Construction of CDNs for IEC 1000-4-6 EMC Testing

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In-house construction of a CDN can save time and money.

INTRODUCTION

Effective January 1996, virtually all electronic equipment shipped to Europe is required to comply with the EC EMC Directive 89/336/EEC, a part of which is known as the International Electrotechnical Commission (IEC) 1000-4-6 specification.[1] One result is that if electronic products do not have the CE certification marking they cannot be used in the UK, Germany, France, Italy or Spain.[2]

Manufacturers who have postponed getting their products certified and now attempt to schedule testing with a lab that can test to the European standard may find that the lab is booked well into 1996. This situation offers an opportunity to smaller test labs that previously have not performed any testing for European certification. These labs usually have all the necessary test equipment, such as RF signal generators and power amplifiers, detection systems, impedance meters, resistive pads, etc. However, one device these labs probably lack that is unique to the IEC 1000-4-6 test procedures is the coupling-decoupling network (CDN).

One of the European EMC tests is concerned with testing all electronic products for immunity to conducted signals induced by radio frequency fields on the power, control and signal lines connected to the equipment under test (EUT). The details of this signal immunity test requirement are given in Section 6, Part 4 of the IEC specification 1000, *Immunity to Conducted Disturbances Induced by Radio-Frequency Fields.* This document states that the source of the spurious emanation covered by this section is an electromagnetic field coming from intended RF transmitters that may act as a common-mode signal on the whole length of cables connected to the EUT. The ingoing and outgoing leads, such as power mains, signal lines, interface cables, etc., will behave as passive receiving antennas because they can be several wavelengths long. The cable systems connected to the EUT are assumed to be in a resonant mode and can be represented by a CDN having a common impedance of 150 ohms relative to the ground reference plane.

To test an EUT for conducted immunity compliance, the common-mode test signal specified in the IEC publication is injected onto the EUT lines through a CDN that couples the test signal onto the lines being tested, while also decoupling the test signal so it does not affect other equipment not under test. The CDN function can be accomplished by assembling several common electrical components in a single box with appropriate input and output connectors. The electrical components are selected to provide the impedance and coupling parameters as defined in paragraph 6.2 of the IEC publication. Any CDN fulfilling these parameters may be used.

Suitable CDNs are commercially available,[3] but there may be a delivery delay of up to four weeks. If a testing schedule requires a particular CDN to be available within a week, a possible alternative to buying a CDN is to build it in-house. Although the IEC publication provides sufficient information on CDN construction, finding the optimum combination of components, connectors, enclosures and the sources for these parts can be time-consuming. Instead, the following information can be used to expeditiously order the parts and assemble a CDN.

GENERAL CONFIGURATION OF THE CDN

The typical CDN consists of three parts: a common-mode impedance in series with the lines under test, a decoupling capacitance at the auxiliary equipment (AE) port, and an RC-series coupling network between the input port and the EUT port for injecting the test signal onto the EUT lines. Figure 1 shows the general configuration of the typical CDN. Auxiliary equipment is defined as that equipment necessary to provide the EUT with the signals required for normal operation, and equipment necessary to verify the EUT performance.

The common-mode impedance usually consists of a large and small inductor in series to provide a high common-mode impedance over the entire test frequency range. The large inductance consists of a high-resistivity nickel-zinc toroidal or binocular-type core having an initial permeability of 850, although a manganese-zinc core with a higher permeability of 2000 can be used if its low-resistivity surface is taped to insulate it from the windings. Between 11 and 17 bifilar turns typically produce a common-mode inductance of more than 250 μH. The toroidal or binocular inductor provides the desired decoupling impedance at the low-to-medium frequencies (0.15 - 10 MHz). The smaller inductance consists of several large ferrite beads strung one after another on the wires between the toroidal or binocular core windings and their connections to the terminals at the EUT port. This smaller inductance of about 8 μH provides the desired decoupling impedance in the frequency range above 10 MHz. The toroidal or binocular inductor by itself is not effective in the higher frequency range because of the high capacitance-to-ground of its windings.

The decoupling capacitors connect from the AE port terminals to ground. A 0.047-μF decoupling capacitance is suggested for each line as a compromise in that it is small enough to minimize the line-to-ground leakage current (for 110/220-V 50/60-Hz power lines), while being large enough to effectively bypass the lines to ground over the test frequency range.

The injection circuit for each line consists of separate series-connected resistor-capacitor combinations between the single input port terminal and each EUT line. For single or multiple lines, there are the same number of RC coupling circuits as there are lines, and each circuit has an RC product of about 2 μF ohms. For example, the resistances for 1, 2, 3 and 4 lines are standard values of 100, 200, 300 and 390 ohms, respectively, and the associated coupling capacitors are 0.02, 0.01, 0.0068 and 0.0056 μF.

CDNs FOR UNSHIELDED POWER LINES

The CDN power lines are designated as the protective earth (PE) or safety ground, the neutral (NEUT) and the line (LINE), or high side of the ac power line. The RF-test signal is injected via the input port connector onto these lines. The power line CDNs are designated with an M prefix.

