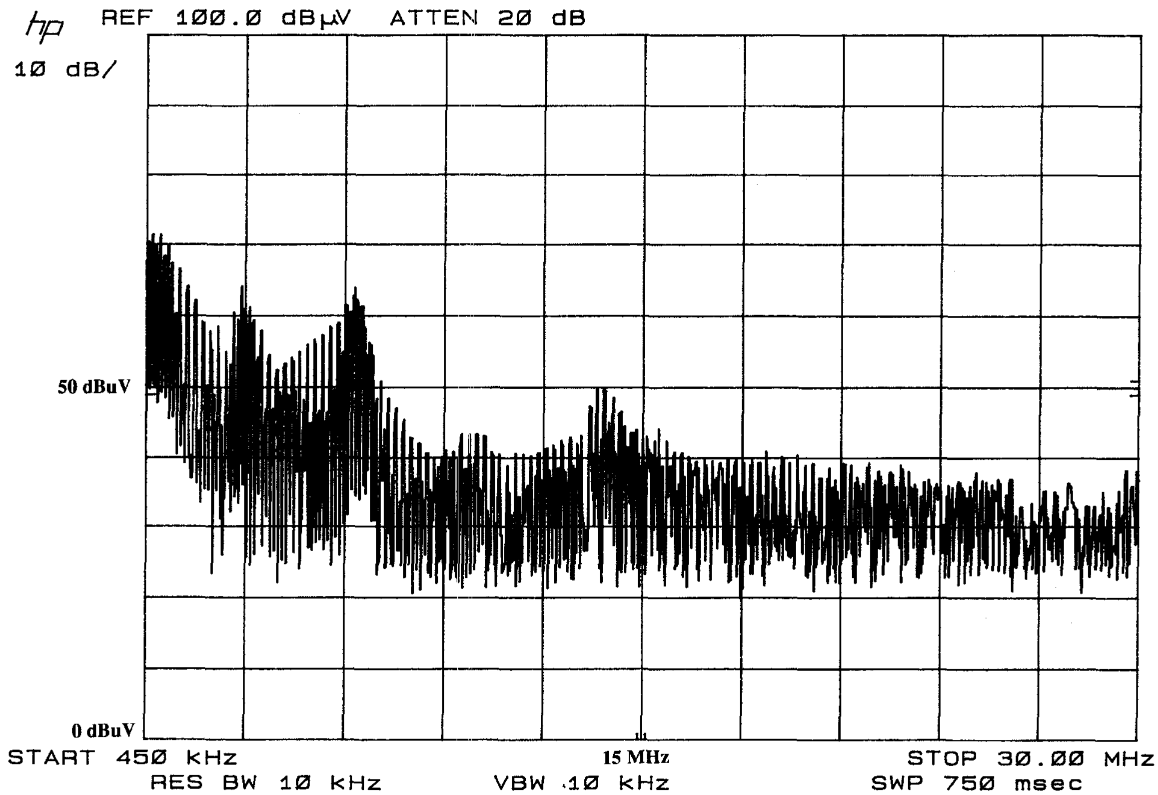


(d)

Fig. 7. (*Continued*). (c) DM noise. (d) CM noise.



(a)



(b)

