INDUCTIVE COUPLING DEVICE FOR CS10 AND CS11 TEST METHODS: CHARACTERISTICS, TYPICAL PROBLEMS AND PERFORMANCE

Understanding the inductive coupling device is necessary before testing for CS10 and CS11 specifications.

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BACKGROUND

The new version of MIL-STD-462, Notice 5, dated August 4, 1986, addresses the test methods for CS10 and CS11 specifications when a damped sinusoid test signal is applied onto a cable (CS11) or a terminal/pin termination (CS10), using an indirect injection. Indirect injection is performed by either an inductive coupling device (ICD) or by a capacitive coupling device (CCD). The rationale for the use of indirect drive injection originated with the common mode current which is excited when an EMP strikes a multiple-wire structure. Indirect coupling devices allow common mode current injection with less coupling to the cable under test. Thus, the test sample's performance might be affected by the applied test signal, rather than by the presence of the current driver.[1] This article deals with one of the two coupling devices, the inductive coupling device (ICD), and describes the device's major characteristics, the technical difficulties of designing a high-frequency transformer, recommendations for ICD building, and a few experimental results using different core materials.

Table 1. Wire Coupling Methods.

Wire Type	Frequency Range	Coupling	Comments
Single Wire	10 kHz - 10 MHz	Inductive	
	Above 10 MHz	Capacitive	
Multiple Wire or Balanced Pair	10 kHz - 10 MHz	Inductive	
	Above 10 MHz	Capacitive	
Shielded Twisted Leads	10 kHz - 100 MHz	Inductive	Shield Grounded at both ends
	10 kHz - 10 MHz	Inductive	Shielded grounded at one end only
	Above 10 MHz	Capacitive	
Coax or Triax	10 kHz - 100 MHz	Inductive	Outer shield grounded at both ends
	10 kHz - 10 MHz	Inductive	Outer shield grounded at one end only
	Above 10 MHz	Capacitive	

INDUCTIVE COUPLING — REQUIRED PERFORMANCE PER MIL-STD-461C[2]

Figure 1 depicts the test signal (damped sinusoid) frequency range and current amplitude applied to a cable (CS11) or lead (CS10). Table 1 (Table CS10-2 in MIL-STD-462) details the coupling techniques recommended for various wire types and shield terminations. Note that for some wire configurations, the inductive coupling method is recommended for the entire frequency range of 10 kHz to 100 MHz. In fact, Figure 1 depicts the required peak current amplitude to be driven into a calibration loop terminated with a resistive load of 100 ohms (Figure CS10-3 and Figure CS11-2 in MIL-STD-462, Notice 5). The highest current amplitude (10 amps) is applied in the frequency range of 0.63 MHz to 10 MHz. Since this current should be driven throughout a 100-ohm resistor, it implies transformation of 10 kilowatts (first crest) in this frequency range. Inductive coupling of such a high power at frequencies above 1 MHz poses technical problems in the design of the ICD. The ICD's frequency bandwidth should enable coupling of the damped sinusoid spectrum shown in Figure 2. Figure 2 shows a relative spectrum of a damped sine wave whose characteristic frequency is ω_o. Note that the spectrum contents start at dc and peak about ω_o, then fall off rapidly for frequencies above ω_o. For high damping factors, Q (see equation in Figure 1), the low frequency content becomes insignificant, i.e., the signal approaches a true sine-wave. However, MIL-STD-462, Notice 5 requires a Q value between 10 and 20, where the low-frequency contents cannot be ignored.[3]