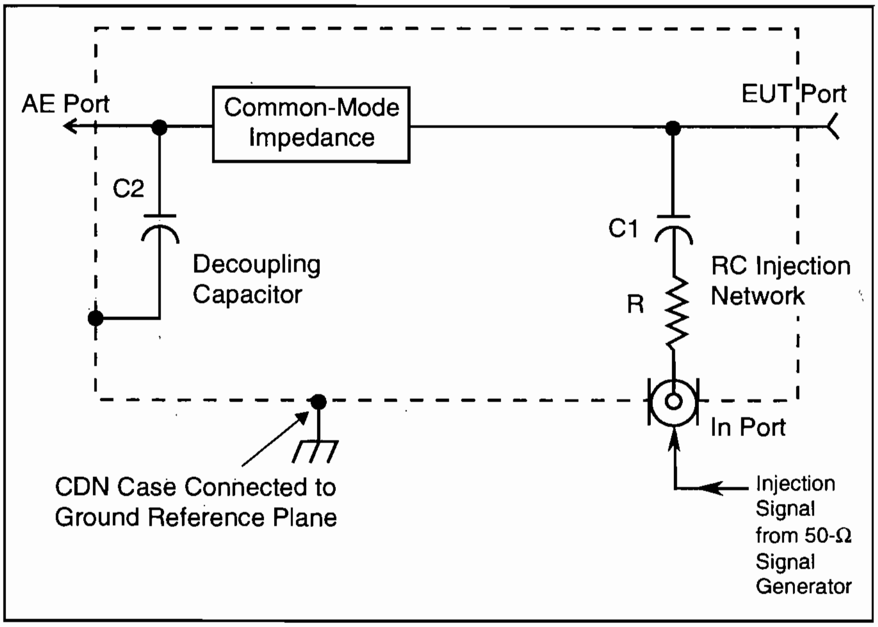

Figure 1. *Configuration of a Typical CDN.*

The schematic diagrams of the M1, M2 and M3 CDNs to be used with unshielded power lines are shown in Figures 2a, 2b and 2c, respectively. The R, L and C values are included with each diagram. The common-mode inductance, L_{cm}, is shown consisting of two inductors, L1 and L2, in series. L1 is a toroidal or binocular inductor of about 250 μH wound on a ferrite core and L2 is a number of series-connected ferrite bead inductors. The ferrite bead inductors provide an added inductance of 8 to 10 μH.

As indicated by the polarity dots, the windings of inductors L1 and L2 in the M2 and M3 CDNs are wound in a common-mode configuration. Since the NEUT and LINE currents flow through the common-mode windings in opposite directions, there is a flux-canceling effect that eliminates the possibility of core saturation. Because of this flux canceling effect, it is feasible to use a ferrite core with a relatively high permeability; consequently, fewer turns are needed. In comparison, the M1 CDN has only one winding, and the flux canceling effect of the two-winding common-mode configuration is absent. For this reason, the M1 CDN should be used only for those applications where the expected EUT current level is small. Typical examples are for testing the susceptibility of an EUT safety-ground or RF ground wire where the expected current level is only a few percent of the normal power line current level.

According to paragraph 6.2 of the IEC publication, a CDN is recommended for injecting the test signal onto power lines having current levels up to 16 A. Details of recommended components and their manner of assembly in the M-type CDNs are discussed later in the CDN Construction Details section.

CDNs FOR UNSHIELDED SIGNAL AND CONTROL LINES

Two types of CDNs are used for testing unshielded signal or control lines that are either unbalanced or balanced. The AF prefix identifies a CDN for unbalanced lines and a T prefix is used for CDNs intended for testing balanced lines. The IEC publication gives examples of a 2-line AF CDN and a 2-, 4- and 8-line T CDN. Only the AF2, T2 and T4 types are discussed in this article. For tests requiring more than 8 lines, the IEC publication recommends using the

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clamp-injection method of signal coupling to the EUT lines.

Figures 3a, 3b and 3c show the schematic diagrams of the AF2, T2 and T4 CDNs, respectively. The AF2 CDN is schematically the same as the M2 CDN, but the L1 and L2 inductors in the AF2 CDN can be physically much smaller than in the M2 CDN because the AF2 CDN needs to carry only signal-line current in the mA level. For the same reason, the L_{cm} inductors in the T2 and T4 CDNs can also be physically much smaller than those used in the M2 CDN. For the T2 and T4 CDNs, with single- and two-pair balanced lines, bifilar-wound transformers are used to maintain a balance both to ground at the AE port and to the input port by using the transformer center taps as the connection to ground or to the input port. The IEC publication shows no capacitive/transformer decoupling in the T4 CDN, but if decoupling is needed, it can be accomplished in the same manner used in the T2 CDN.

CDN IMPEDANCE

The CDN impedance relative to the ground reference plane at the EUT port terminals is specified over the 0.15 MHz to 80 MHz range. The impedance test is made with all the AE terminals tied together, all the EUT terminals tied together, and the input port terminated in a 50-ohm load. If a CDN meets the impedance specification using the component values and configurations suggested in the IEC publication and in this article, it is very likely that the CDN will be completely satisfactory for performing the IEC 1000-4-6 tests.

Table 1 lists the CDN impedance specifications for the frequency bands given in the IEC publication. Generally, the stop frequency will be 80 MHz. However, for small EUTs the stop frequency may be extended to 230 MHz. (See Annex A of IEC 1000-4-6 and IEC 1000-4-3.) The CDN discussion in this article is concerned only with the upper test limit of 80 MHz.

Although paragraph 1 (Scope) of IEC 1000-4, Part 6, states that the section "... relates to the conducted immunity requirements of equipment to electromagnetic disturbances, coming from intended radio-frequency transmitters in the frequency range of 9 kHz up to 80 MHz," paragraph 5 (Test Levels) states that "no tests are required ... in the frequency range of 9 kHz to 150 kHz." Consequently, the starting frequency for the CDN impedance compliance test is 150 kHz.