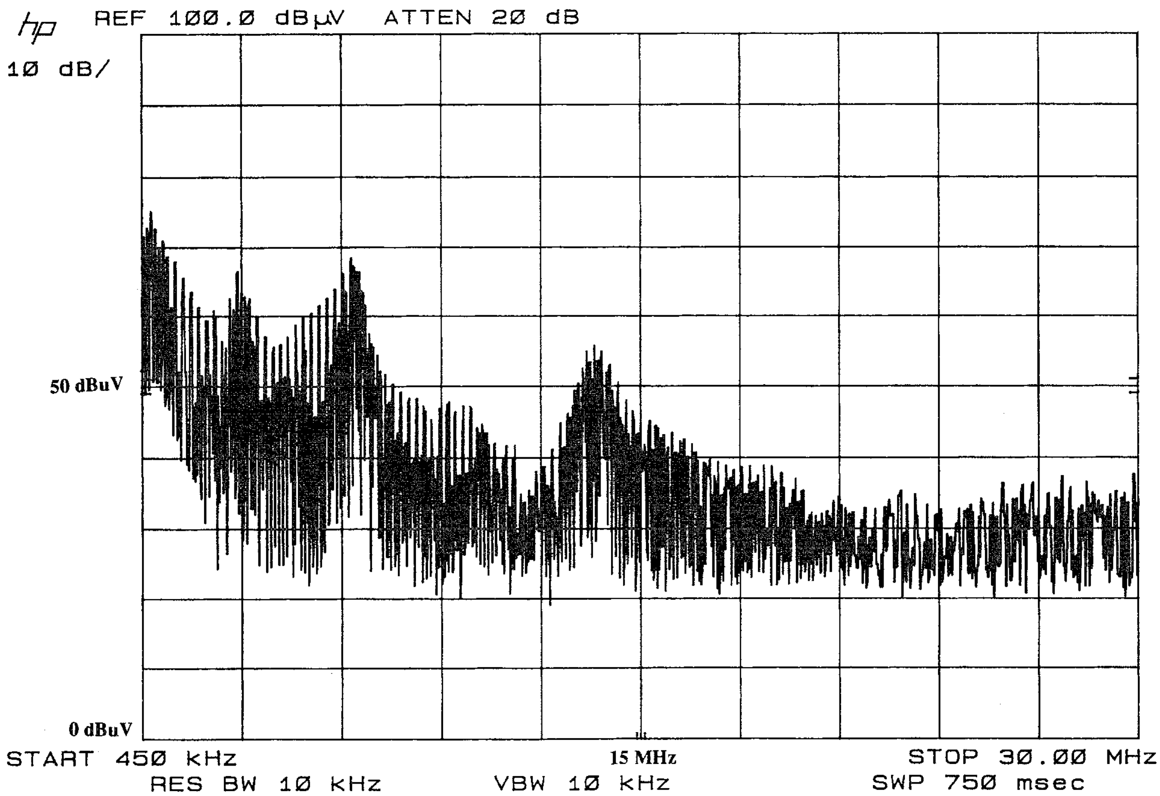
Fig. 8. (a) Diagram. (b) Total noise.

measurement. According to the description of the standard measurement given in Section II, a 50-ohm resistance should be seen between point A and ground when the line phase conducted noise is measured. The same comment applies to the neutral side. When a combiner is used, the internal 50-ohm resistors in the LISN are not connected. The 50-ohm resistance between point A and ground (also point B and ground) is the reflected 50-ohm input impedance of the spectrum analyzer. A more detailed description of power splitter is given in [3]. Power combiners meeting the above requirements are commercially available.

