八、用分離器診斷傳導性 EMI

(Diagnosis Using Separator)

Tests Using a Noise Separator

Test # 1: No filter is inserted.

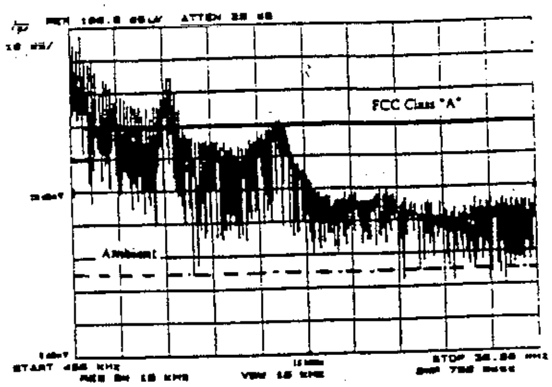


Figure 5(a) Total Noise

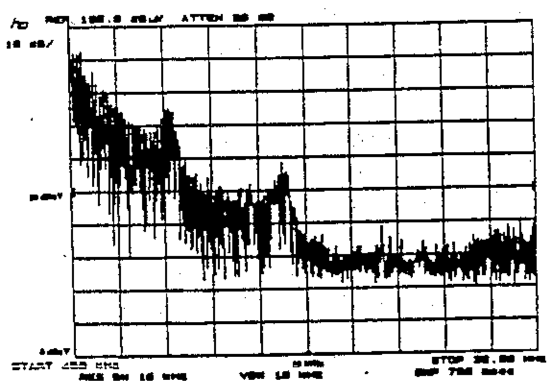


Figure 5(b) DM Noise

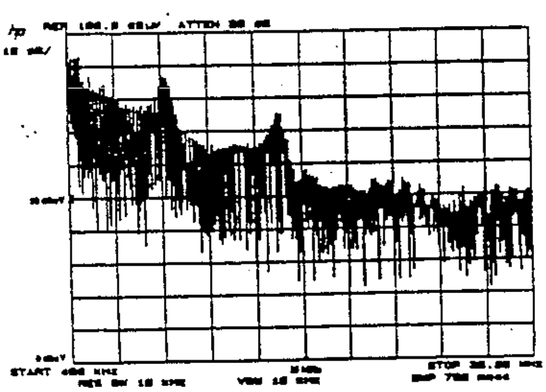


Figure 5(c) CM Noise

Test # 2: "Tests Using Noise Separator"

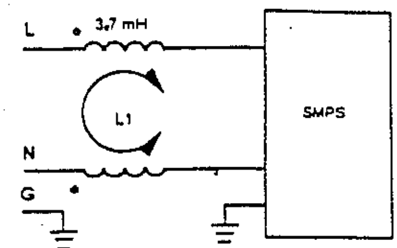


Figure 6(a) Test 2 Diagram

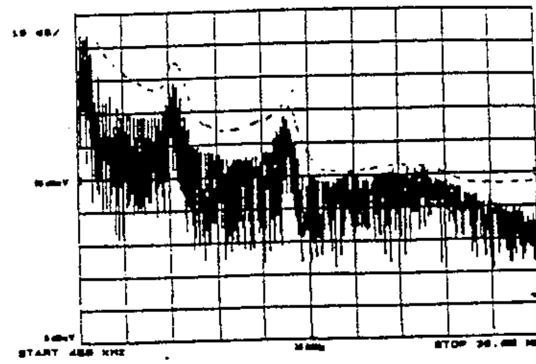


Figure 6(b) Total Noise

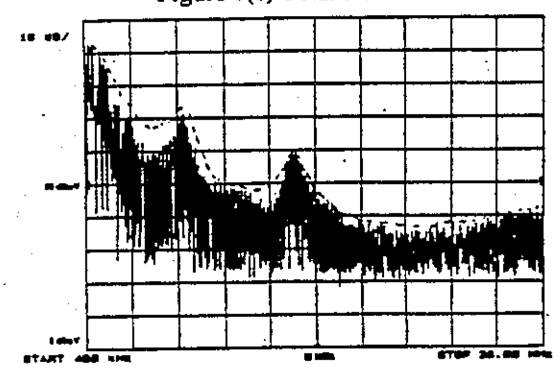


Figure 6(c) DM Noise

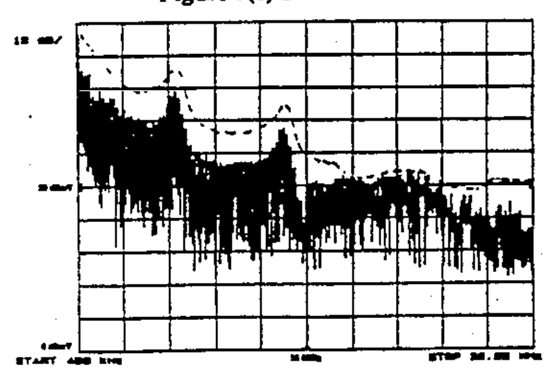


Figure 6(d) CM Noise

Test # 3:

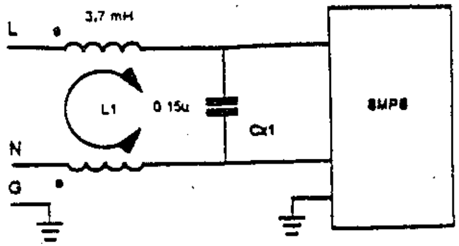


Figure 7(a) Test 3 Diagram

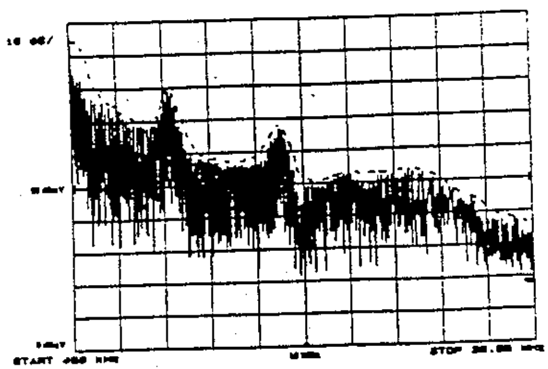


Figure 7(b) Total Noise

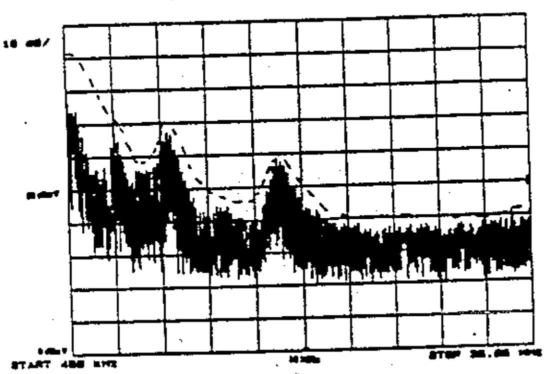


Figure 7(c) DM Noise

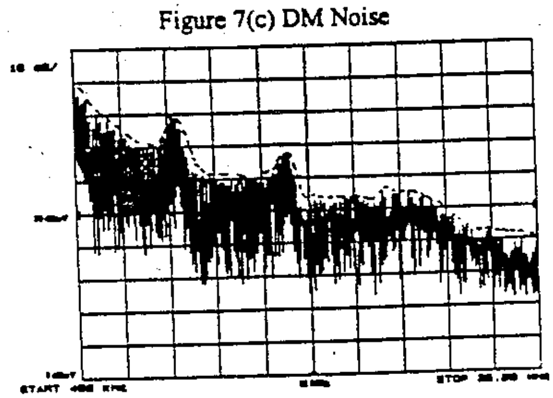


Figure 7(d) CM Noise

Test # 4:

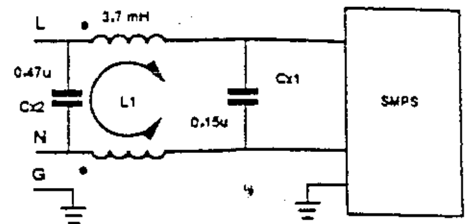


Figure 8(a) Test 4 Diagram

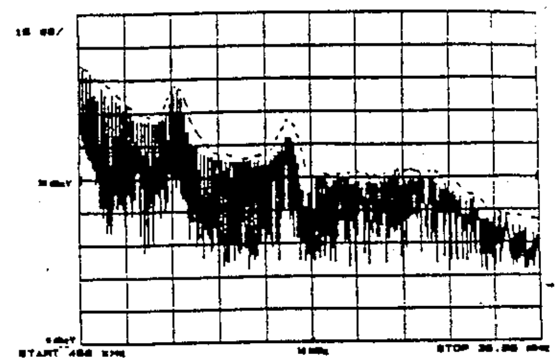


Figure 8(b) Total Noise

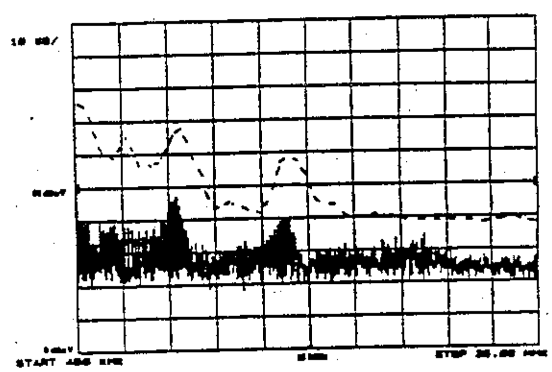


Figure 8(c) DM Noise

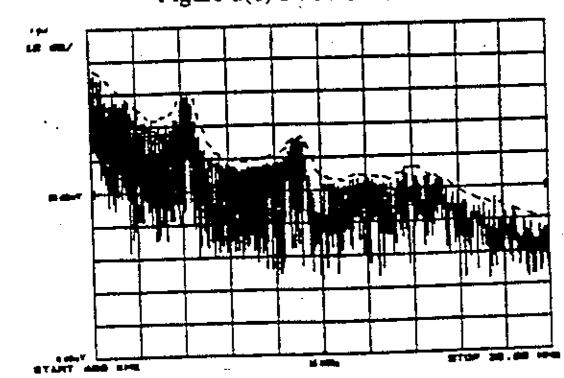


Figure 8(d) CM Noise

Test # 5:

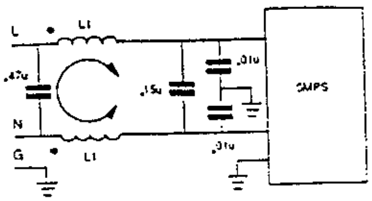


Figure 9(a) Test 5 Diagram

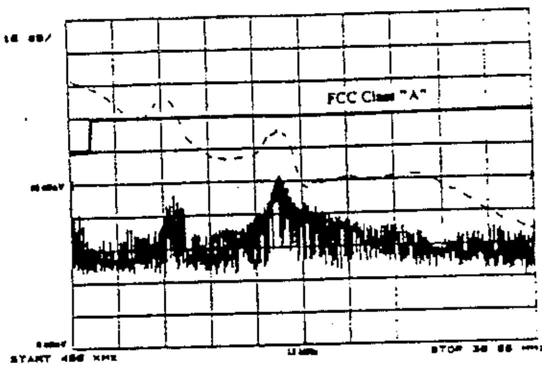


Figure 9(b) Total Noise

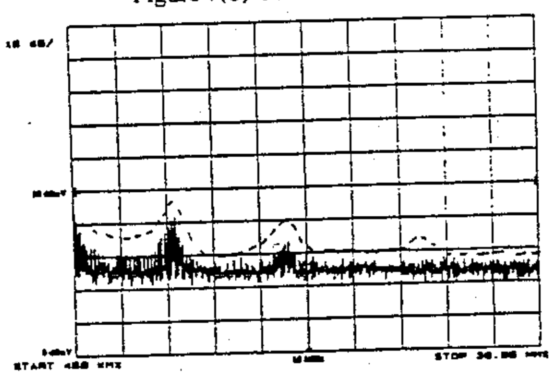


Figure 9(c) DM Noise

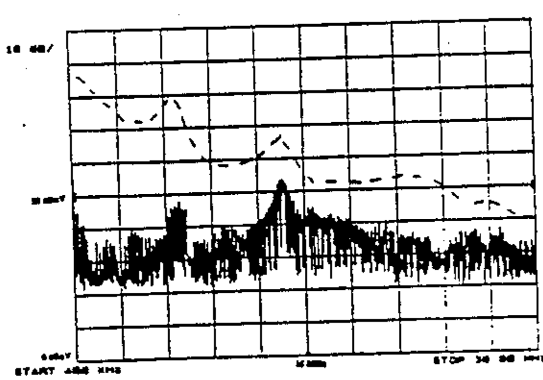


Figure 9(d) CM Noise

Test # 6:

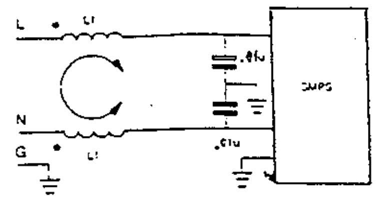


Figure 10(a) Test 6 Diagram

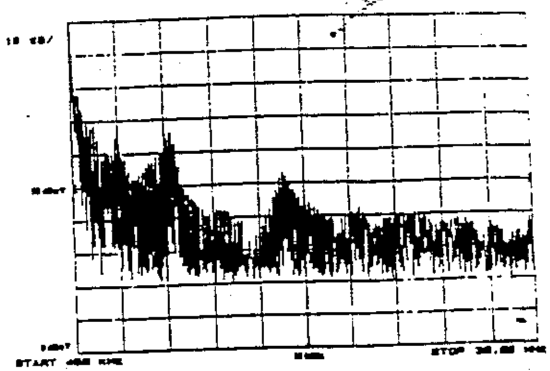


Figure 10(b) Total Noise

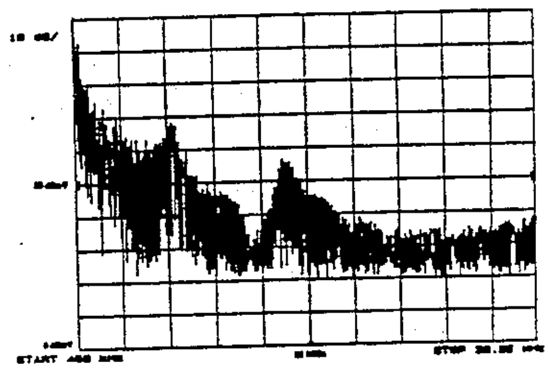


Figure 10(c) DM Noise

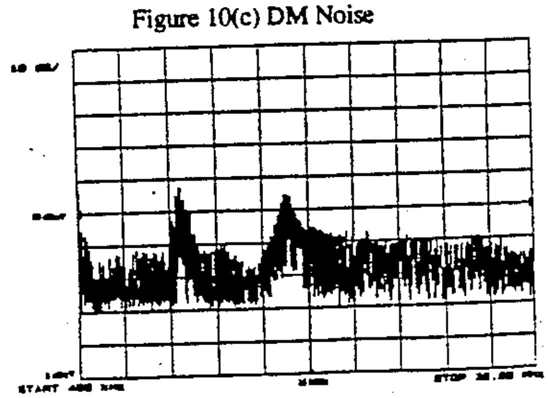


Figure 10(d) CM Noise

Test # 7:

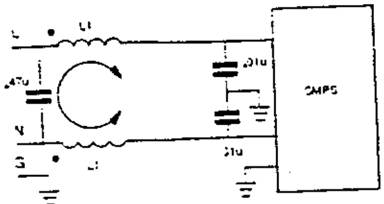


Figure 11(a) Test 7 Diagram

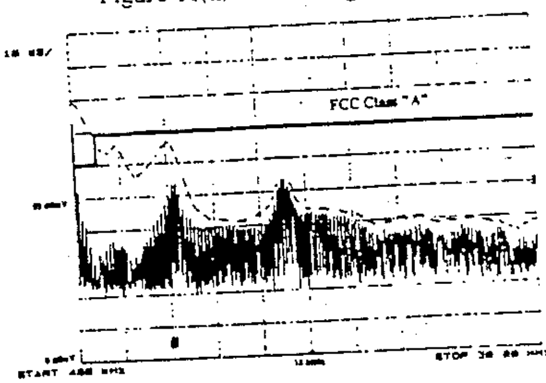


Figure 11(b) Total Noise

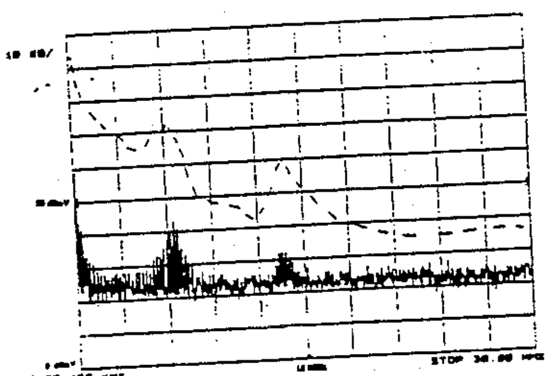


Figure 11(c) DM Noise

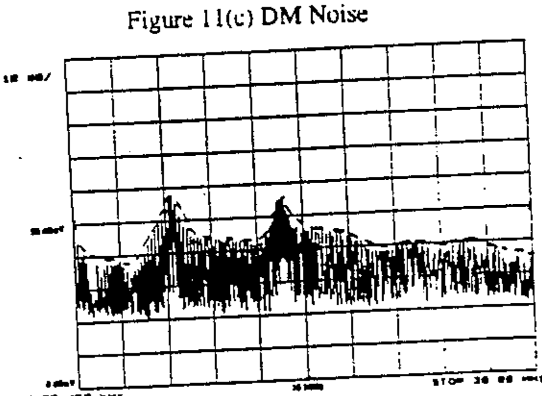


Figure11(d) CM Noise

Test # 8:

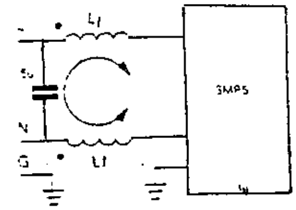


Figure 12(a) Test 8 Diagram

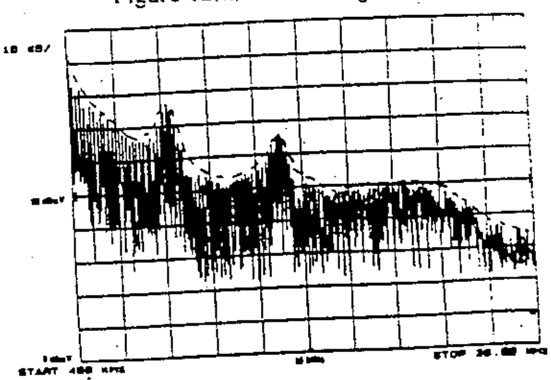


Figure 12(b) Total Noise

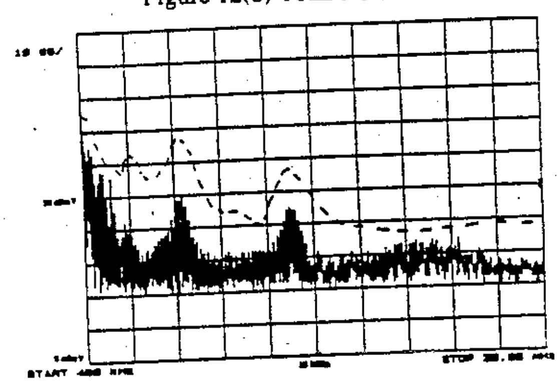


Figure 12(c) DM Noise

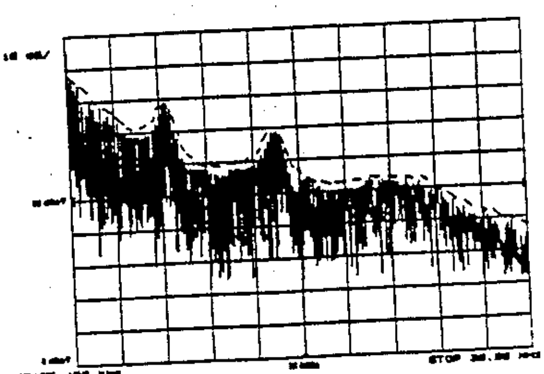


Figure 12(d) CM Noise

Test # 9:

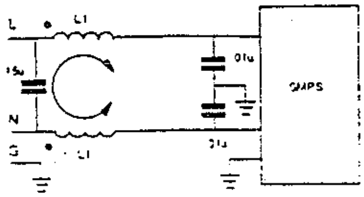


Figure 13(a) Test 9 Diagram

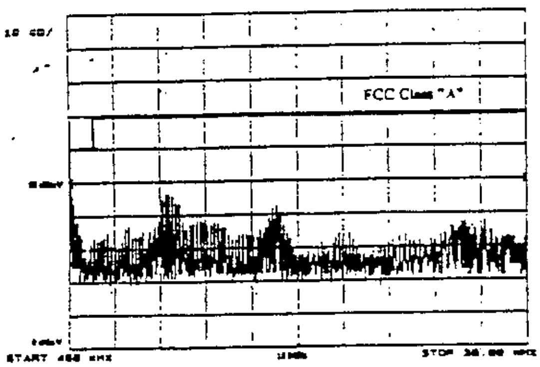


Figure 13(b) Total Noise

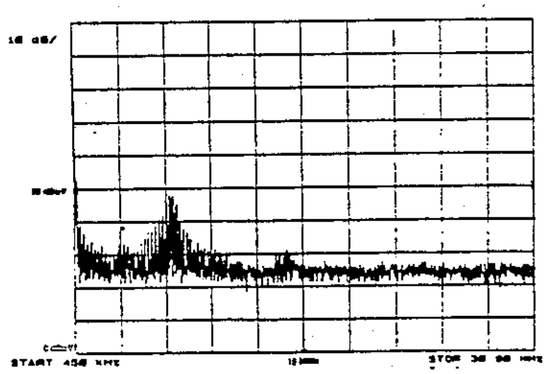


Figure 13(c) DM Noise

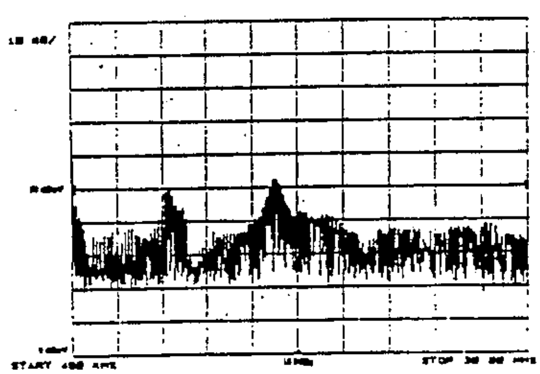


Figure 13(d) CM Noise

Test # 10:

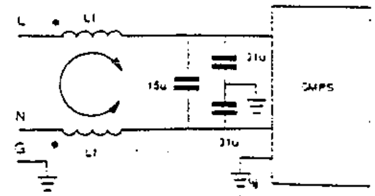


Figure 14(a) Test 10 Diagram

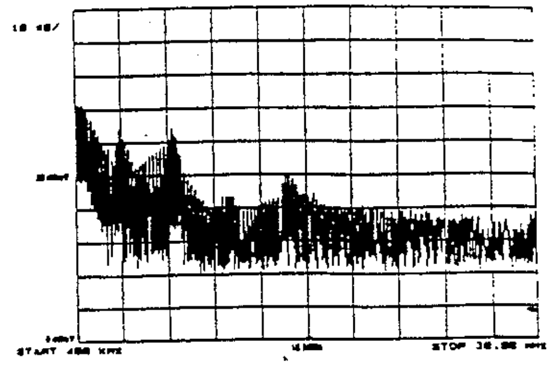


Figure 14(b) Total Noise

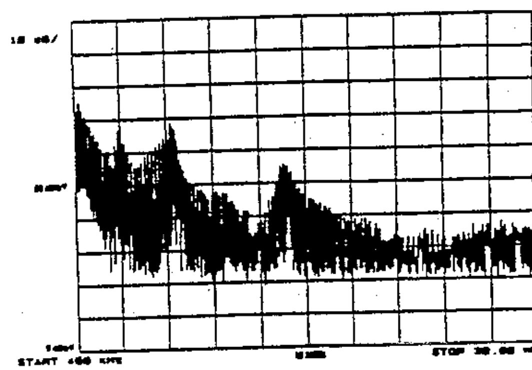


Figure 14(c) DM Noise

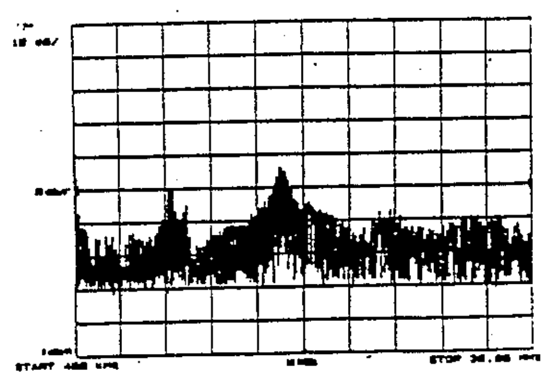


Figure 14(d) CM Noise

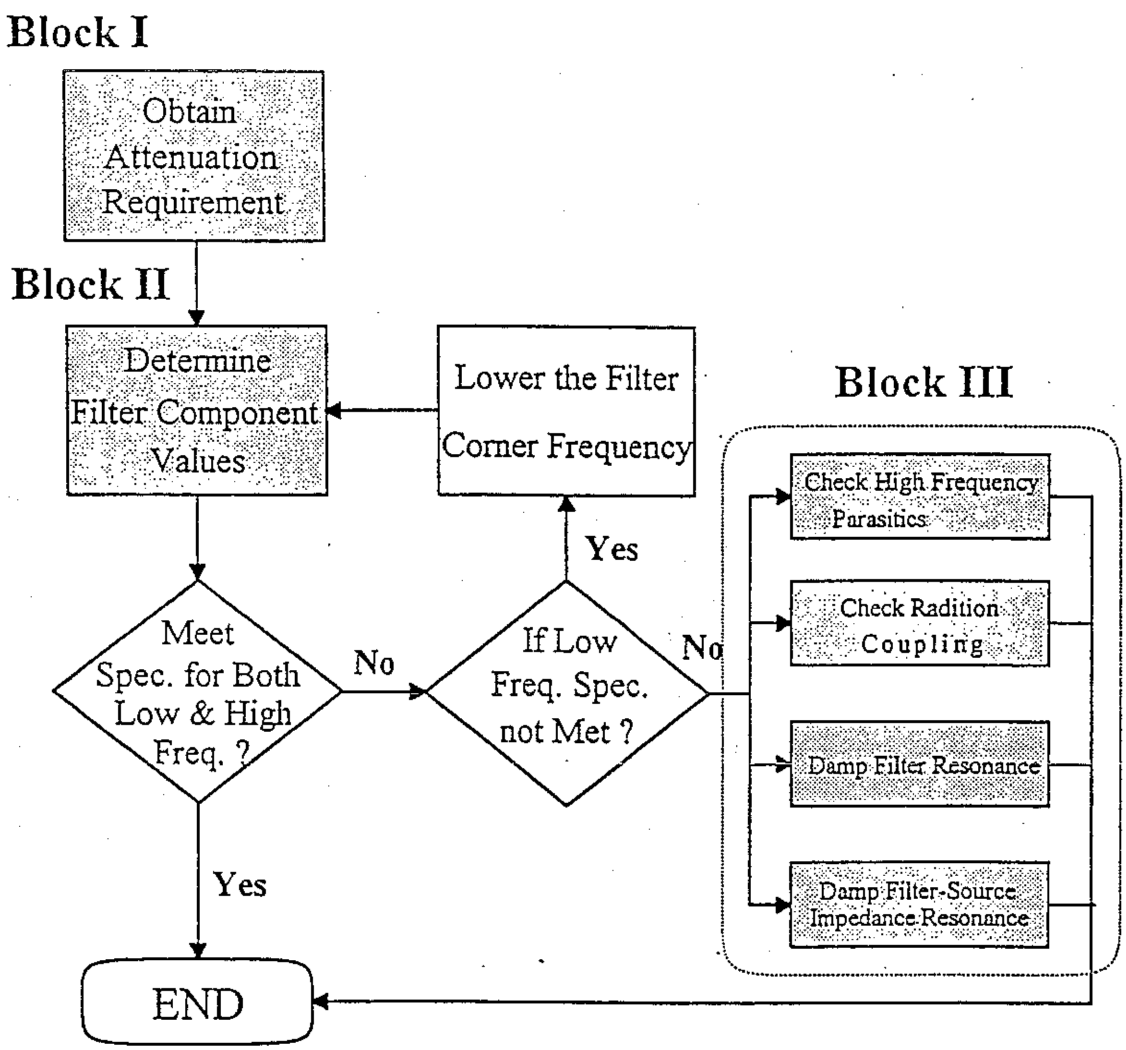
Difficulties of EMI Filter Design

- Base-line (no filter) EMI unknown without measurement
- Noise source impedance unknown
- High-frequency effects difficult to predict

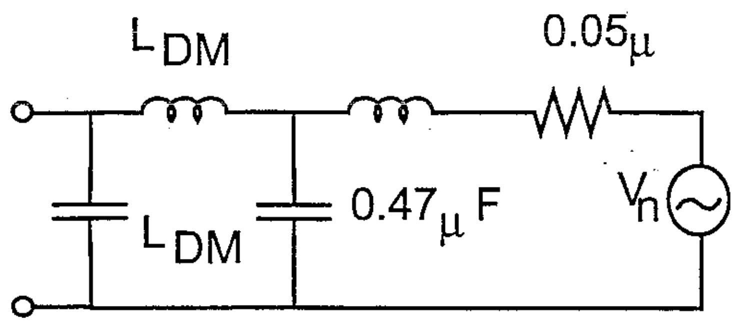
九、濾波器設計

(Filter Design)

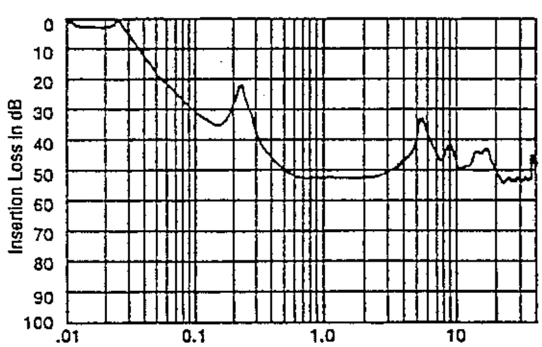
Filter Design Flow Chart



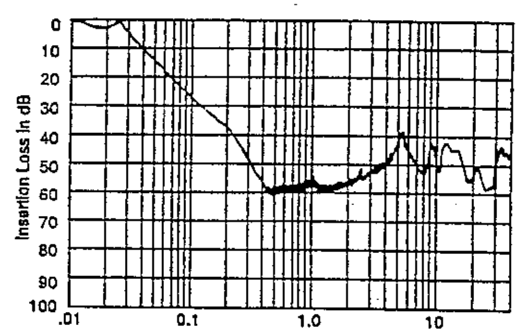
Filter-Source Impedance Resonance



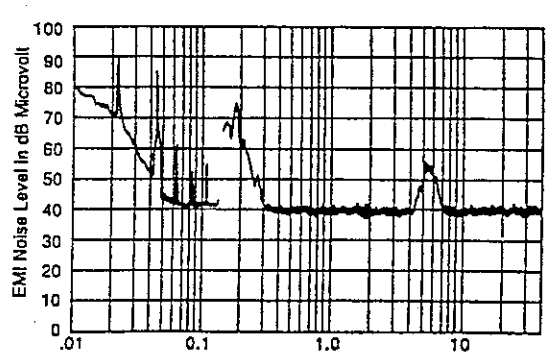
Attenuation

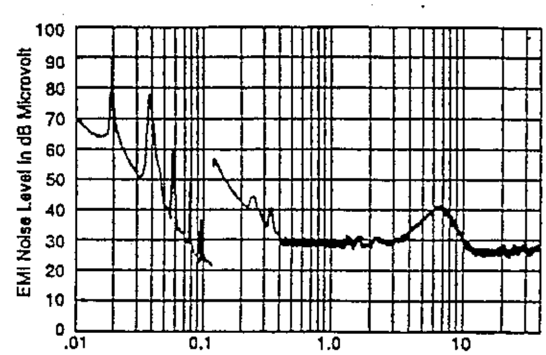


EMI



Before damping





After damping

*Permission fro Mark Nave, EMC Service

A Procedure for Determining Filter Component Values

Step 1: Measure base-line (i.e. without filter) common-mode EMI noise (V_{CM}) and differential-mode EMI noise (V_{DM}) using a Noise Separator.

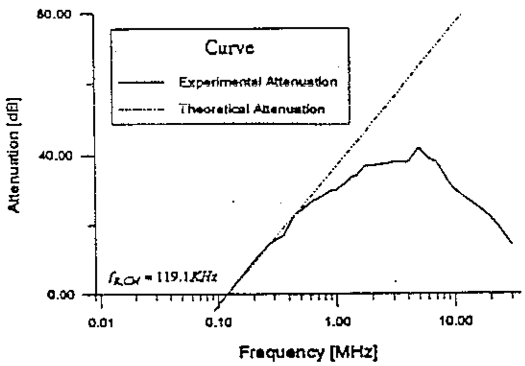
Step 2: Determine CM attenuation requirement $V_{req,C}$ and DM attenuation requirement $V_{req,DM}$

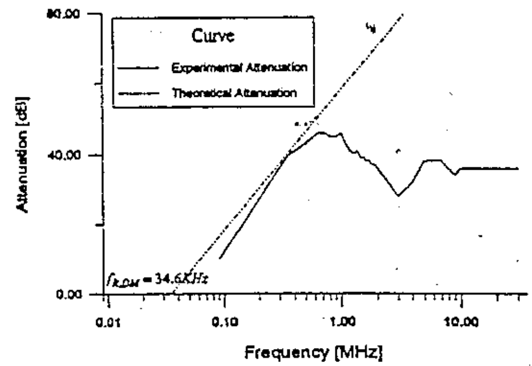
$$\left(V_{req,CM}\right)_{dB} = \left(V_{CM}\right)_{dB} - \left(V_{Limit}\right)_{dB} + 3dB$$

$$\left(V_{req,DM}\right)_{dB} = \left(V_{DM}\right)_{dB} - \left(V_{Limit}\right)_{dB} + 3dB$$

where $(V_{CM})_{dB}$ and $(V_{DM})_{dB}$ are obtained from Step 1.

Step 4: Determine filter corner frequencies.





Step 4: Determine filter component values.

(a) CM component L_C and C_y
C_y is determined by leakage current requirement

$$L_C = \left(\frac{1}{2\pi \cdot f_{R,CM}}\right)^2 \cdot \frac{1}{2 \cdot C_y} \qquad \text{...Eq.(1)}$$

(b) DM component L_D, C_{X1} and C_{X2}

$$C_{X1} = C_{X2} = C_{DM} = \left(\frac{1}{2\pi \cdot f_{R,DM}}\right)^2 \cdot \frac{1}{L_{DM}}$$

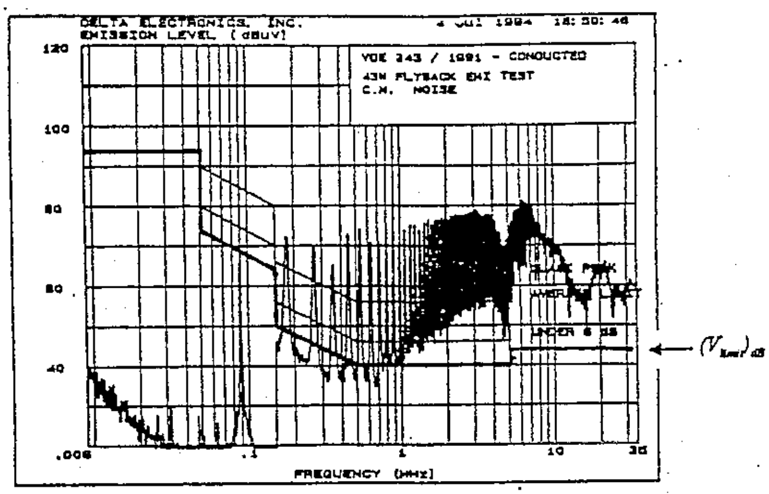
...Eq.(2)

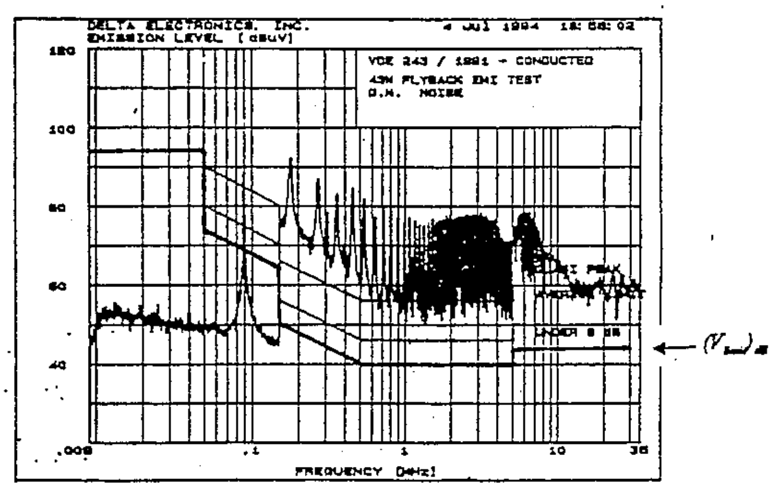
Converter - filter interaction should be taken into consideration in choosing L_{DM} and C_D

Design Example 1

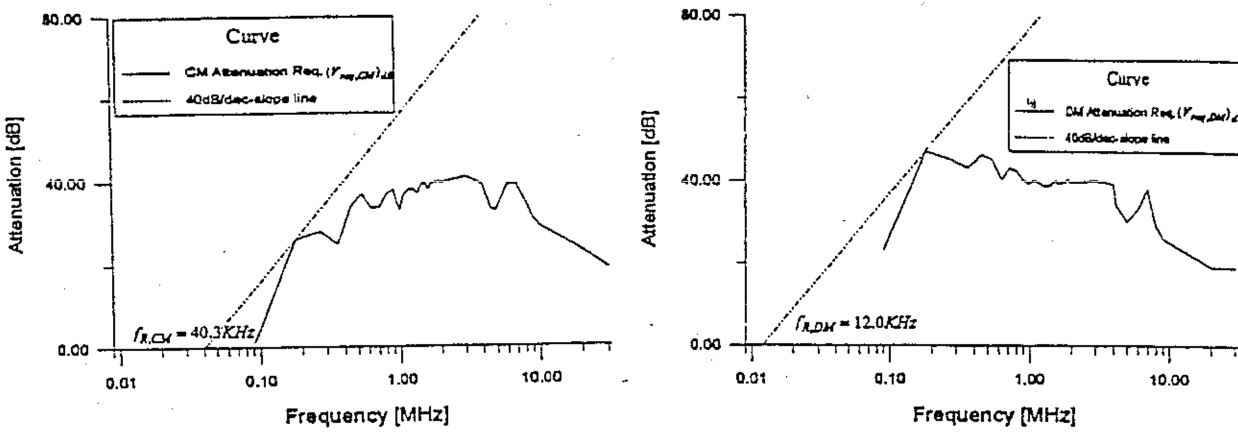
Example 1: Design an EMI filter for an off-line (90V-260V) flyback converter switching power supply (90khz, 43w output), to meet a VDE limit. For proper margin, under 6dB limit is used in the design.

Step 1: Base Line EMI Measurement





Step 2: Plot Filter Attenuation Requirement



Step 3: Determine Corner Frequency

$$f_{R,CM} = 40.3\text{KHz} \quad \text{and} \quad f_{R,DM} = 12.0\text{KHz}$$

Step 4a: Determine C_y, and L_C. Use $C_y = 3300\text{pF}$, calculate L_C according to Eq.(1),

$$L_C = \left[\frac{1}{2\pi\left(40.3\text{x}10^3\right)}\right]^2 \cdot \frac{1}{2 \cdot 3300\text{x}10^{-12}} = 2.36\text{mH}$$

Select $L_C = 2.4\text{mH}$, and the leakage inductance $L_{leakage} = 36\mu\text{H}$ can be obtained by measurement.