LINE IMPEDANCE STABILIZATION NETWORKS

Part No.	Amps	uH	Recommended Frequency Range	Power Connection	Line/Ground Voltage Rating 50-60 Hz	400 Hz
NOTICE 3 MIL-STD-462						
6338-5-TS-50-N	50	5	150 KHz-65 MHz	¼-20 Stud	270	130
6338-5-PJ-50-N	50	5	150 KHz-65 MHz	Plug & Jack	270	130
6338-57-TS-50-N	50	57	14 KHz- 4 MHz	¼-20 Stud	270	130
6338-57-PJ-50-N	50	57	14 KHz- 4 MHz	Plug & Jack	270	130
6516-5-TS-10-BNC	10	5	150 KHz-25 MHz	8-32 Stud	270	130
6516-57-TS-10-BNC	10	57	14 KHz- 4 MHz	8-32 Stud	270	130
7333-5-TS-50-N	50	5	150 KHz-65 MHz	¼-20 Stud	500	240
7333-5-PJ-50-N	50	5	150 KHz-65 MHz	Plug & Jack	500	240
7333-57-TS-50-N	50	57	14 KHz- 4 MHz	¼-20 Stud	500	240
7333-57-PJ-50-N	50	57	14 KHz- 4 MHz	Plug & Jack	500	240
‡ 8116-50-TS-100-N	100	50	10 KHz-30 MHz	¼-20 Stud	135	120
8309-5-TS-100-N	100	5	150 KHz-50 MHz	¼-20 Stud	500	240
8328-50-TS-50-N	50	50	10 KHz-50 MHz	¼-20 Stud	270	130
‡ 8610-50-TS-100-N	100	50	10 KHz-30 MHz	¼-20 Stud	500	240
8616-5-TS-200-N	200	5	150 KHz-50 MHz	3/8-16 Stud	270	130
8616-50-TS-200-N	200	50	10 KHz-30 MHz	3/8-16 Stud	270	130
F.C.C. PART 15 AND PART 18						
6516-5-TS-10-BNC	10	5	150 KHz-25 MHz	8-32 Stud	270	130
6516-57-TS-10-BNC	10	57	14 KHz- 4 MHz	8-32 Stud	270	130
6338-5-TS-50-N	50	5	150 KHz-65 MHz	¼-20 Stud	270	130
6338-5-PJ-50-N	50	5	150 KHz-65 MHz	Plug & Jack	270	130
8012-50-R-24-BNC	24	50	10 KHz-50 MHz, Dual	A.C. Recept. & Plug	135	120
8028-50-TS-24-BNC	24	50	10 KHz-50 MHz, Single	Binding Posts	270	130
8308-50-RR-24-BNC	24	50	10 KHz-50 MHz, Dual w/Relay Control	A.C. Recept. & Plug	135	120
8309-5-TS-100-N	100	5	150 KHz-50 MHz, Single	¼-20 Stud	500	240
8328-50-TS-50-N	50	50	10 KHz-50 MHz, Single	¼-20 Stud	270	130
‡ 8610-50-TS-100-N	100	50	10 KHz-30 MHz, Single	¼-20 Stud	500	240
8616-50-TS-200-N	200	50	10 KHz-30 MHz	3/8-16 Stud	270	130
TEMPEST						
6338-5-TS-50-N	50	5	150 KHz-65 MHz	¼-20 Stud	270	130
6338-5-PJ-50-N	50	5	150 KHz-65 MHz	Plug & Jack	270	130
6338-57-TS-50-N	50	57	14 KHz- 4 MHz	¼-20 Stud	270	130
6338-57-PJ-50-N	50	57	14 KHz- 4 MHz	Plug & Jack	270	130
6330-100-TS-50-N	50	100	10 KHz- 4 MHz	¼-20 Stud	270	130
6330-100-PJ-50-N	50	100	10 KHz- 4 MHz	Plug & Jack	270	130
6330-250-TS-50-N	50	250	8 KHz- 4 MHz	¼-20 Stud	270	130
6330-250-PJ-50-N	50	250	8 KHz- 4 MHz	Plug & Jack	270	130
6330-600-TS-50-N	50	600	7.5 KHz- 5 MHz	¼-20 Stud	270	130
6330-600-PJ-50-N	50	600	7.5 KHz- 5 MHz	Plug & Jack	270	130
7225-1 (BNC)	10	—	5 KHz- 1 GHz	Binding Posts	270	130
‡ 8116-50-TS-100-N	100	50	10 KHz-30 MHz	¼-20 Stud	270	130
‡ 8116-100-TS-100-N	100	100	10 KHz- 4 MHz	¼-20 Stud	270	130
‡ 8116-250-TS-100-N	100	250	8 KHz- 4 MHz	¼-20 Stud	270	130
8208-330/990-TS-10-BNC	10		Switch selects 330, 660 or 990 uH	Binding Posts	270	130
8615-2-TS-100-N	100	2	1 MHz- 1 GHz	¼-28 Stud	270	130
8616-5-TS-200-N	200	5	150 KHz-50 MHz	3/8-16 Stud	270	130
8616-50-TS-200-N	200	50	10 KHz-30 MHz	3/8-16 Stud	270	130
V.D.E. and C.I.S.P.R. STYLES (50 OHM)						
§ 8012-50-R-24-BNC	24	50	10 KHz-50 MHz, Dual	A.C. Recept. & Plug	135	120
§ 8028-50-TS-24-BNC	24	50	10 KHz-50 MHz, Single	Binding Posts	270	130
‡§ 8116-50-TS-100-N	100	50	10 KHz-30 MHz, Single	¼-20 Stud	270	130
§ 8308-50-RR-24-BNC	24	50	10 KHz-50 MHz, Dual w/Relay Control	A.C. Recept. & Plug	135	120
# 8410-250-R-24	24	250	Choke for use with 8012-( )	A.C. Recept. & Plug	135	120
8602-50-TS-50-N	50	50	10 KHz-50 MHz, Single w/250 uH Filter	¼-20 Stud	270	130
‡§ 8610-50-TS-100-N	100	50	10 KHz-30 MHz, Single	¼-20 Stud	500	240
8611-50-TS-10-N	10	50	10 KHz-30 MHz, Single w/250 uH Filter	Binding Posts	270	130