The test setup geometry used to verify the CDN impedance is well documented in Figure 7b of the IEC publication and need not be repeated here. However, the publication gives no suggestions as to what specific equipment is best suited for the impedance measurements. The following suggestions are based on

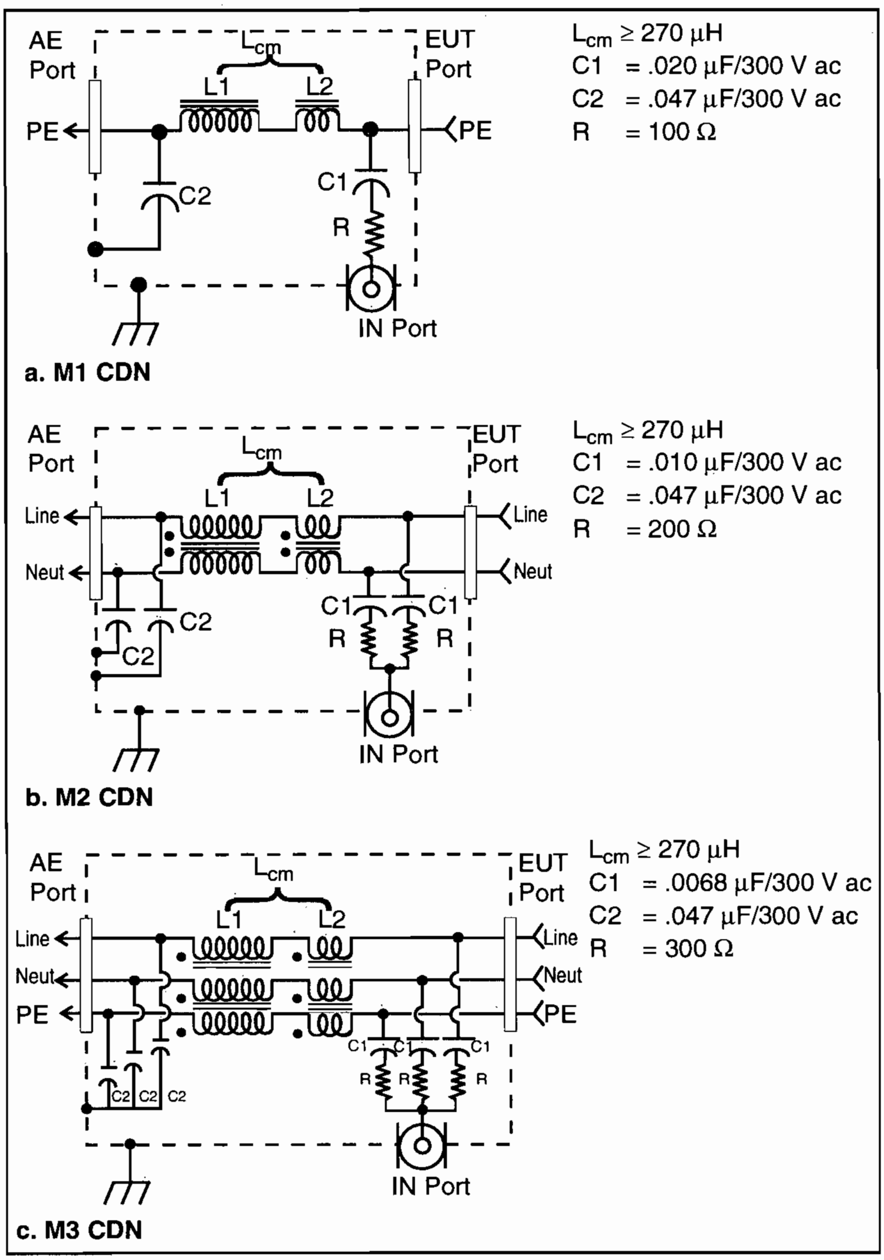
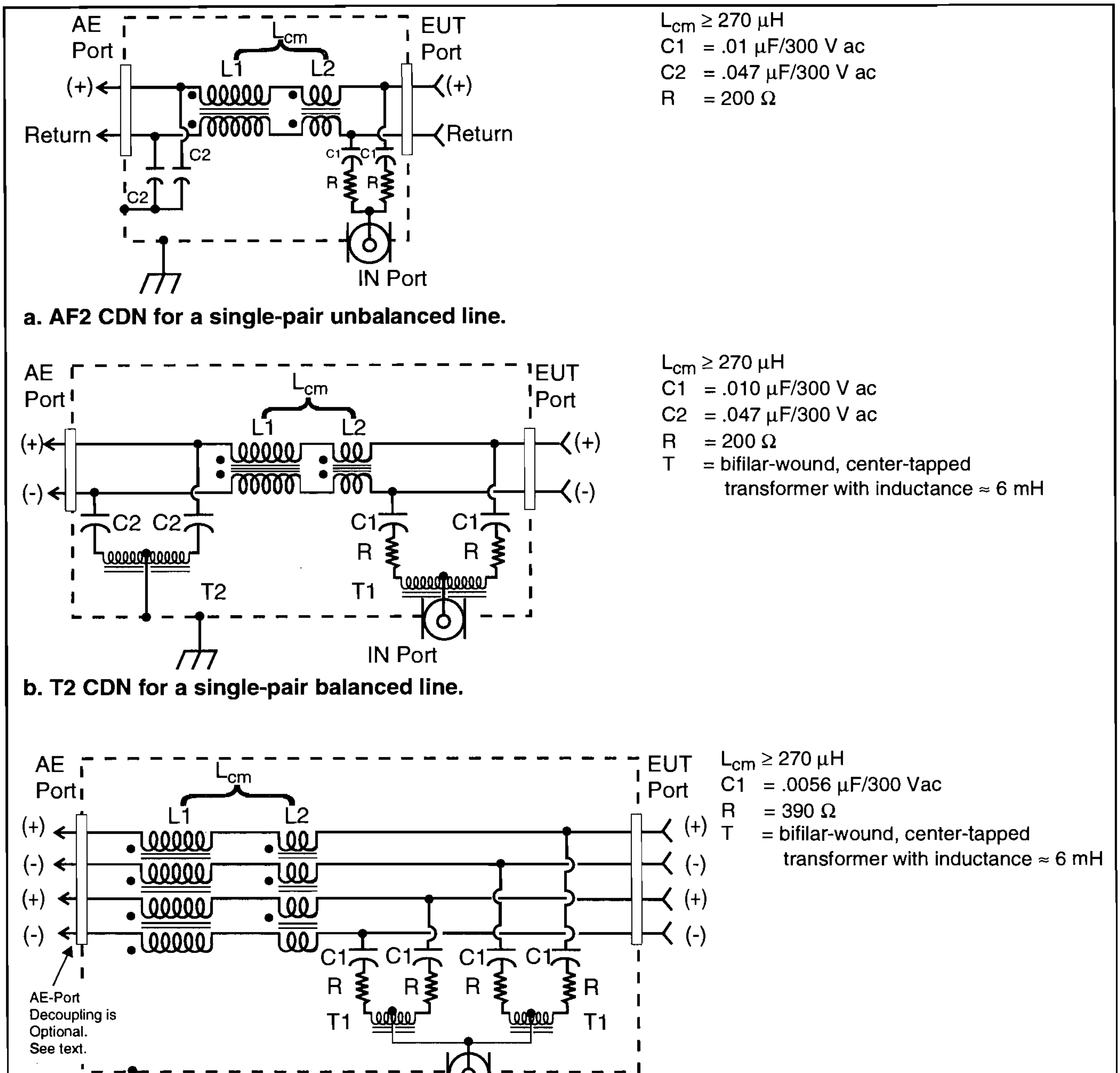