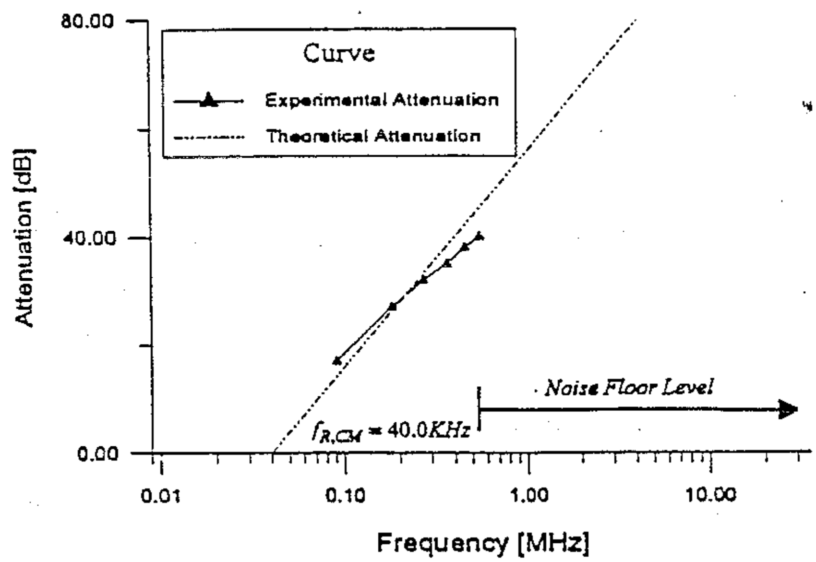
Step 4(b) *Determine* C_{X1}, C_{X2} and L_{DM}.

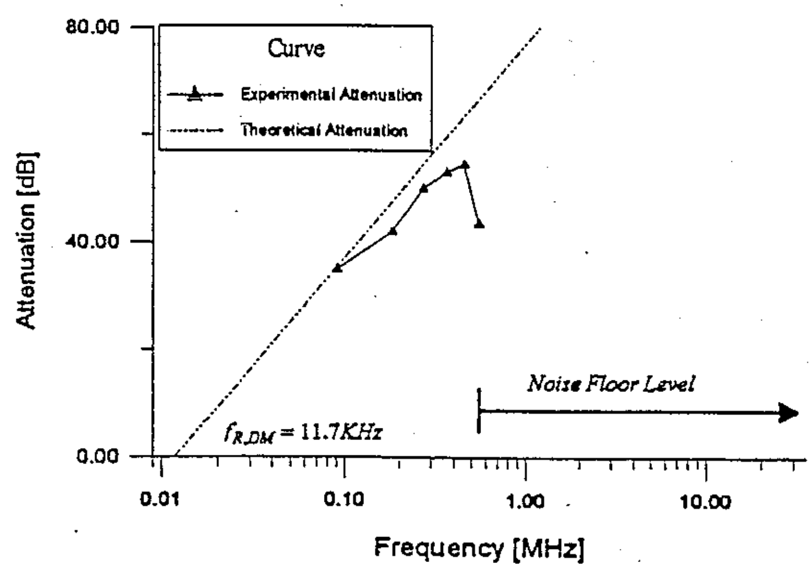
Using $f_{R,DM}$ = 12.0KHz *in Eq.(2), there are infinite sets of solution for* L_{DM} *and* C_{DM} *Three sets of solutions are listed for discussion in the following:*

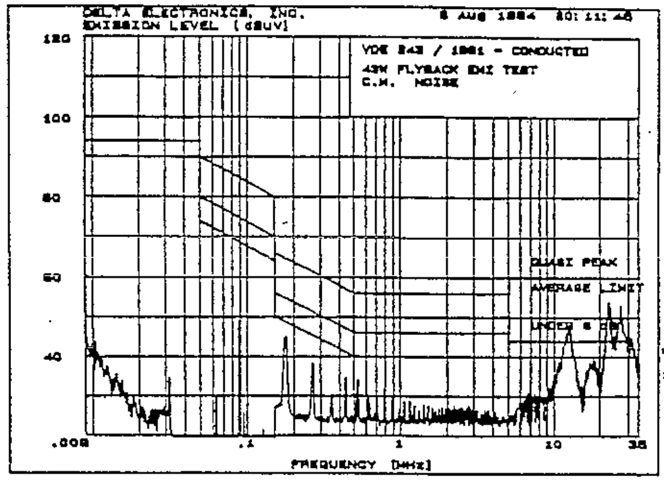
(1) Use the leakage inductance as the DM choke. Since $L_{DM} = L_{leakage} = 36\mu H$, then $C_{CM}(= C_{X1} = C_{X2}) = 4.75\mu H$ which is an impractical calue for line-voltage rated filter capacitor. The physical volume of such a capacitor is much to bulky.

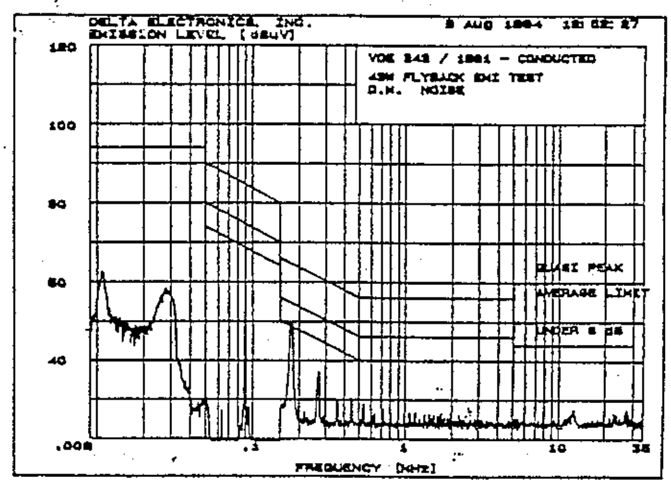
(2) If C_{DM} are chosen to be 0.47μF, a commonly available filter capacitor value, then $L_{DM} = 374\mu H$ and
$$L_D = \frac{L_{DM} - L_{leakage}}{2} = 169\mu H,$$
a practical inductance value. Select $L_D = 180\mu H$.

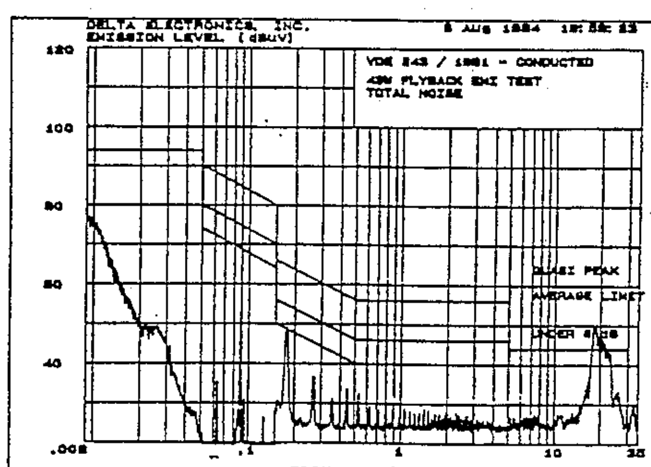
(3) If $C_{DM} = 0.22\mu F$, then $L_{DM} = 800\mu H$ and $L_D = 382\mu H$, a practical value also. Select $L_D = 380\mu H$.

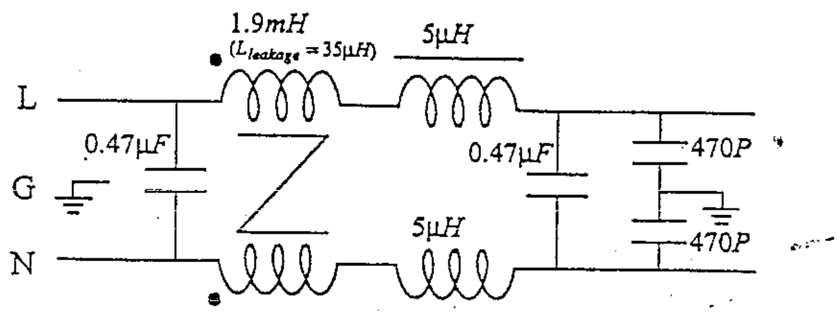

80.00
40.00
0.00
Attenuation [dB]
Curve
Experimental Attenuation
Theoretical Attenuation
Noise Floor Level
$f_{R,CM}$ = 40.0KHz
0.01
0.10
1.00
10.00
Frequency [MHz]

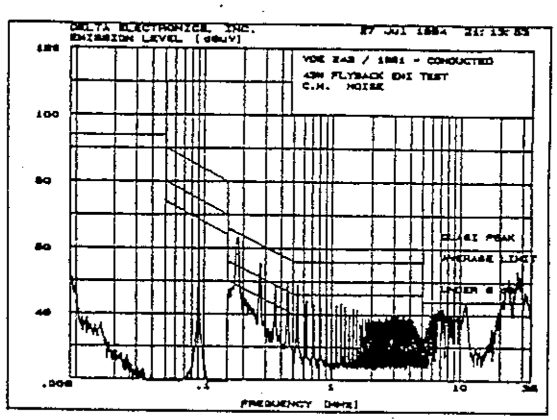

80.00
40.00
0.00
Attenuation [dB]
Curve
Experimental Attenuation
Theoretical Attenuation
Noise Floor Level
$f_{R,DM}$ = 11.7KHz
0.01
0.10
1.00
10.00
Frequency [MHz]

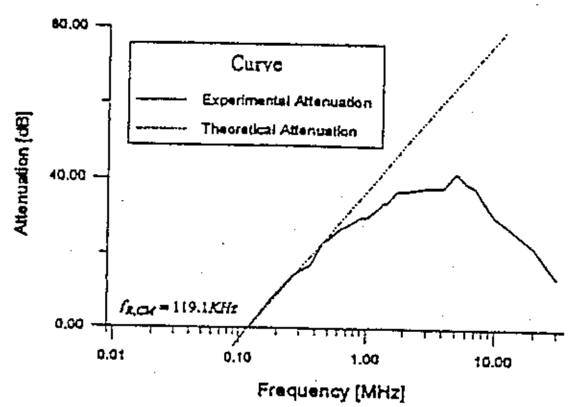

DELTA ELECTRONICS, INC.
EMISSION LEVEL [dBuV]
CONDUCTED
FLYBACK EMI TEST
C.M. NOISE
QUASI PEAK
AVERAGE LIMIT
120
100
80
60
40
.1
1
10
FREQUENCY [MHz]

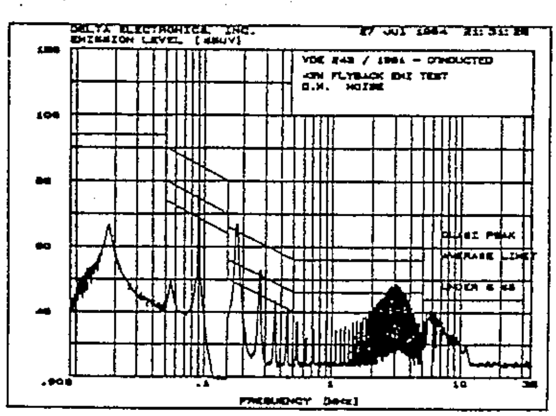

DELTA ELECTRONICS, INC.
EMISSION LEVEL [dBuV]
CONDUCTED
FLYBACK EMI TEST
D.M. NOISE
QUASI PEAK
AVERAGE LIMIT
120
100
80
60
40
.1
1
10
FREQUENCY [MHz]

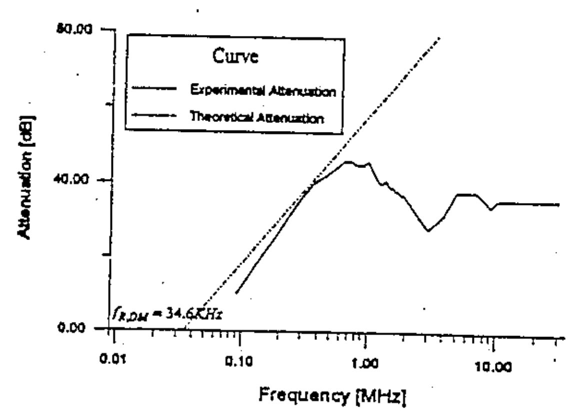

DELTA ELECTRONICS, INC.
EMISSION LEVEL [dBuV]
CONDUCTED
FLYBACK EMI TEST
TOTAL NOISE
QUASI PEAK
AVERAGE LIMIT
120
100
80
60
40
.1
1
10
FREQUENCY [MHz]