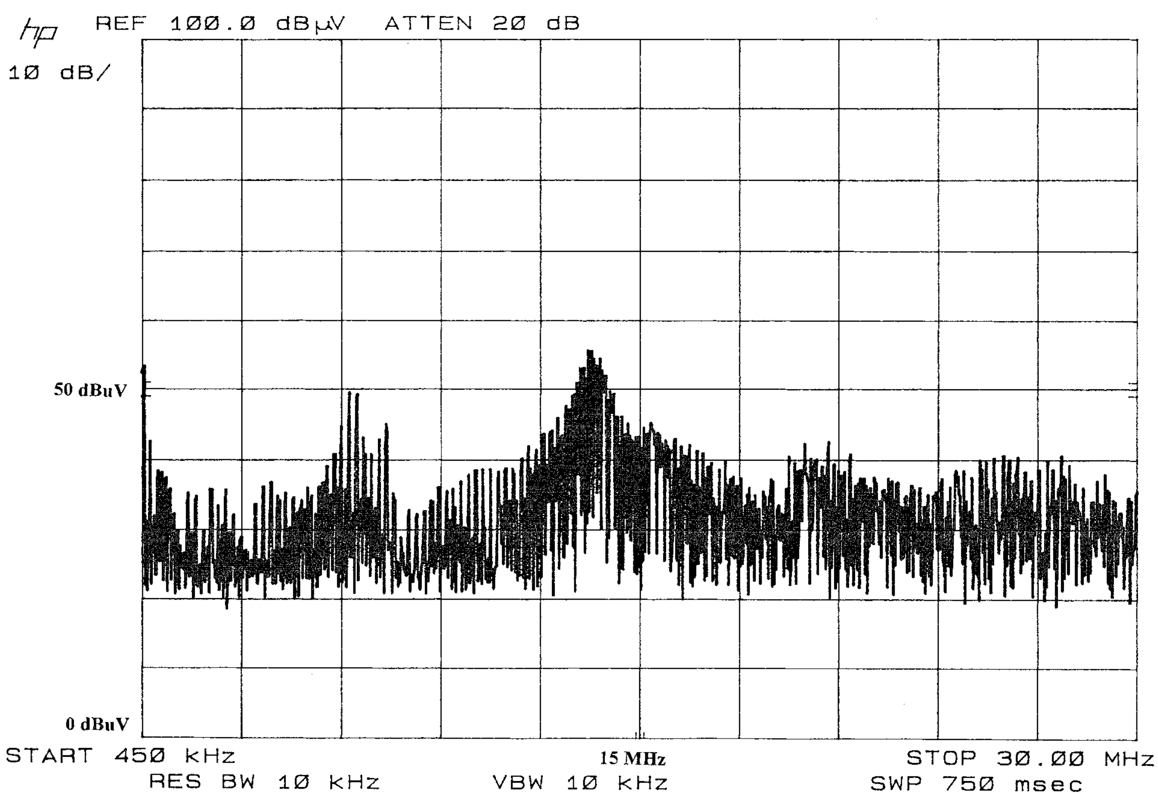
B. The Construction and Performance of the Noise Separator

A noise separator has been constructed according to the basic principles described in earlier sections. A two-way 0^0 power combiner (ZFSC-2-6-75) and a two-way 180^0 power combiner (ZFSCJ-2-1) manufactured by Mini-Circuits are used. The noise separator can be used to measure the CM, the DM, or the total noise via selection of a three-way built-in switch. A 0^0 combiner is used to reject the DM noise and let the CM noise go through intact. This portion of the noise separator network is called differential-mode rejecter (DMR). A 180^0-combiner is used to reject the CM and let through the DM, and this portion is called common-mode rejecter (CMR). In a measurement, the CM and DM noises can be selected by a switch in the noise separator. To measure the total noise, the input signal bypasses both DMR and CMR.

The performance of the noise separator has been evaluated by measuring the rejection attenuation of both modes of noise going through the CMR or the DMR. Fig. 5(a) and (b) shows the diagrams of the experimental setup to conduct such an evaluation. An impedance analyzer is used to generate an input voltage, V_i, of sweeping frequency and to plot the output-to-input ratio V_o/V_i. In Fig. 5(a), a CM signal $\tilde{V}_i$ is generated to



(c)



(d)

Fig. 8. (*Continued*). (c) DM noise. (d) CM noise.