Figure 2. *CDN Circuits for 120-V ac 50-60 Hz Unshielded Power Lines.*

Parameter		Frequency Band (MHz) 0.15 - 26	Frequency Band (MHz) 26 - 80
Z (ohms) at EUT Port	Max.	170	210
	Nom.	150	150
	Min.	130	105

***Table 1**. CDN Impedance Limits at EUT Port when the AE Terminals are Grounded or Ungrounded.*



a. AF2 CDN for a single-pair unbalanced line.

b. T2 CDN for a single-pair balanced line.

c. T4 CDN for a two-pair balanced line.

Figure 3. *Schematic Diagrams of CDN Circuits for Unshielded Unbalnced and Balanced, Signal/Control Lines.*

the author's experience and are included to give the reader a start.

The Hewlett-Packard Model 4193A Vector Impedance meter is recommended as a convenient means of measuring the CDN impedance from 0.4 MHz to 80 MHz. This meter gives impedance magnitude in ohms and phase in degrees, both to the nearest tenth on an LED read-out and with an accuracy within 3 percent of the reading. The meter can automatically sweep the test range and provide an output to a plotter. Although the HP meter does not cover 0.15 MHz to 0.4 MHz, this range can be evaluated using a procedure previously described in the literature.[4] This procedure is capable of measuring the CDN impedance magnitude to the nearest tenth of an ohm using only standard lab equipment. Because there are no abrupt impedance changes in the 0.15 MHz to 0.4 MHz range, only four or five measurements are necessary to establish that the CDN impedance is greater than the minimum level of 130 ohms.

Over the 0.15 MHz to 10 MHz

range, the test configuration of the CDN on the ground plane and the interface connection between the CDN and the impedance meter are not important; however, as the frequency increases above 10 MHz, these positional variables become correspondingly critical. Consequently, because of their significant effect on the measured CDN impedance, all the configuration dimensions given in the IEC publication must be strictly observed if repeatable and valid results are to be obtained above 10 MHz.

CDN CONSTRUCTION DETAILS

The CDN construction procedures found to be effective are discussed in the following paragraphs for the M, AF and T CDNs. Specifications and sources of all parts recommended for use in the CDN construction are available.* With this information, anyone interested should be able to quickly construct a CDN.

Boxes

Two different-sized plastic boxes are recommended for containing the CDN parts. A plastic box minimizes circuit capacity to ground and is easier to work with and less expensive than a metal box. A smaller box is suitable for the AF2, T2 and M1 networks. Figure 4 shows the M1 CDN with a typical assembly in the smaller plastic box. A larger box is needed to contain the M2, M3 and T4 networks because a wider panel is needed for the terminal posts and because of the larger ferrite cores. The plastic sides are easily drilled or punched with ½-inch holes for the binding posts without the danger of cracking or splitting. The boxes are readily available.[5]

Each box has an external 1/8-inch thick aluminum base plate bolted to the outside bottom of the box. The base plate has notched side flanges for bolting the CDN to the test system ground plane. An internal copper strap provides continuity between the shell of the BNC input-port connector and the grounded side of capacitors C2. The #6 flat-head countersunk screws securing the baseplate to the bottom of the box provide continuity between the internal and external grounds of the CDN.

EUT and AE Port Connectors

The recommended connectors for all CDNs are single-and-double-assembly, 5-way, 30-A binding posts.[6] Each post fits in a 1/2-inch hole. Captive thumbnuts with a positive stop allow enough space to make external wire connections to the posts, yet reduce the chance of an accidental contact with energized surfaces. The double-assembly posts have a terminal-to-terminal fixed spacing of 3/4 inch and are used in the AF- and T-type CDN assemblies. The single posts are used in the M-type CDN assemblies and their spacing is dependent on the size of box used. The colors of the double-assembly posts are red and black, and the colors of the separate terminals used in the M-type CDNs are red (LINE), blue (NEUT) and green (PE).

The binding posts in all boxes must be placed so the horizontal center line of all posts is 30 mm above the ground reference plane of the test setup. See Figure 7b of the IEC publication for details.

*Those wishing to build this CDN may obtain a parts list from the author. For details, send a self-addressed, stamped business-sized envelope to the author at 1426 Catlyn Place, Annapolis, MD 21401-4208.