‡ With 115 V 50-60 Hz Ventilating Fan § Without 250 uH Filter Circuit # Use with 8012-( ) for V.D.E. applications

An ICD is also a high-pass filter; thus some distortions of the induced current are inevitable (Ref. 1, Para. 5.6.4). Moreover, to minimize distortion, the ICD frequency response should be kept flat up to one octave over the characteristic frequency. Thus, the ICD should have a flat frequency response up to 200 MHz.

ICD — THEORY OF OPERATION

The coupling of electrical power by means of inductive elements is explained by the term electrical transformation. It utilizes primary and secondary copper windings coupled by the transformer's core — air, ferrite or iron. In fact, the inductive coupling device (ICD) is a current transformer which has a primary of one to three turns and a secondary of one turn, the test sample's interconnecting wire or cable. The transformer's core is a toroidal iron or ferrite core. Figure 3 portrays a typical inductive coupling device.

For a better understanding of the ICD's performance, Figure 4 illustrates a simplification of the equivalent network of the current transformer.

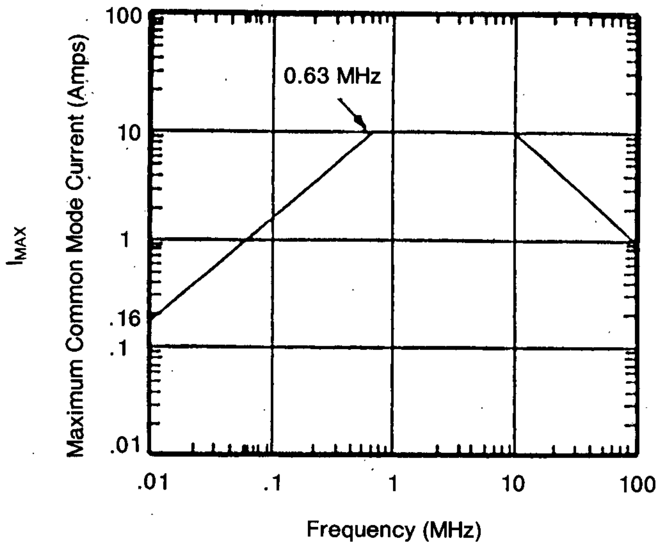
V_g = Generator output voltage
R_g = Generator output impedance
L_p = Primary inductance
L_{ps} = Leakage inductance between the primary and the secondary
C_{ps} = Equivalent shunt capacitance between the primary and the secondary
R_L = Load impedance

The coupling efficiency, K, of the transformer is approximately given by the following equation:

$$K = 1/(1 + L_{ps}/L_p) \quad (1)$$

To obtain maximum coupling ($K \rightarrow 1$), the leakage inductance shall be minimized and the primary inductance maximized.