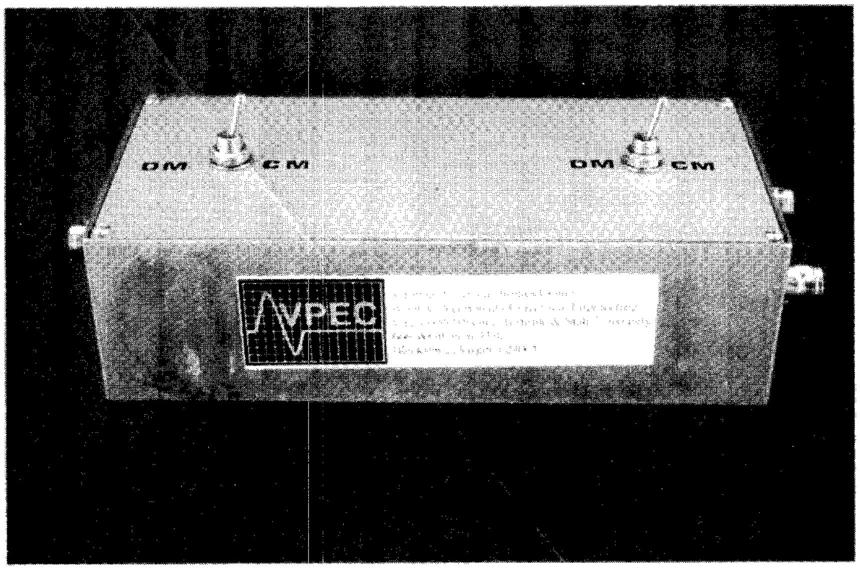


Fig. 9. Noise separator.

the input of a CMR or a DMR. In Fig. 5(b), an input signal $\tilde{V}_i$ is split into a DM signal (by the 180^0 power splitter), which serves as the input to a DMR or a CMR. Fig. 6(a) shows the result of the CM noise rejection test in which a CM signal is applied to both inputs of the rejecter. Ideally, the rejection is infinity for CMR and 0 dB for DMR. Fig. 6(b) shows the results of the DM noise rejection test in which a DM signal is created using a 180^0 splitter. Ideally, the rejection is infinity for DMR and 0 dB for CMR. As shown in Fig. 6(a), the CM noise rejection of a CMR is at least 50 dB for the frequency ranging from 10 to 30 MHz. The DM noise passed the CMR essentially intact. Fig. 6(b) shows similar performance for the DMR. This performance is equal to or better than any other DM or CM measurement techniques mentioned in the introductory section.

It is to be noted that the wiring of the construction of the noise separator hardware should be kept as balanced as possible to maintain high performance. For example, when two unequal lengths of cables were used as the two input cables to the DMR (one is about half the length of the other) and tested, the DM rejection degraded by more than 25 dB at 20 MHz.

IV. Use of Noise Separator in Power Supply EMI Measurement

A commercial power supply was used in a EMI measurement. All of the test results are displayed with three parts: total combined noise, DM noise, and CM noise. Test frequency range covers from 450 KHz to 30 MHz (FCC Class A). Notice that all horizontal axes are in linear scales.

Fig. 7 shows the results when no filter was used. It can be seen from this figure, that the CM noise dominates. Fig. 8 shows the results when a filter was used. In this case, the DM noise dominates because the CM noise is greatly reduced by the common-mode choke and the common-mode capacitors. From the results obtained, it can be clearly seen that to improve the performance, the dominant-mode noise needs to be suppressed. There is no point in adding filter components to suppress the less-dominant mode any further because it will not affect the total noise.

V. Conclusion

A differential-mode and common-mode noise separator has been developed. The device consists of only passive components and requires no power supply. This new device should provide the designer a valuable tool for noise diagnosis and filter design.

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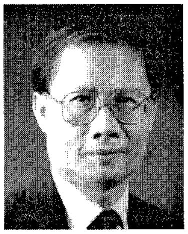

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Dr. Lee is a recipient of the 1985 Ralph R. Teeter Educational Award of the Society of Automotive Engineering, the 1989 William E. Newell Power Electronics Award of the IEEE Power Electronics Society, the 1990 PCIM Award for Leadership in Power Electronics Education, and the 1990 Virginia Tech Alumni Award for Research Excellence. He is a Past President of the IEEE Power Electronics Society.