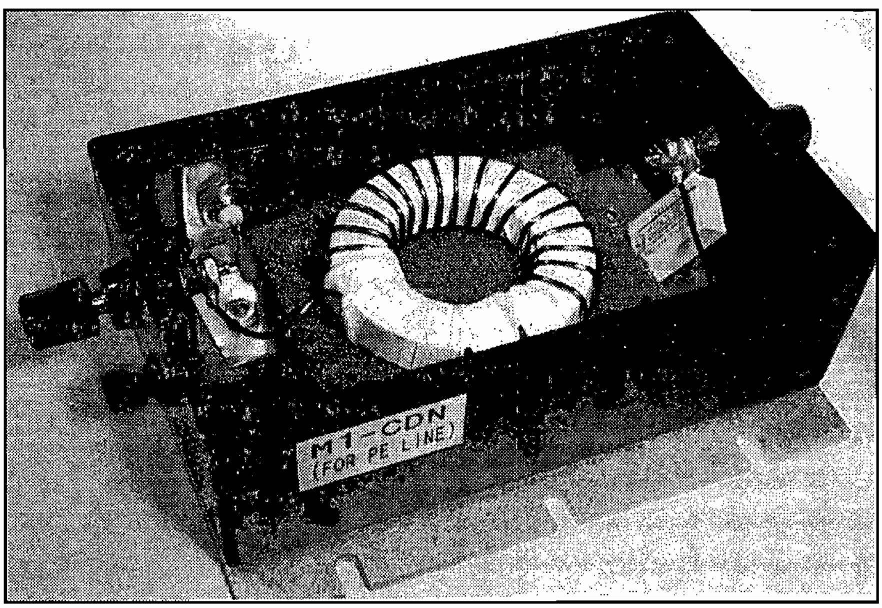


***Figure 4.** M1 CDN Installed in a 6 x 3.5 x 1.9-inch Black Plastic Box.*

Capacitors

All coupling capacitors (C1 in Figures 1, 2 and 3) used in the M-type CDNs are X- or Y-rated ceramic-disc types intended for ac power line applications. The M CDN AE port bypass capacitor (C2) is a Y-rated polyester film type. These capacitor types can be used in the AF and T CDNs, but a metallized Mylar film type may be preferred because of its smaller size and lower cost.[7] Because the AF and T CDNs are not intended for 115/220-volt ac power line applications, the capacitors used in these CDNs need not have an X or Y rating, and the metallized Mylar capacitors are acceptable.

Inductors

The inductors providing the common-mode impedance are the most critical elements of the CDN, and satisfactory performance of the CDNs is primarily dependent on the correct assembly of the L1 toroidal inductors. The CDN inductors can be assembled with a minimum of difficulty if the following suggested procedures are followed. A reference for all ferrite cores is recommended.[8]

M1 CDN Inductors

The M1 common-mode inductance, L_{cm}, depicted in Figure 2a, consists of a 19-turn toroidal inductor wound with #20 AWG magnet wire on a nickel-zinc (NiZn) ferrite toroidal core with outer and inner diameters of 2.4 and 1.4 inches, respectively, and a height of 0.5 inch. With 19 turns, the inductance should be more than 300 µH. Before the core was wound, it was wrapped with a layer of glass-cloth tape to provide a buffer between the core and winding. Figure 4 shows the M1 CDN with the toroidal inductor resting on a piece of foam padding inside a plastic box. A similar piece of foam padding on the inside of the cover keeps the core securely in place when the cover is fastened to the box.

The inductor was wound on a toroidal core available on the West Coast[9] and on the East Coast.[10]

It is important when winding any ferrite core, such as that used for L1, that the core not be stressed during the winding process. If the core is stressed by pulling too hard on the wire while winding it around the core, the core permeability may be adversely affected with an inductance drop of 20 to 30 percent. This inductance drop may occur after the winding is completed, or it may occur gradually over a period of a day or two. Consequently, the L1 inductance should be checked daily for several days after the M1 assembly is completed to confirm that the desired inductance has not changed. If the inductance has substantially dropped from its initial value, the core should be discarded and a new core wound with a looser winding.

For the M1 L1 core, #20 AWG wire (.032-inch diameter) is adequate because the M1 CDN is not intended to carry more than 0.6 A. Because the #20 wire is relatively flexible, it is easily wound around the core and is therefore unlikely to cause any stress in the core. In comparison, the L1 inductances of the M2 and M3 CDNs require a larger wire size so up to 16 A can be carried with a total voltage drop of less than 1 V. Winding with a wire size heavier than #20 requires a special technique to eliminate any danger of stressing the ferrite core. This special technique is explained in the following paragraphs discussing the M2 and M3 CDN construction.

The L2 portion of the L_{cm} inductance usually consists of several ferrite beads in front of the toroidal inductor. For the M1 assembly, the beads were not necessary because the effectiveness of the toroidal inductor over the entire frequency range was such that the M1 impedance remained well within the limits. However, a resonance at 70 MHz was observed that caused the M1 impedance to drop to a minimum of 119 ohms, and this impedance dip probably could be prevented by placing one or two ferrite beads on the lead at the EUT port terminal.

M2 and M3 CDN Inductors

The M2 and M3 toroidal inductors are similar in that they both use a core with a 2.9-inch outer diameter available either in a nickel-zinc (NiZn) or manganese-zinc (MnZn) material. The 2.9-inch NiZn core, with an initial permeability of 850, a resistivity of 10^5 ohm-cm, an inductance factor of 1375 nH/N^2 (+/-20%) and a mix designation of 43, is recommended for the M2 and M3 toroidal inductors because this core size will accept 15 bifilar or trifilar turns of #18 AWG magnet wire. With 15 turns, the L1 portion of L_{cm} will be a minimum of 250 µH. With the additional inductance contributed by the L2 ferrite beads, the total L_{cm} inductance will be enough to make the EUT port impedance greater than 130 ohms at 150 kHz.