The shunt capacitor, C_{ps}, might affect both the amount of current which is driven through the load and the signal wave shape fidelity. Note that the capacitive current coupled to a wire flows in the direction opposite to the wire's end terminations. Simultaneously, the inductive current is circulating in one direction only. The total current throughout the load is a complex superposition of both current components. Ac-



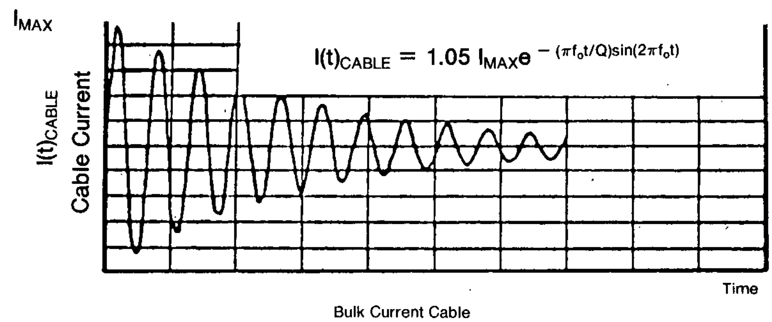


Figure 1. Limit for CS10/CS11.

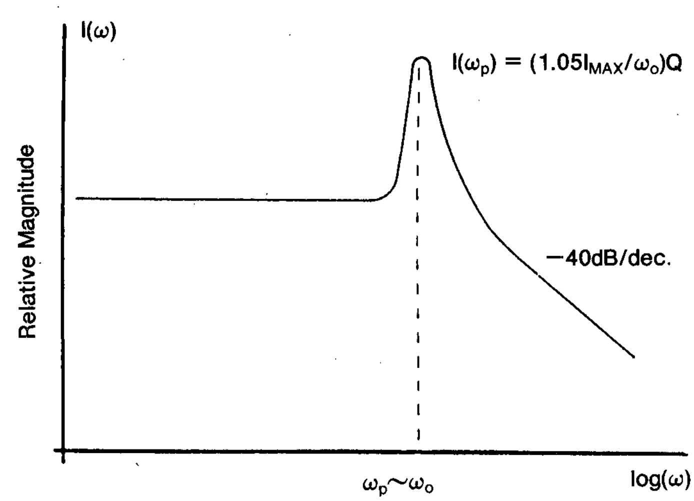


Figure 2. Damped Sinusoid Amplitude Spectrum.

NOTES:

The applicability of each requirement may vary by procuring activity. These are samples only as to the variances; this list is not complete.

1. Only for equipment installed in aircraft having ASW capability and Navy equipment and subsystems for use on aircraft and having ULF equipment and subsystems.
2. Applicable only when specified by contract.
3. Limits vary based upon current and procuring activity.
4. Limits vary based upon current.
5. LISNs required for Army procurements.
6. Different limits for AC and DC power-lines.
7. N/A for Army procurements.
8. Application varies by procuring activity.
9. N/A ±5% of power frequency.
10. N/A on AC lines for Army procurements.
11. May be deleted by procurement activity if circuit sensitivity ≤100 mV (for Navy AC leads only).

11A. Conducted switching spikes ≥50 μs. Must meet transient requirements of MIL-STD-704.

11B. Special requirement for shielded inter/control leads.

12. Must be applied at connector input, not power cord.
13. For Navy procurements only.
14. Limits vary based upon procuring activity.
15. Limited applicability above 10 GHz.
16. Limits vary based upon intended environment.
17. Applicable only on Navy procurements.
18. N/A to generators >240 kVA.
19. Applicable only for Group 1 devices.
20. Applicable only when electronic controls and circuits are in use.
21. For Navy interconnecting control leads providing AC/DC power to/from test sample as well as equipment system and subsystem AC and DC power leads.
22. Special limits imposed by procuring activity.
23. Called out in procurement document for Army.
24. Army only.

BREAKDOWN OF MIL-STD-461C PARTS

PART 1	Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnet Interference	**PART 6**	Requirements for Equipments and Subsystems Installed in Submarines
PART 2	Requirements for Equipment and Subsystems Installed Aboard Aircraft, Including Associated Ground Support Equipment	**PART 7**	Requirements for Ancillary of Support Equipments and Subsystems Installed in Noncritical Ground Areas
PART 3	Requirements for Equipment and Subsystems Aboard Spacecraft and Launch Vehicles, Including Associated Ground Support Equipment	**PART 8**	Requirements for Tactical and Special Purpose Vehicles and Engine Driven Equipment
PART 4	Requirements for Equipment and Subsystems Installed in Ground Facilities (Fixed and Mobile, Including Tracked and Wheeled Vehicles)	**PART 9**	Requirements for Engine Generators and Associated Components, Uninterruptible Power Sets (UPS) and Mobile Electric Power (MEP) Equipment Supplying Power to or Used in Critical Areas
PART 5	Requirements for Equipments and Subsystems Installed in Surface Ships	**PART 10**	Requirements for Commercial Electrical and Electromechanical Equipment