1.9mH
(L_leakage = 35μH)
5μH
L
0.47μF
0.47μF
470P
G
5μH
470P
N

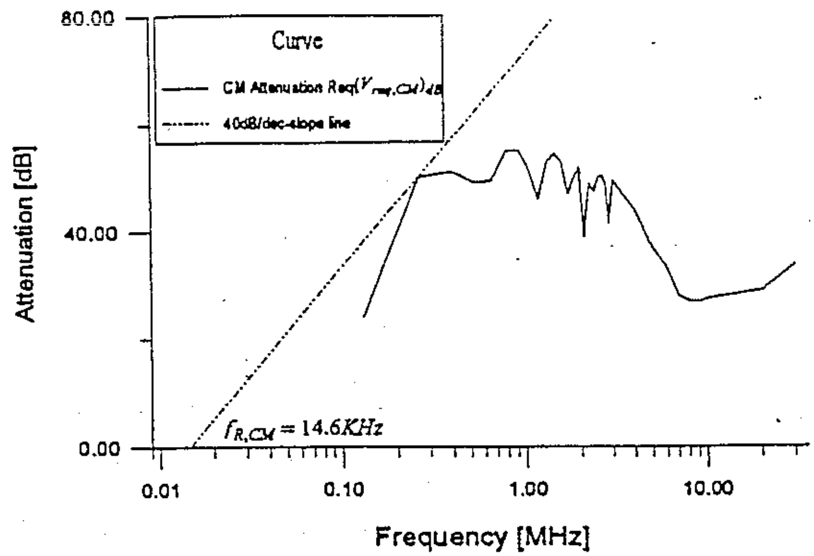


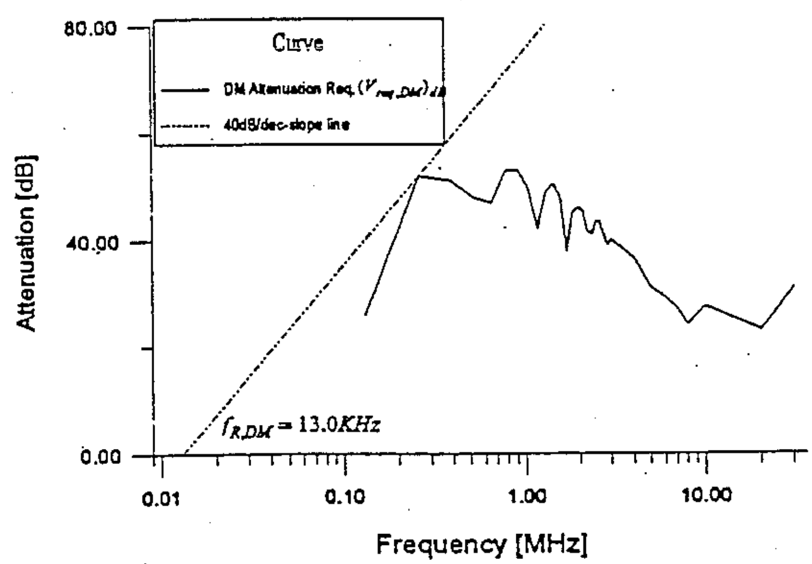

80.00
40.00
0.00
Curve
Experimental Attenuation
Theoretical Attenuation
Attenuation [dB]
f_R,CM = 119.1KHz
0.01
0.10
1.00
10.00
Frequency [MHz]

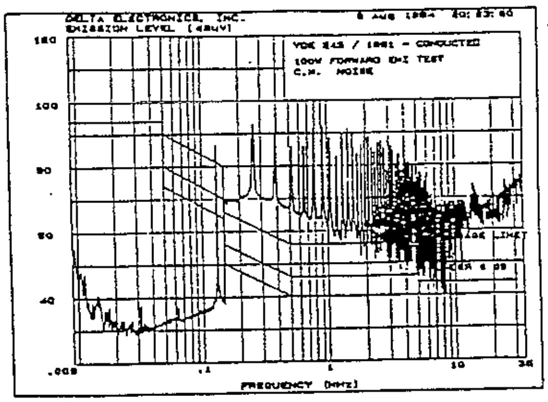
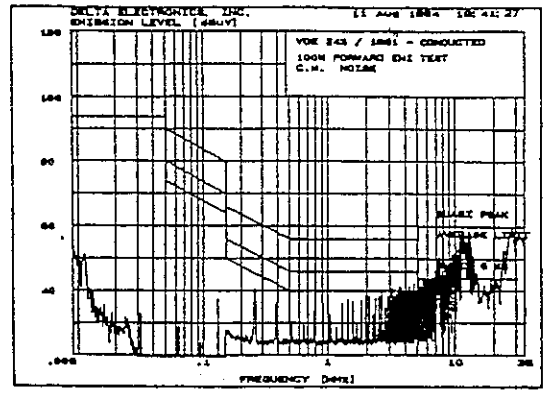
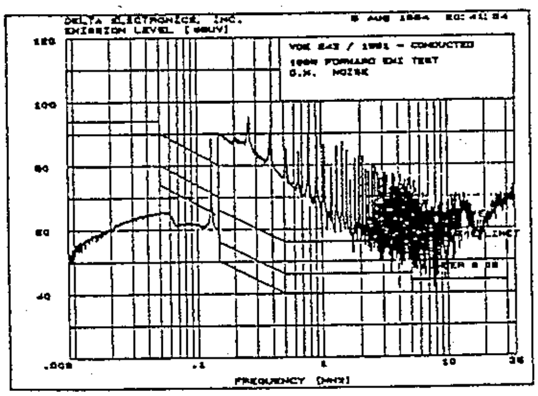
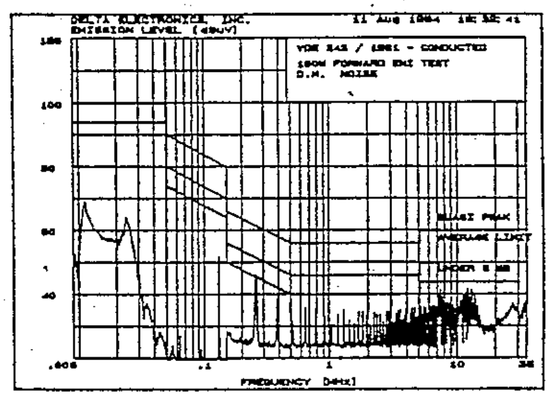
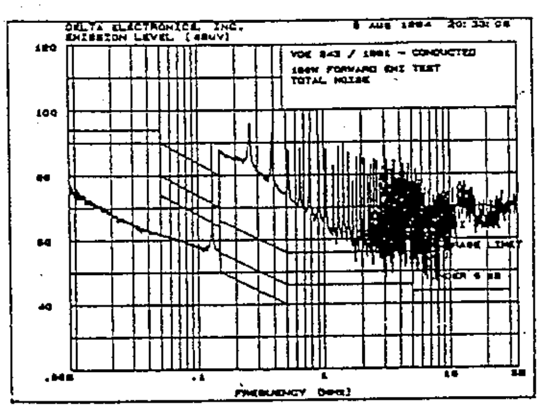
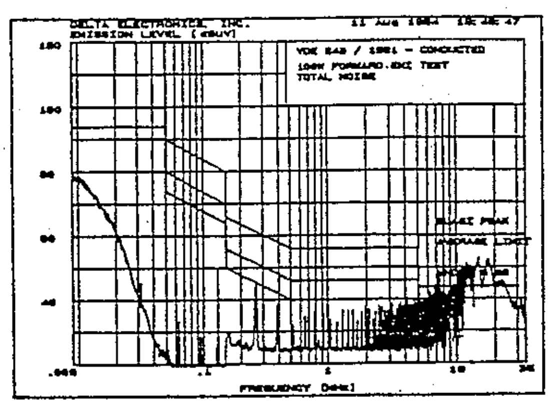



80.00
40.00
0.00
Curve
Experimental Attenuation
Theoretical Attenuation
Attenuation [dB]
f_R,DM = 34.6KHz
0.01
0.10
1.00
10.00
Frequency [MHz]

EXAMPLE 2: 100-W Off-Line Forward Converter Power Supply





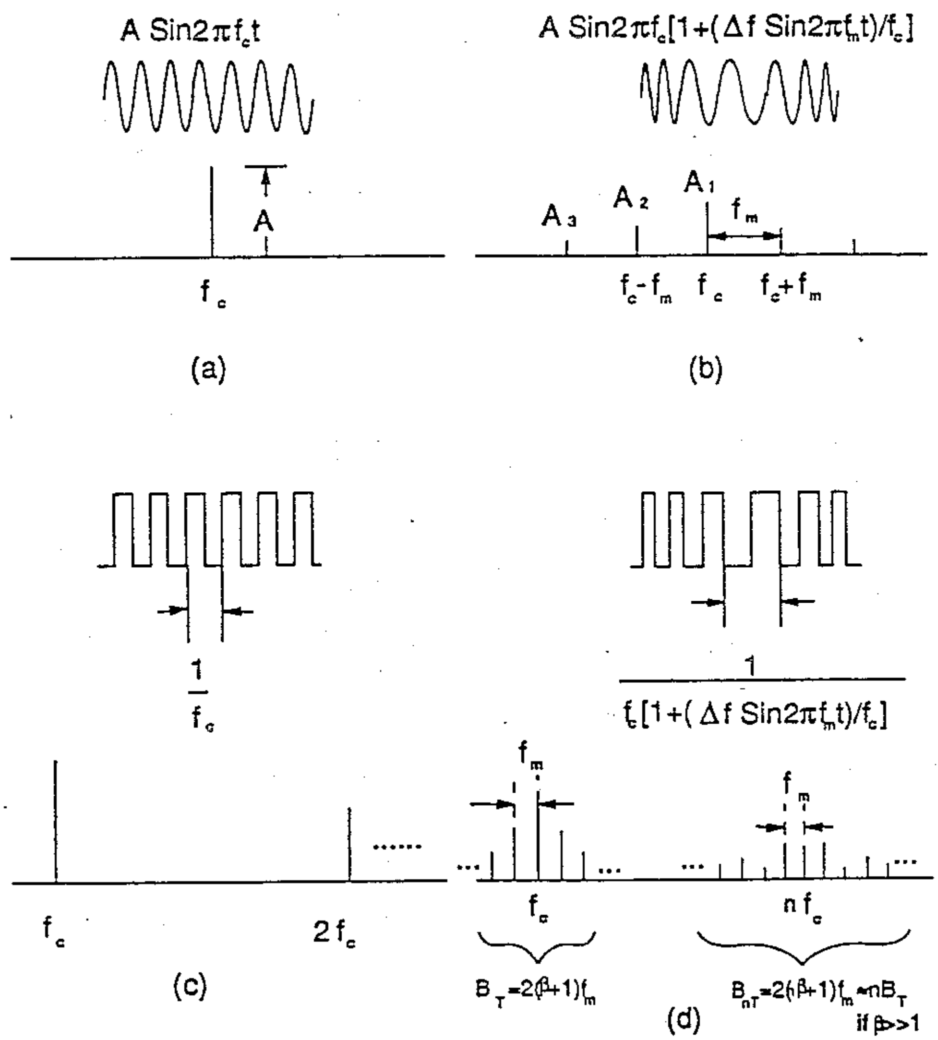
Without Filter	With Filter
	
	
	

十、用調頻方法減少 EMI
(EMI Reduction by FM)