Although the IEC publication suggests the L_{cm} common-mode inductance be equal to or greater than 280 µH, a computer simulation of the circuit elements indicates that the CDN input impedance specification at 150 kHz can be met with a common-mode inductance as low as 258 µH. Figure 5 shows the schematic diagram of a CDN computer simulation using software.[11] For the given inductor, resistor and capacitor values, the input impedance (based on the indicated input signal current with a 1-V source) is 139.7 ohms, or 9.7 ohms above the required minimum value. In this simulation, the AE port terminals were open circuited. If the AE terminals had been grounded, the input impedance would have increased by 4 ohms because of the elimination of the negative capacitive reactance. If the negative capacitive reactance is removed, the net positive inductive reactance increases, thus increasing

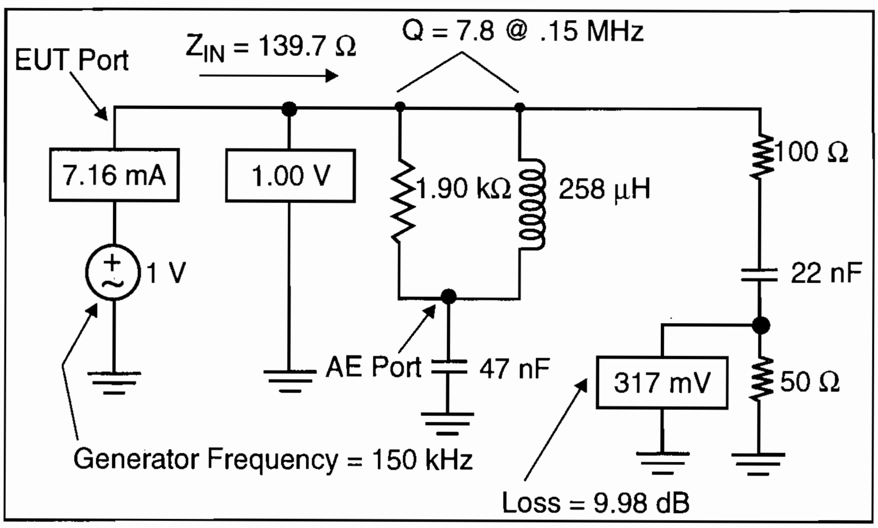


Figure 5. *Computer Simulation Used to Find the CDN Input Impedance at 150 kHz with the AE Port Terminals Open-Circuited.*

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the CDN impedance. The CDN simulation diagram also indicates that there is a 10-dB loss in signal level across the RC coupling network.

When winding a ferrite toroidal core with #18 or larger wire, the core must be wound in such a manner that the wire does not place any stress on the core, or the permeability may be reduced. The most sensitive parts of the core to winding stress are the edges where the wire is usually pulled with enough tension to make a tight winding that stays in place. Unfortunately, there are no protective covers commercially available for any of the ferrite cores which could be used to buffer the core from the stresses incurred during the winding process. However, it is possible to fabricate a handmade cover from a peanut butter or mayonnaise plastic jar cover. Figure 6 shows a 2.9-inch trifilar-wound ferrite core installed inside a protective plastic cover along with the separate parts used in the final assembly. A bare core is shown on the left. In the center, a cardboard disk is shown on top of the 2.9-inch core installed inside the plastic cover. On the right is the final assembly consisting of three windings, two of which are #18 magnet wire separated by a third winding of plastic-insulated #20 wire. Three ferrite beads complete the assembly. (Note: In order for the core to fit inside the plastic cover, the threads inside the cover must be removed.)

From several 2.9-inch cores, select one having an outside diameter on the low side of the nominal value, or not more than about 72.5 mm. Trace the inside circumference of the toroidal core onto the plastic cover and the cardboard disk. Cut out a hole in the plastic jar cover slightly smaller than the hole tracing using the point of a hot soldering iron. The hole in the cardboard disk can be cut with an X-ACTO knife.

Because the holes in the cardboard disk and in the plastic cover are slightly smaller than the hole in the ferrite core, all the winding stress will be taken by the inner and outer edges of the plastic cover and the cardboard disk. Using this winding technique, the wires may be wound tightly enough to maintain their position without stressing the core.

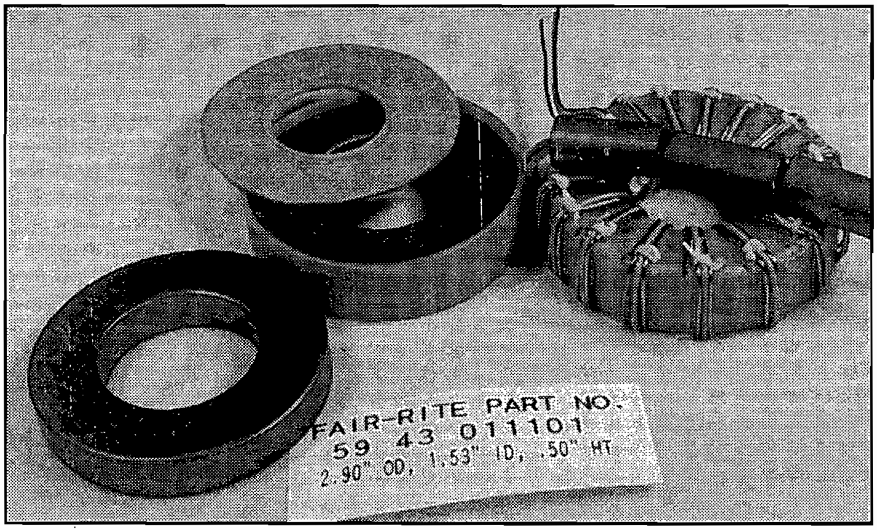

Figure 6. *Components Used to Make M2- and M3-type Common-mode Inductor with the Ferrite Torodial Core Installed Inside a Protective Plastic Case.*

The toroidal inductor shown in Figure 6 is intended for use in an M3 CDN rated for 11 A with a total IR drop of less than 1 V. For a 120-volt, ac power line, an acceptable maximum voltage drop caused by the resistance of the CDN inductor winding is arbitrarily assumed to be about 1 percent of the line voltage, or about 1 V. After several hours under load, the temperature rise of the #18 windings was about 54°C for an 11-A current level.

To meet the IEC maximum current specification of 16 A with less than a 1-V drop, the LINE and NEUT windings should be made with #16 AWG magnet wire. Because the ratio of the higher to lower current levels (16/11 = 1.45) is slightly less than the ratio of circular mil cross-sectional areas of the larger to smaller wires (2583/1624 = 1.59), the voltage drop and temperature rise with #16 wire at 16 A will be slightly less than with #18 wire at 11 A. The wire size of the PE winding can remain #20 as it carries no load current.