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MIL-STD-461C
AUGUST 1986

REQUIREMENTS TREE*

CONDUCTED

SUSCEPTIBILITY

		PARTS 2	3	4	5	6	7
CS01[9,11]	Pwr Leads 30 Hz-50 kHz	X[10]	X	X	X	X	X
CS02[12]	Pwr-Inter. Leads 50 kHz-400 MHz	X	X	X	X[21,22]	X	X[2]
CS03	Intermodulation 15 kHz-10 GHz	X	X[8]	X[8]	X	X	X[2]
CS04	Rej. of Undes. Signal 30 Hz-20 GHz	X	X[8]	X[8]	X	X	X
CS05	Cross Modulation 30 Hz-20 GHz	X	X[8]	X[8]	X	X	X
CS06	Spike-Pwr Leads	X	X	X	X	X	X
	100V, 10 µs			X			
	200V, .15 µs	X[7]	X[7]	—	—	—	—
	200V, 10 µs	X	X	—	—	—	—
	400V, 5 µs	—	—	X[7]	X[21]	X	X
CS07	Squelch Circuits	X	X	X	X	X	
CS09[13]	Structure Current 60 Hz-100 kHz	X		X	X	X	
CS²10[8]	Damped Sine. Trans. Pins	X[17]		X	X	X	
CS11	Damped Sine. Trans. Cables	X[17]		X	X	X	

EMISSION

		PARTS 2	3	4	5	6	7	9	10
CE01	Pwr & Interconnect Up to 15 kHz	X[1]	X[2]	X[3]	X[4]	X[4]			
CE03	Pwr & Interconnect 15 kHz-50 MHz	X[5]	X[5]	X[3,5] [11B,6]	X[6] [11B]	X	X[3,6,7]		
CE06	Antenna Terminals								
	10 kHz-26 GHz Receivers	X	X	X	X	X	X	—	—
	XMTRS (Key Up)	X	X	X	X	X	X	—	—
	XMTRS (Key Down)	X[8]	X[8]	X[8]	X	X	X		
CE07	Transients Time Domain (Pwr)	X[7,11A]	X	X			X[2]		
UM04	Pwr Lines 15 kHz-50 MHz							X[18]	
UM05	Pwr Lines 50 kHz-50 MHz								X[19]

RADIATED

SUSCEPTIBILITY

		PARTS 2	3	4	5	6	7	9	10	8
RS01	"H" Field 30 Hz-50 kHz	X[1]		X[8,14]	X	X				
RS02	"H" Field Pwr Frequency	X[7]	X	X[13,23]	X	X	X[2]			
	Spikes 100V, 10 µs			X						
	200V, .15 µs	X[7]	X[7]	—	—	—	—	—	—	—
	200V, 10 µs	X	X	—	—	—	—	—	—	—
	400V, 5 µs	—	—	X[13]	X	X	X	—	—	—
RS03[15]	"E" Field 14 kHz-40 GHz	X[14]	X	X[14]	X[16]	X	X			
RS05	Electromagnetic Field Transients	X		X	X	X				
UM04	"E" Field 2 MHz-10 GHz							X[20]		
UM05	"E" Field 150 kHz-400 MHz								X[19,20]	
UM03	"E" Field 2MHz-10 GHz									X[20]

EMISSION

		PARTS 2	3	4	5	6	7	8	9	10
RE01	"H" Field 30 Hz-50 kHz	X[1]	X[2]	X[8]	X	X				
RE02	"E" Field 14 kHz-10 GHz	X[14]	X	X[14]	X	X	X[14]			
RE03[8]	Spur. & Harmonics Radiated Technique	X	X	X	X	X	X			
UM03	"E" Field 150 kHz-10 GHz							X		
UM04	"E" Field 14 kHz-1000 MHz								X	
UM05	"E" Field 150 kHz-10 GHz									X[19]

*COMPILED FROM MIL-STD-461C DATED 4 AUGUST, 1986
SUPERCEDES ALL PREVIOUS ISSUES

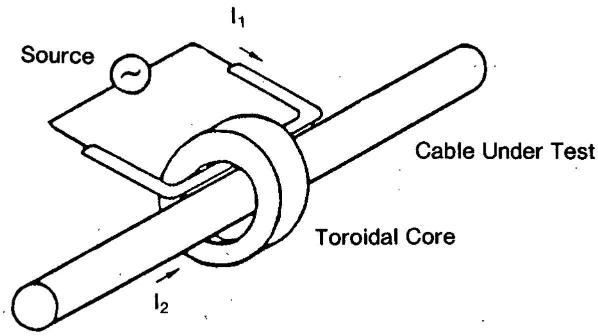

Figure 3. Typical Inductive Coupling Device.