Conducted EMI Reduction by Frequency Modulation

- Suppression
- Decoupling
- Filtering / Shielding
- Frequency Modulation

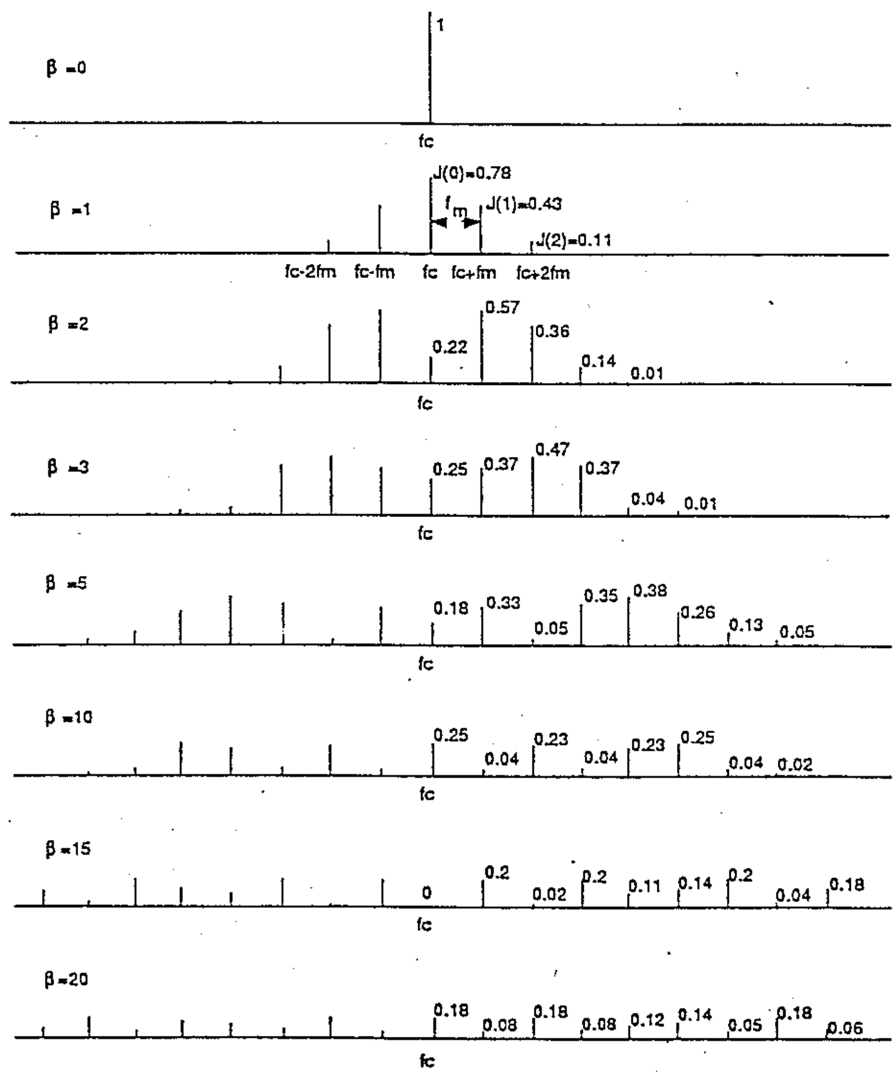
Frequency Spectrum of FM Signals



Effects of $\beta (\triangleq \Delta f / f_m)$ on FM Spectrum

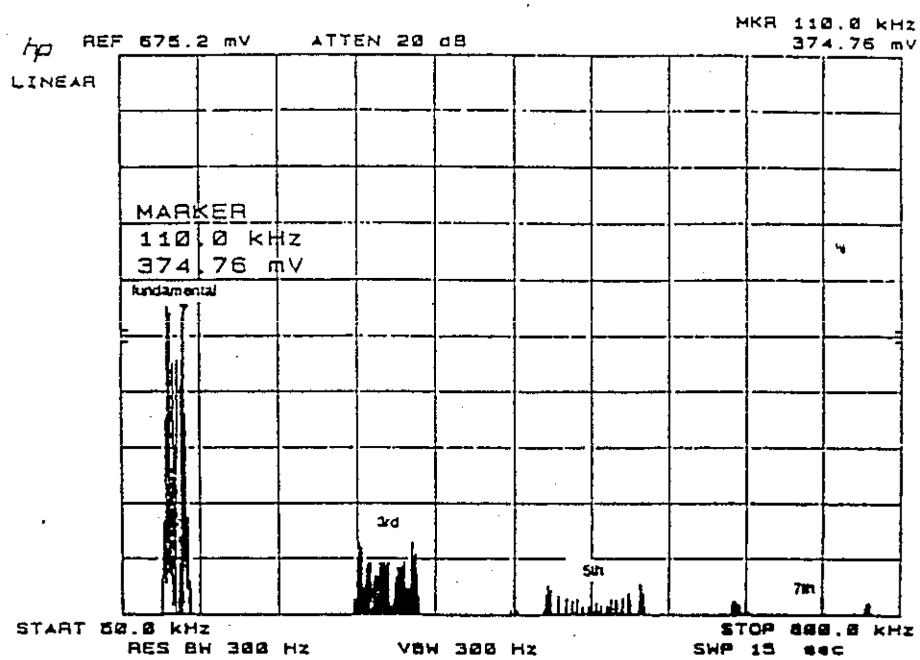
$\Delta f: (f_{max} - f_{min}) / 2$

f_m : modulating signal



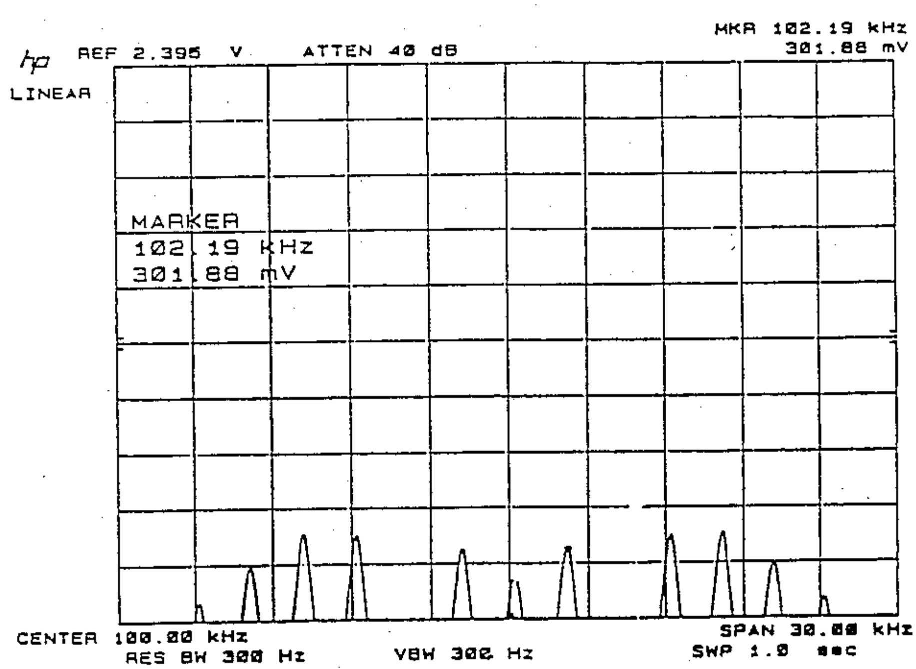
Carlson's Rule:

1. Total Energy Unchanged
2. 98% of Energy is contained within $B_T = 2(\beta + 1)f_m$



fc = 100 kHz, fm = 2 kHz, Δf = 10 kHz, β = 5 , RBW = 10 kHz

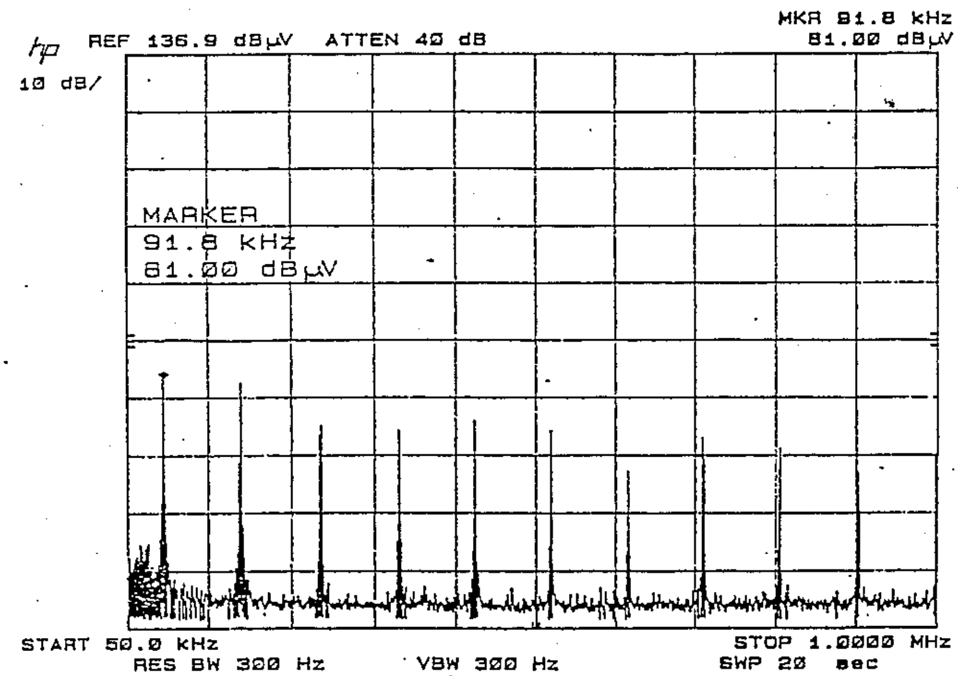
Spectrum Of A Modulated Pulse-Train Signal



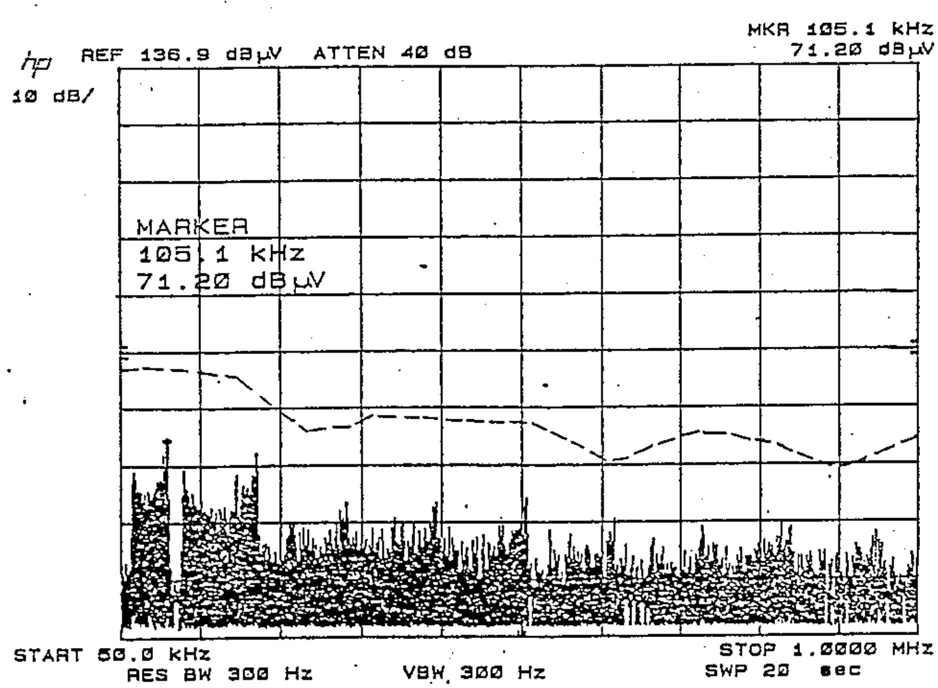
Δ f = 10 kHz, fm = 2 kHz, β = 5 , RBW = 300 Hz