Figure 7 shows an M3 CDN with the common-mode inductor installed in a 7.5 x 4.3 x 2.3-inch plastic box and connected between the LINE, NEUT and PE binding posts at each end of the box. The input port BNC connector (not visible in the photo) is installed on the box cover. The BNC connector solder terminal is aligned to meet the single common lead of the three resistors when the cover is lowered into place. While the cover is about 1 inch above the end of the box, the single 3-resistor lead is soldered to the BNC terminal. The cover is then lowered all the way and secured to the corners of the box with four screws. The resistor-capacitor leads flex downward into an open area inside the box when the cover is secured. A copper strap connects the BNC shell to the decoupling capacitors at the AE end of the box and to the aluminum base plate. Teflon sleeving insulates the #18 NEUT and LINE wires going through the large ferrite beads.

The EUT port input impedance of the M3 CDN was measured and the results are shown in Figure 8. The impedance between 0.15 MHz and 0.4 MHz was measured using a resistance substitution method.[4] The measured impedance at 0.15 MHz is within 2.3 ohms of the computer-calculated value shown in Figure 5. The impedance was measured between .4 and 100 MHz with the vector impedance meter. The 2-ohm difference observed between 0.4 and 0.6 MHz using these two different methods of impedance measurement is attributed to a 2-percent error in the meter, which is within its specified 3-percent accuracy tolerance. Because the M3 CDN impedance level remains between the upper and lower limits shown on the graph, the CDN therefore complies with the impedance specification.

For 3-phase applications requiring 4 common-mode windings, a ferrite MnZn 2.9-inch core is recommended because its higher permeability requires fewer turns to obtain the required inductance. However, because of its low resistivity (100 ohm-cm), the core must be either taped or covered with a plastic cap (as previously discussed) to prevent the possibility of one of the windings shorting to the core.

T2 and T4 CDN Inductors

Figure 9 shows the components of a T2 CDN installed in a 6 x 3.5 x 1.9-inch plastic box. Referring to Figure 3b, both transformers, T1 and T2, are wound on NiZn binocular cores with 22 turns of #28 bifilar magnet wire (#B2282211).[12] The center taps of T1 and T2 connect to the input port terminal and to the CDN ground, respectively.

The common-mode inductor, L1, has 17 turns of #28 bifilar wire wound on a smaller NiZn binocular core. Inductor L2 consists of five NiZn beads strung on the leads between L1 and the AE port terminals. The positions of the beads and the small binocular core in the photograph are reversed from that shown in Figure 3b, but this does not affect the CDN performance. However, for all the power-line M-type CDNs, it is important that the ferrite beads be installed next to the EUT port terminals to provide maximum RF isolation between the EUT port terminals and the toroidal winding with its relatively high capacity to ground. This arrangement helps to keep the impedance above 105 ohms between 26 and 80 MHz.

Figure 10 shows the components of a T4 CDN installed in the larger 7.5 x 4.3 x 2.3-inch plastic box. The construction and components are similar to those used in the T2 CDN, except inductor L1 of the common-mode inductance L_{cm} is wound on a larger-sized binocular core. The larger core is necessary because the T4 CDN has twice the number of lines as compared to the T2 CDN. The two transformers, designated as T1 in Figure 3c, are wound in the same manner as in the T2 CDN.

SUMMARY

The recently published IEC 1000-4-6 EMC test specification requires a coupling-decoupling network (CDN) to perform tests on an EUT for immunity to conducted disturbances induced by radio frequency fields. Because there may be as much as a four-week delay

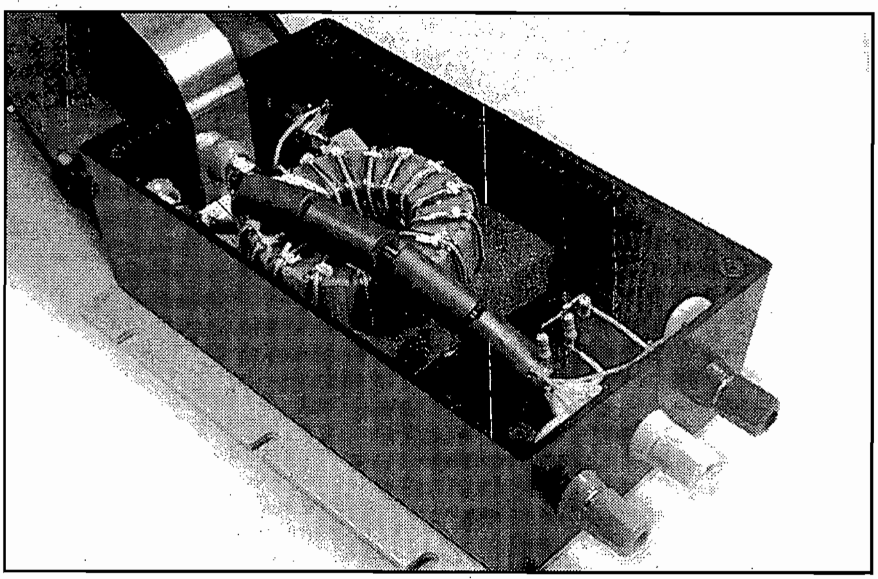

Figure 7. *The M3 Inductor Assembly of Figure 6 is Shown Connected between the AE and EUT Port Terminals to Complete an M3 CDN.*