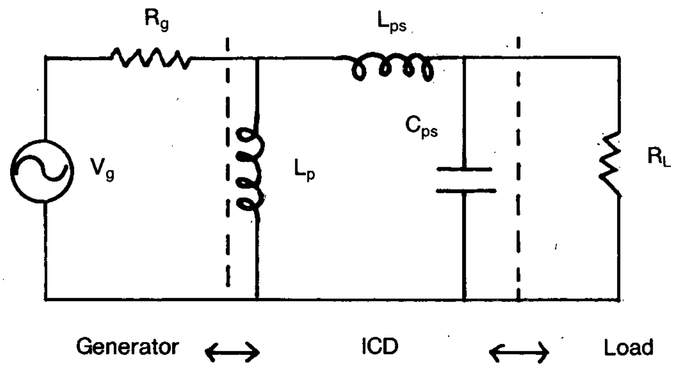

Figure 4. Equivalent Network of the Current Transformer.

cordingly, for a high frequency transformer design, it is mandatory to minimize both the leakage inductance and the shunt capacitance, and to maximize the primary inductance. The equivalent primary inductance (inductance measured when the secondary is open) is proportional to:

$$L = \mu N^2 A/l \text{ Henrys} \quad \textbf{(2)}$$

where:

μ = Core permeability factor (henry/m)

N = Primary number of turns

A = Core cross-sectional area (m^2)

l = Mean length of magnetic circuit (m)

The parameters of Equation 2 show how to increase the primary inductance. This can be accomplished by selecting a core with maximum permeability, maximum cross-sectional area, and minimum magnetic circuit length. The number of turns is limited to a maximum of three or less, since the upper cut-off frequency decreases by the coil length, the induced voltage by $1/N$ and the leakage inductance by N^2. Another consideration is the core magnetic saturation. To provide signal-shape fidelity, the core should operate in the linear section of its hysteresis curve. In other words, the magnetic flux density, B, must be kept smaller than the saturation value, B_{sat}. To enable distortionless coupling of the transient (i.e., damped sinusoid), the following inequality must be satisfied:

$$V_{peak} < NB_{sat}A/t_r \quad \textbf{(3)}$$

where:

V_{peak} = Transient peak amplitude (volts)

t_r = Transient rise-time or the quarter of the cycle duration of the damped sine.

The following paragraphs address a method of winding the ICD's core, selection of the magnetic core material, and the core's physical considerations.

METHOD OF WINDING THE ICD CORE

Reviewing the ICD design considerations that are briefly discussed in the previous paragraphs, the primary winding should minimize:

- the number of turns,
- leakage inductance, and
- shunt capacitance between the primary and secondary.

On the other hand, it should maximize the equivalent inductance of the primary.

Other alternatives for reducing the leakage inductance include:

- building a physically smaller coil;
- increasing the width of the winding;
- using interleaved windings, i.e., by dividing the primary coil into two sections and placing a secondary winding between the two sections; and
- reducing the space between the primary and the secondary.

Means of minimizing the capacitance include:

- utilizing electrostatic shielding between primary and secondary;
- increasing dielectric thickness (primary coil insulation);
- reducing winding width and, thus, the overlapping area; and
- avoiding large potential differences between winding sections, as the effect of capacitance is proportional to the applied potential squared.

Note: Leakage inductance and capacitance requirements must be compromised since some corrective measures are contradictory. Nevertheless, when electrostatic shielding is utilized, the shunt capacitance is greatly reduced, and the emphasis is on minimizing the leakage inductance, which is preferable.

ICD CORE SELECTION

Core selection is a function of frequency range and transferred power. Figure 1 indicates that the CS10 and CS11 frequency spans four decades and transformed current ratio over 60:1. Therefore, it is most likely that several cores are necessary to obtain inductive coupling capability over the entire frequency range. Inductive coupling of high power requires large cores. However, the smaller a transformer can be made and still meet the low-frequency requirements, the better the transformer will operate at high frequency. These two opposite requirements can be compromised by using a high-permeability core whose permeability will not be significantly degraded at the higher frequency. Also, the core saturation, leakage inductance, and shunt capacitance must be considered.