Side-Band Harmonics Of The Fundamental Switching Harmoni

FM Effect

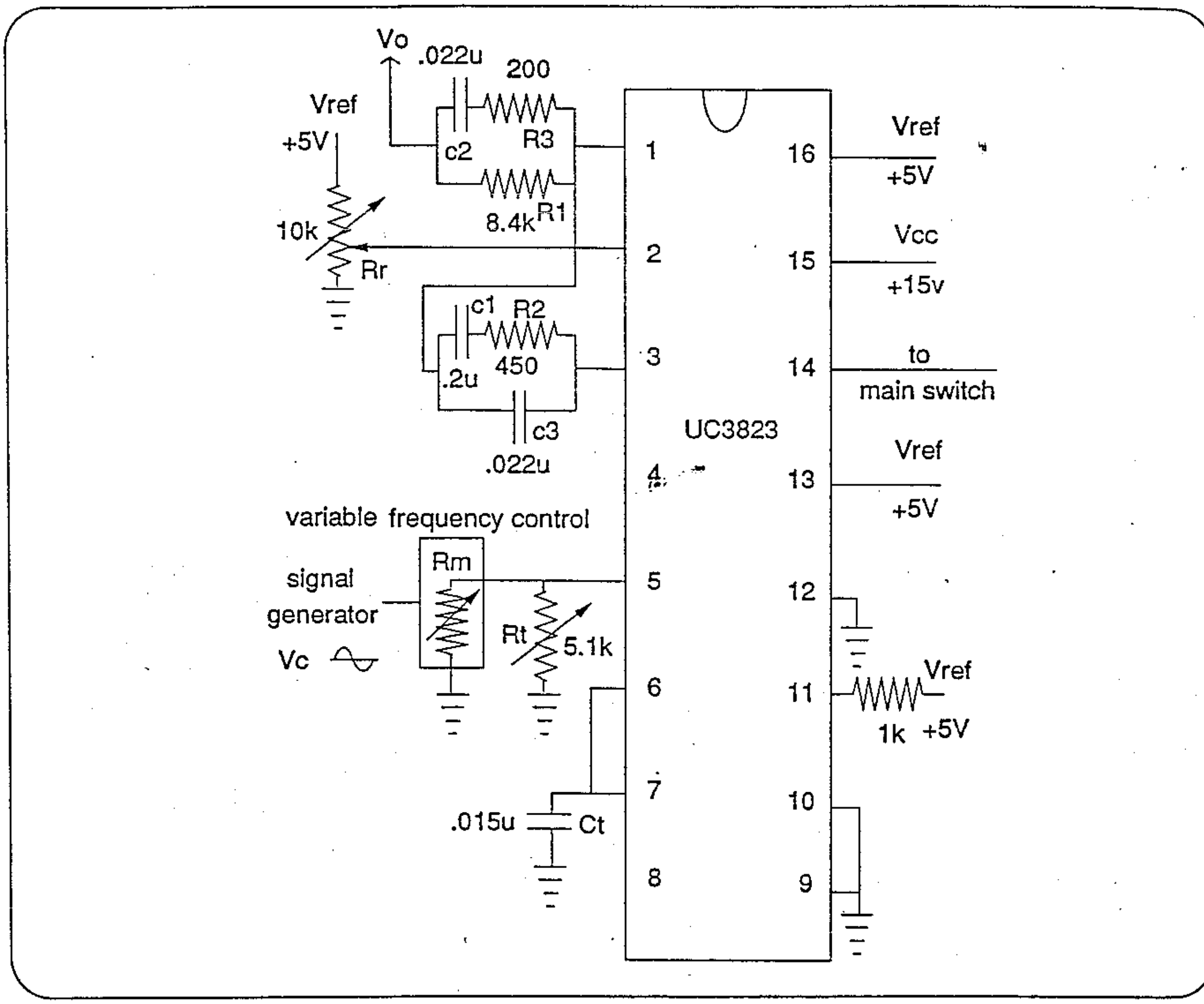


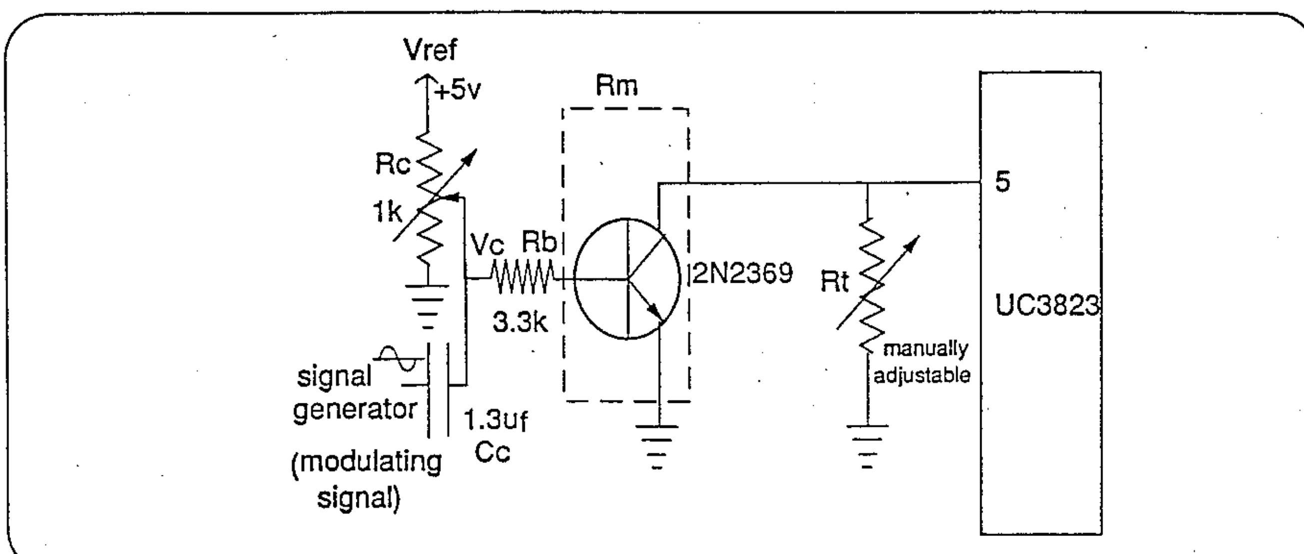
MKR 91.8 kHz
81.00 dBµV
REF 136.9 dBµV ATTEN 40 dB
10 dB/
MARKER
91.8 kHz
81.00 dBµV
START 50.0 kHz
STOP 1.0000 MHz
RES BW 300 Hz
VBW 300 Hz
SWP 20 sec

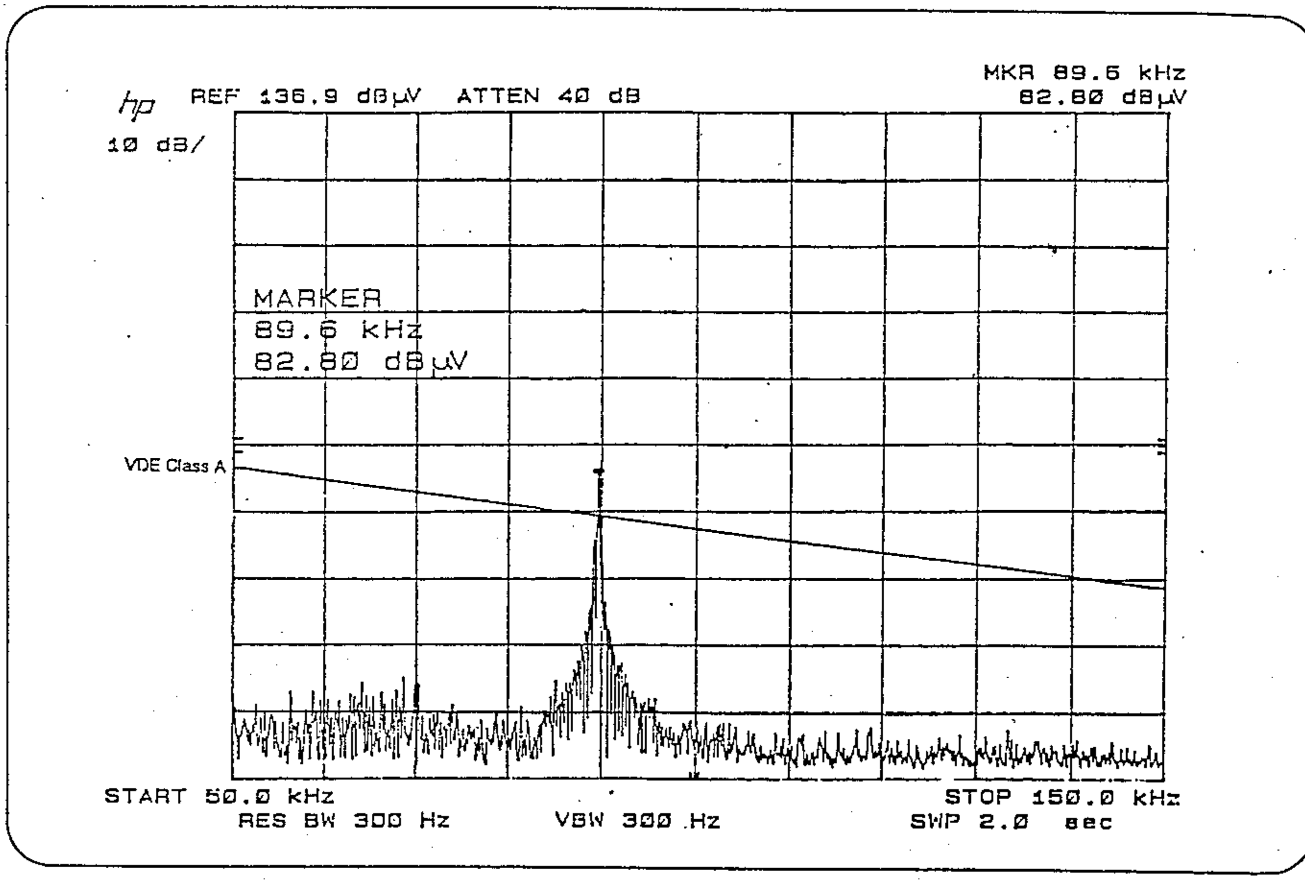


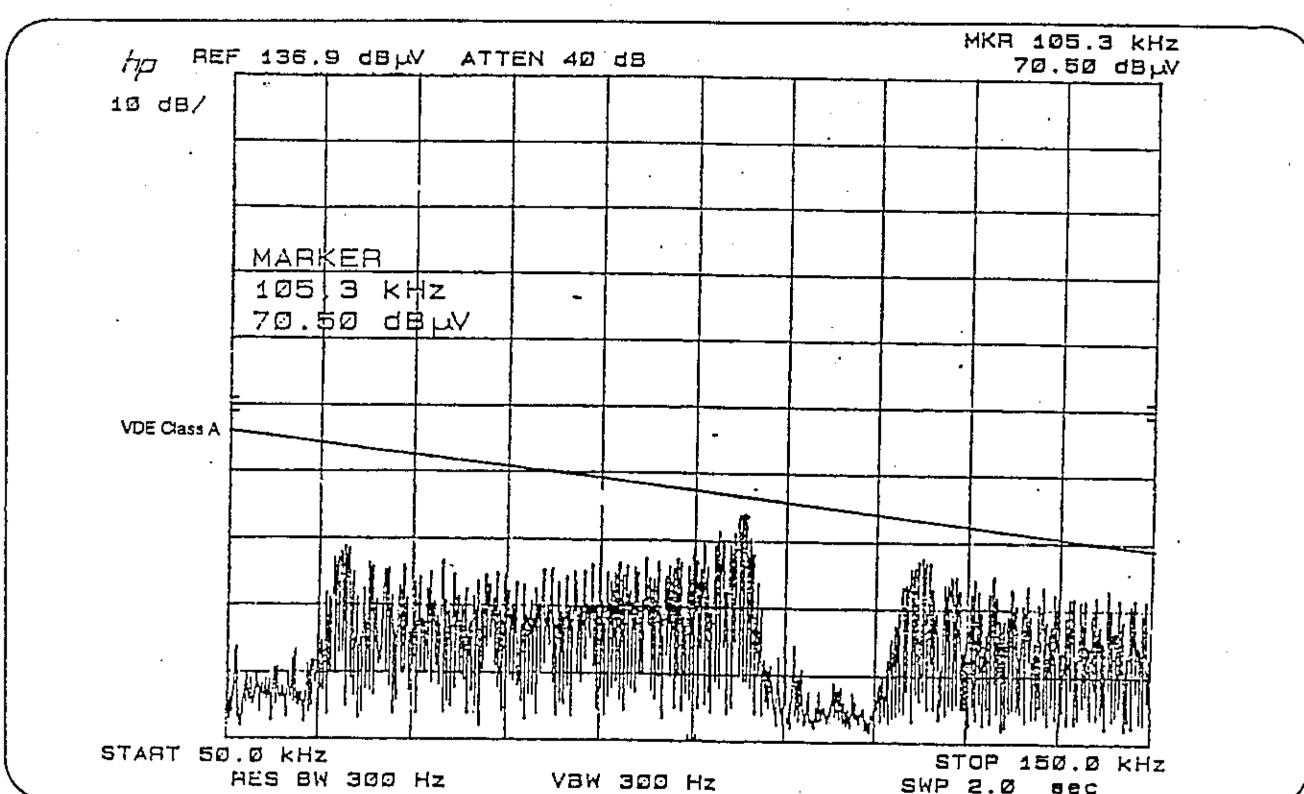
MKR 105.1 kHz
71.20 dBµV
REF 136.9 dBµV ATTEN 40 dB
10 dB/
MARKER
105.1 kHz
71.20 dBµV
START 50.0 kHz
STOP 1.0000 MHz
RES BW 300 Hz
VBW 300 Hz
SWP 20 sec

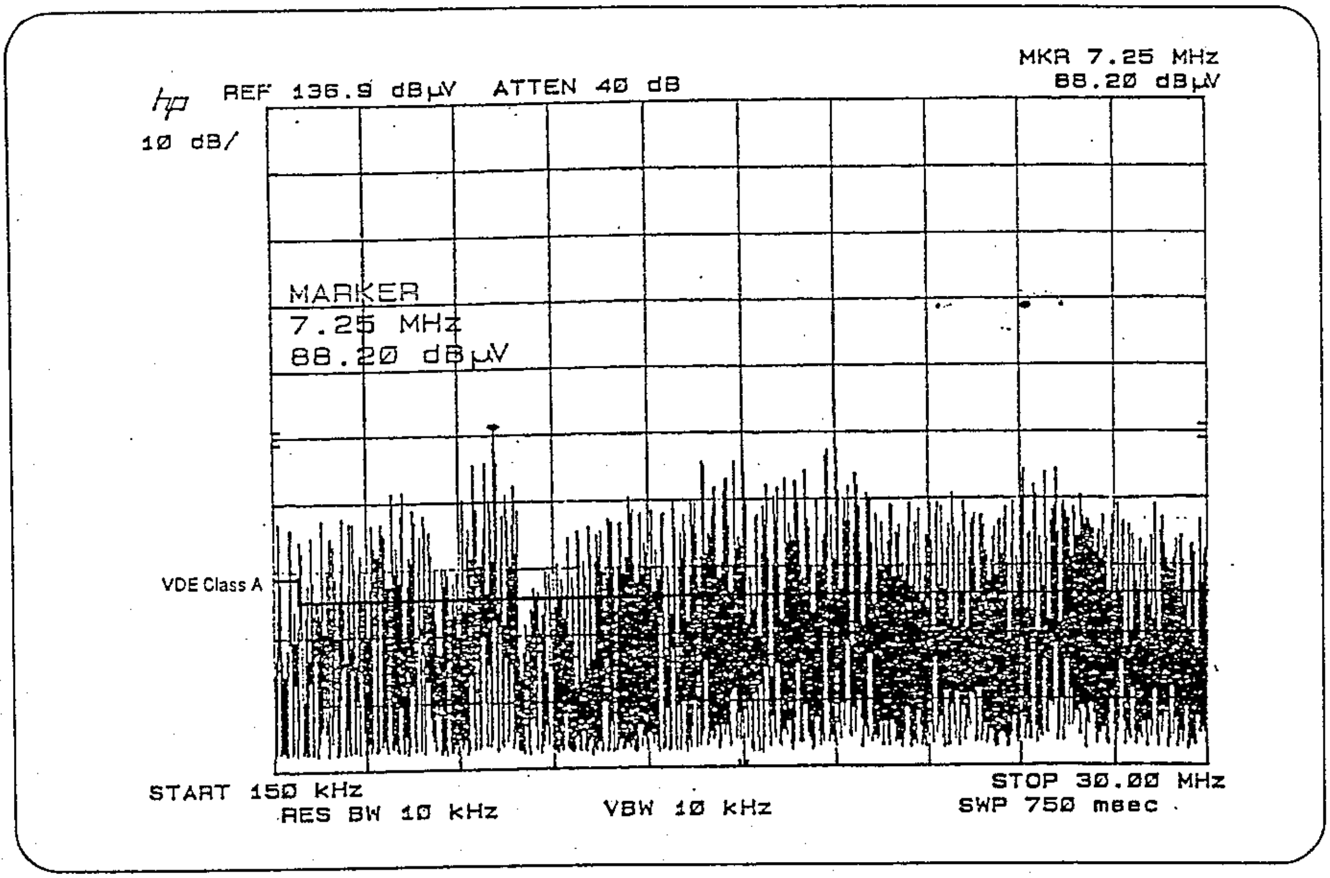
Circuit Implementing FM in Power Supplies