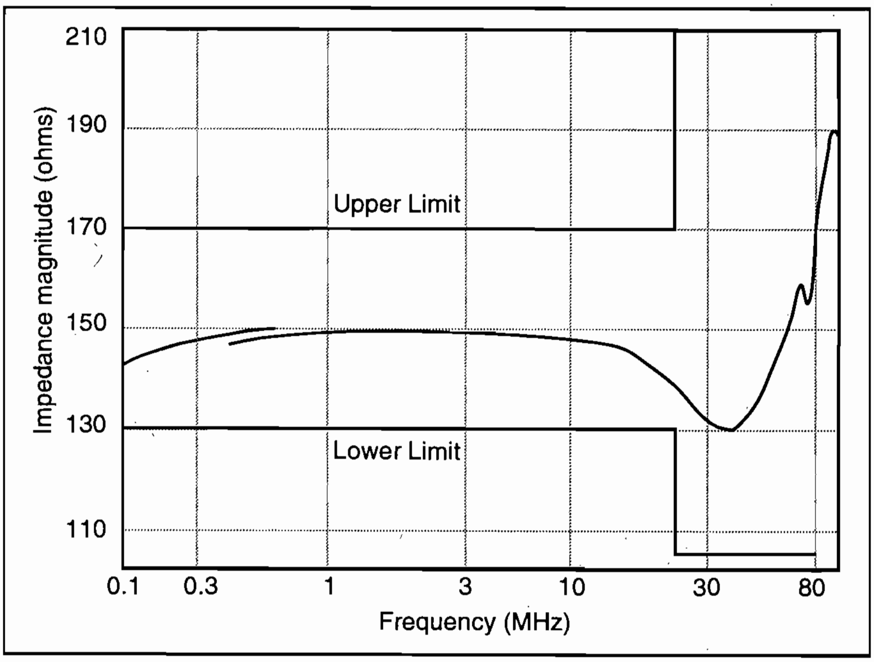

Figure 8. *Measured EUT Port Input Impedance Magnitude vs. Frequency for the M3 CDN Shown in Figure 7. The AE Port Terminals are Open-Circuited.*

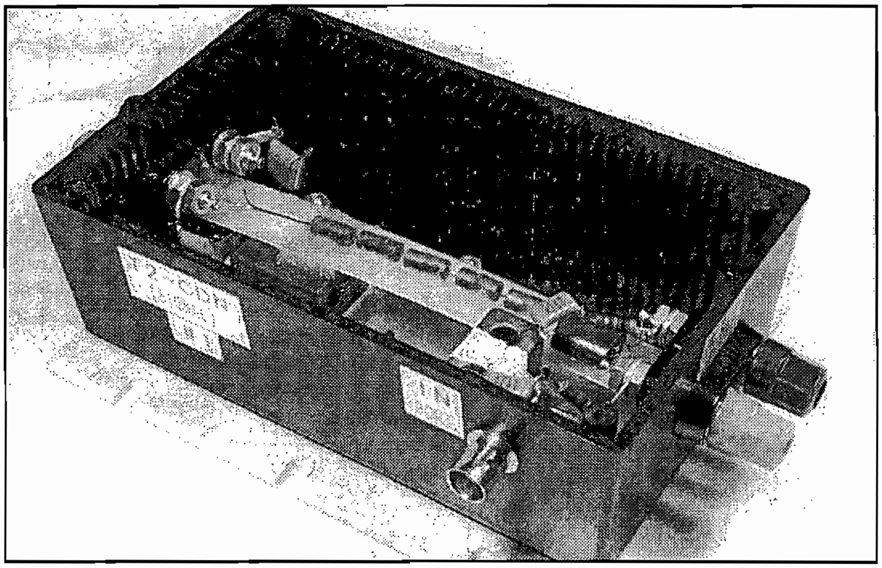

Figure 9. *T2 CDN where a thin Fiber-Board Strip between the Double Binding Posts Provides a Surface for Mounting the Common-mode Inductors. Transformers T1 and T2 are secured to the Bottom and Side of the Plastic Box with Silicone Rubber Adhesive.*

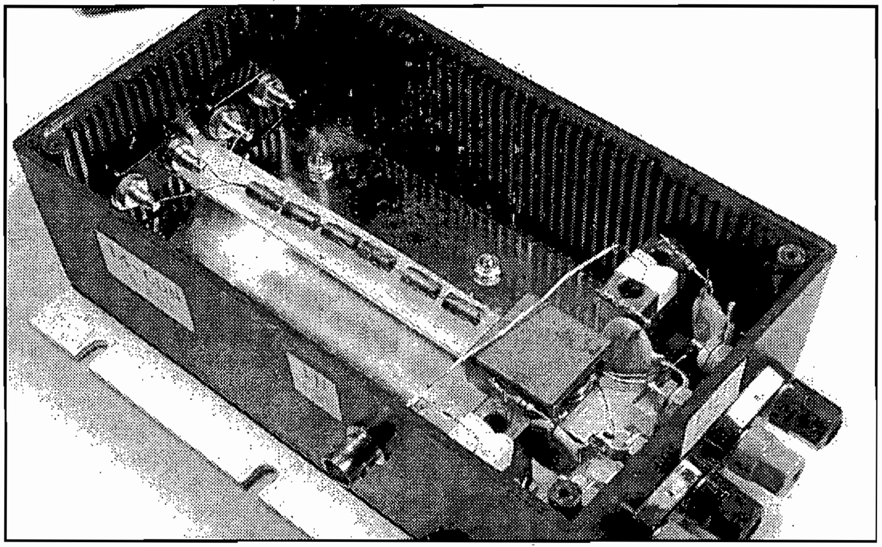

Figure 10. *The T4 CDN is similar to the T2 CDN except that the AE Port Terminals are not Bypassed and a Larger Binocular Core is used for the L2 4-wire Common-mode Inductor.*

in obtaining a CDN from a commercial manufacturer, an attractive alternative is to build the network.

This article discusses the different CDNs mentioned in the IEC publication and suggests components and assembly procedures suitable for CDN construction. A special technique explains how to minimize stress during the winding of a ferrite toroidal core. By following the suggestions in this article, anyone should be able to build a CDN in a few days with little difficulty.

ACKNOWLEDGMENTS

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