Briefly, core saturation can be handled by leaving a small air-gap between the two halves of the toroidal core, which is commonly used with the ICD clamp-on type. Shunt capacitance is reduced successfully using a copper partition between the primary and the secondary winding, i.e., an electrostatic shield.

Leakage inductance reduction is achieved by the proper primary winding method of the primary (Method of Winding the ICD Core, above), but still may be greatly affected by the free space volume between the secondary and the primary, which depends on the core length and aperture in respect to the random cable cross-section area forming the secondary.

The selected core material and its physical shape will influence two of the major ICDs' characteristics:

- the frequency bandwidth, and
- the power transfer capability.

As for the current transfer, Figure 1 and the required calibration load of 100 ohms (resistive) can be used for tailoring the power requirements. Fortunately, the required power transfer in the lower frequency range of 10 kHz to 500 kHz is quite modest. Thus, a high frequency core with poor, low-frequency performance, such as ferrites, performs adequately in the high frequency range.

Any core material is characterized by three major parameters: loss factor ($Tan\delta/\mu_i$) vs. frequency; initial permeability (μ_i) vs. frequency; and, initial permeability (μ_i) vs. temperature. Figure 5 depicts these parameters for various types of ferrites.[4]

More data regarding core materials is given in Table 2 (Table 5, Chapter 12 in Reference 5). The column, "Characteristic Property or Application," in Table 2 indicates several materials which may be appropriate for the ICD core. Experiments made with laminated, 4 percent silicon-iron and with 3C8 Ferrite were very promising, and they demonstrated a frequency range wider than expect-

Continued on page 354

Table 2. Data on Metallic Core Materials.

Metal or Alloy	Material or Trade Name	Composition in Percent (remainder is iron)	Characteristic Property or Application	Permeability		Direct-Current Saturation in Kilogauss	Residual Induction in Kilogauss	Coercive Force in Oersteds	Resistivity in $\mu\Omega$-Centimeters	Curie Temperature in Degrees Celsius
				Initial	Maximum					
Silicon–iron*	Silicon–Iron	4 Si	Transformer	400	7 000	20	12	0.5	60	690
	Hypersil Trancor 3X Silectron	3.5 Si	Grain oriented	1 500	35 000	20	13.7	0.1 to 0.3	50	750
	Sendust	9.5 Si, 5.5 Al	High frequency, powder	30 000	120 000	10	5	0.05	80	—
Cobalt–iron*	Hyperco	35 Co, 0.5 Cr	High saturation	650	10 000	24	>13	>1	28	970
	Permendur 2V	49 Co, 2 V		800	4 500	24	14	2	25	980
Nickel–iron*	Perminvar 45–25	45 Ni, 25 Co	"Constant" permeability	400	2 000	15.5	3.3	1.2	20	715
	Perminvar 7–70	70 Ni, 7 Co		850	4 000	12.5	2.4	0.6	15	650
	Conpernik	50 Ni		1 500	2 000	16	—	—	45	—
	Isoperm 36	36 Ni, 9 Cu	High frequency	60	65	—	—	—	70	300
	Isoperm 50	50 Ni		90	100	16	—	—	40	500
Ferrites‡	3C3	MnZi	High-frequency transformers	2 200±20%		4.6	3.5	0.1	60×10^6	150
	3B7 and 3B9	MnZi	High-Q coils	2 300±20%		4.6	3.0	0.2	100×10^6	170
	3D3	NiZi	High-frequency	750±20%		4.7	3.0	0.5	150×10^6	150
	4C4	NiZi	High-Q coils	125±20%		4.1	2.0	4.5	10×10^9	300

* Reprinted by permission from S. R. Hoh, "Evaluation of High-Performance Core Materials (Part 1)," *Tele-Tech and Electronic Industries*, vol. 12, pp. 86–89, 154–156; October 1953.

† $B_m = 10\ 000$ gauss.

‡ Data furnished by Ferroxcube Corporation of America, Saugerties, N.Y.

Note 1—The table shows characteristics as listed by the manufacturers. The parameters of different lots of material may vary considerably from the above values. In the cases of residual induction and coercive force, the difference may amount to 50 percent.

Note 2—For information on ferrite materials, see Table 23 in Chapter 4, Properties of Materials.