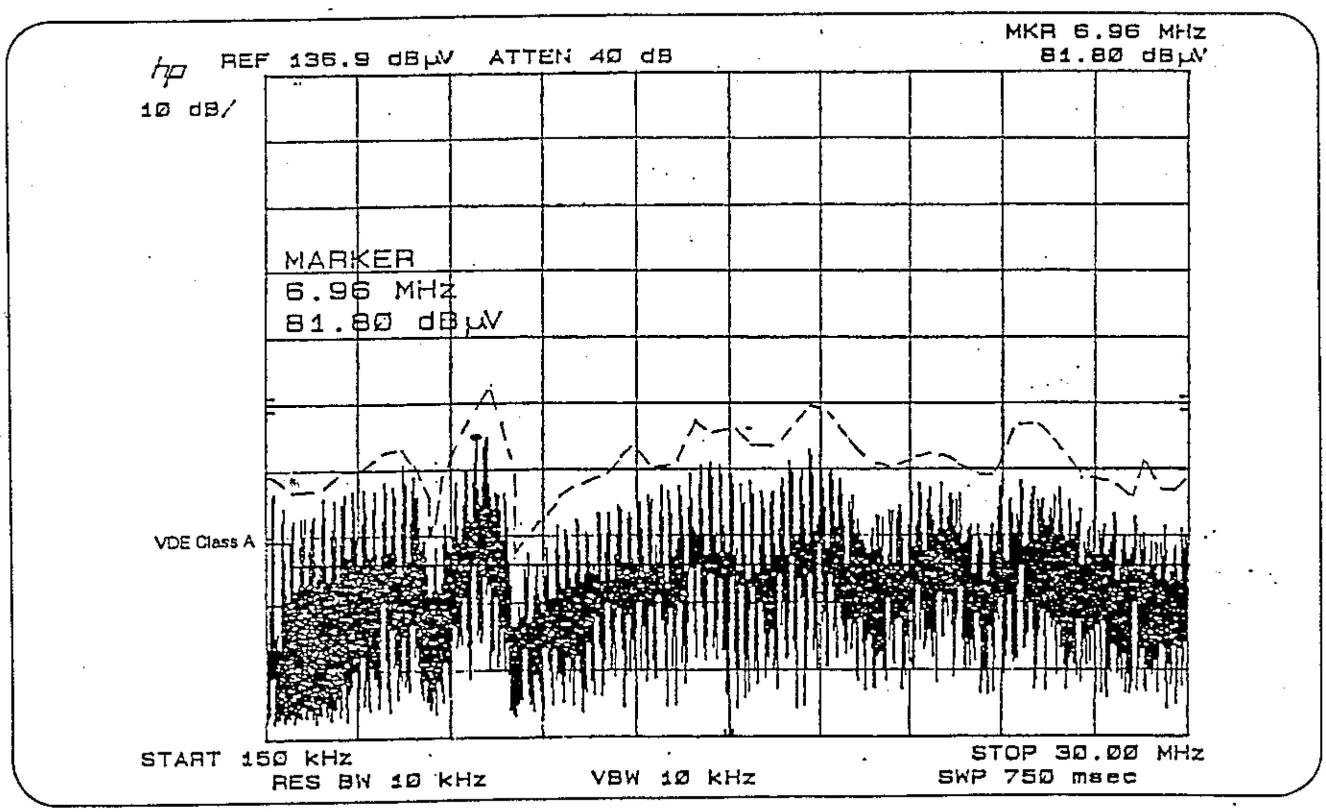





hp REF 136.9 dBµV ATTEN 40 dB
MKR 89.6 kHz
82.80 dBµV
10 dB/
MARKER
89.6 kHz
82.80 dBµV
VDE Class A
START 50.0 kHz
STOP 150.0 kHz
RES BW 300 Hz
VBW 300 Hz
SWP 2.0 sec


hp REF 136.9 dBµV ATTEN 40 dB
MKR 105.3 kHz
70.50 dBµV
10 dB/
MARKER
105.3 kHz
70.50 dBµV
VDE Class A
START 50.0 kHz
STOP 150.0 kHz
RES BW 300 Hz
VBW 300 Hz
SWP 2.0 sec


MKR 7.25 MHz
88.20 dBµV
REF 136.9 dBµV ATTEN 40 dB
10 dB/
MARKER
7.25 MHz
88.20 dBµV
VDE Class A
START 150 kHz
RES BW 10 kHz
VBW 10 kHz
STOP 30.00 MHz
SWP 750 msec


MKR 6.96 MHz
81.80 dBµV
REF 136.9 dBµV ATTEN 40 dB
10 dB/
MARKER
6.96 MHz
81.80 dBµV
VDE Class A
START 150 kHz
RES BW 10 kHz
VBW 10 kHz
STOP 30.00 MHz
SWP 750 msec

Parameters Affecting the Performance

$\beta \triangleq \Delta f / f_m$

Larger β , better noise shattering

Δf: Too small Δf , Small β
Too large Δf , bad for magnetic component selection

fm: Too large fm, small β ; regulation problems
Too small fm, no significant reduction in measured EMI if fm << RBW

Conclusions

1. Modulating Parameters $(\Delta f, f_m, \beta)$ must be chosen properly to have effective EMI reduction without causing significant side effects.

2. To reduce fundamental harmonic noise:

   If $f_s < 150kHz$, use $f_m \approx 200Hz$

   If $f_s > 150kHz$, use $f_m \approx 9kHz$

3. FM is effective in reducing both the DM and the CM noise.

   FM not effective in reducing noise generated by ringing.

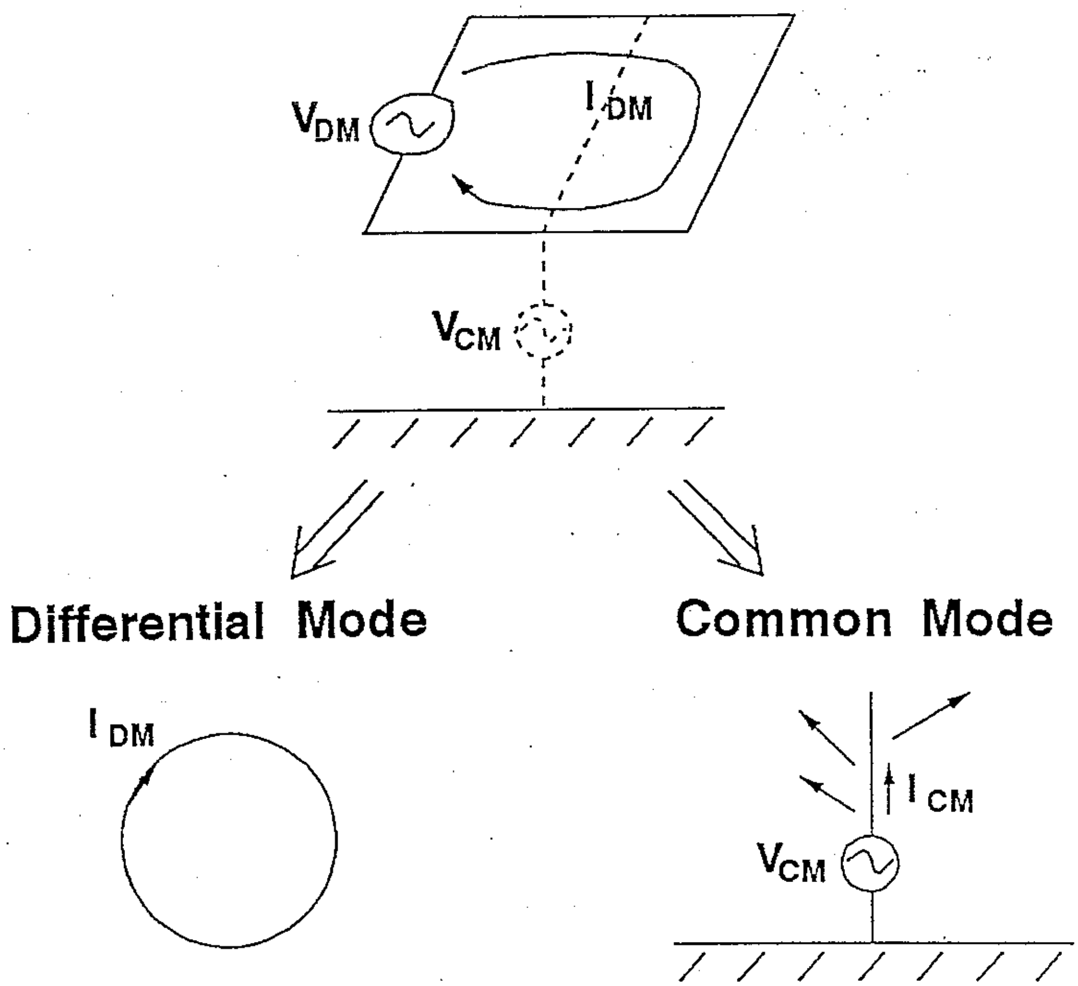
4. EMI filter must be properly damped to avoid possible amplification of noises at the filter pole frequencies.

5. FM should be effective in reducing radiated EMI, but this has not been verified.

6. Other modulating waveforms can be considered to improve the performance.

十一、輻射 EMI 控制
(Radiated EMI)

IX. Radiated EMI



- Requires different treatments
- In general, C.M. noise is harder to control.

Standard

FCC Vs. Military

	FCC	Military
Radiation Test	open field	enclosed chamber
Conducted Test	Measure Voltage	Measure Current

FCC Radiation Test

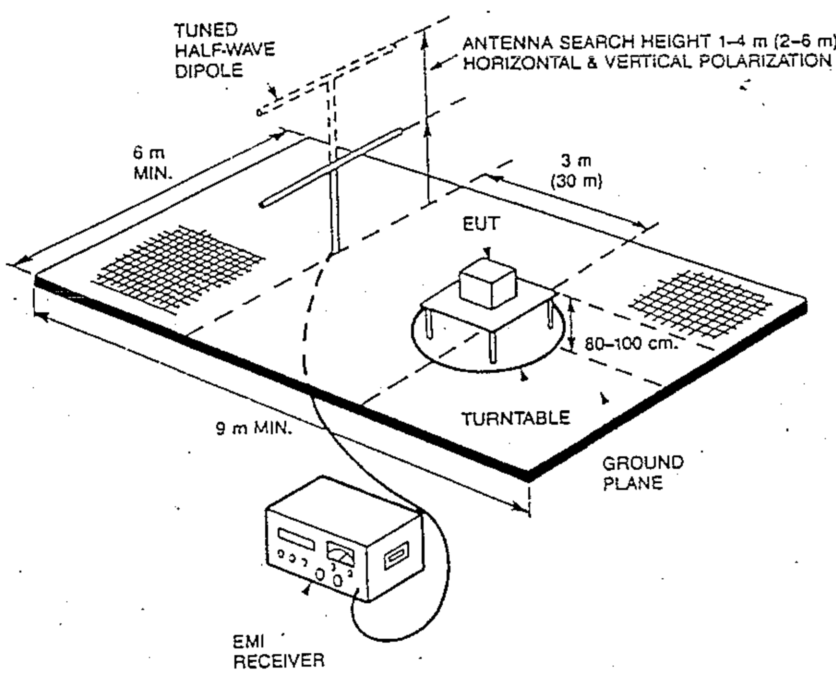


Figure 1-5. *Open field test site for FCC radiated emission test. Equipment under test (EUT) is on the turntable.*

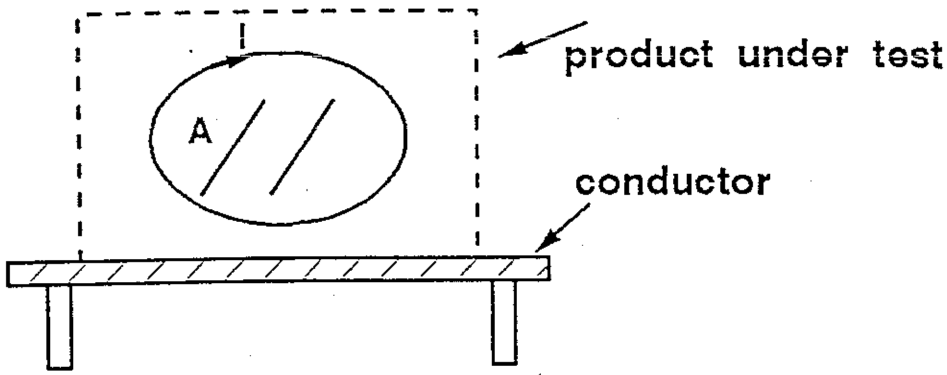
Table 1-1 FCC Class A Radiated Emission Limits

Frequency (MHz)	Measuring Distance (m)	Field Strength (μV/m)
30–88	30	30
88–216	30	50
216–1000	30	70

Table 1-2 FCC Class B Radiated Emission Limits

Frequency (MHz)	Measuring Distance (m)	Field Strength (μV/m)
30–88	3	100
88–216	3	150
216–1000	3	200

Differential - Mode Radiation



- $E_{max} = 263 * 10^{-16} (f^2 A I) * \frac{1}{r}$ $\begin{cases} E : v / m \\ A : m^2 \\ I : A \\ r : m \end{cases}$

- At f = 30 MHz , A = 10 cm^2 , I = 100 mA
  r = 3 m , $E_{max} \cong$ 800 uv /m .

  FCC part 15 , Class B , E = 100 uv / m

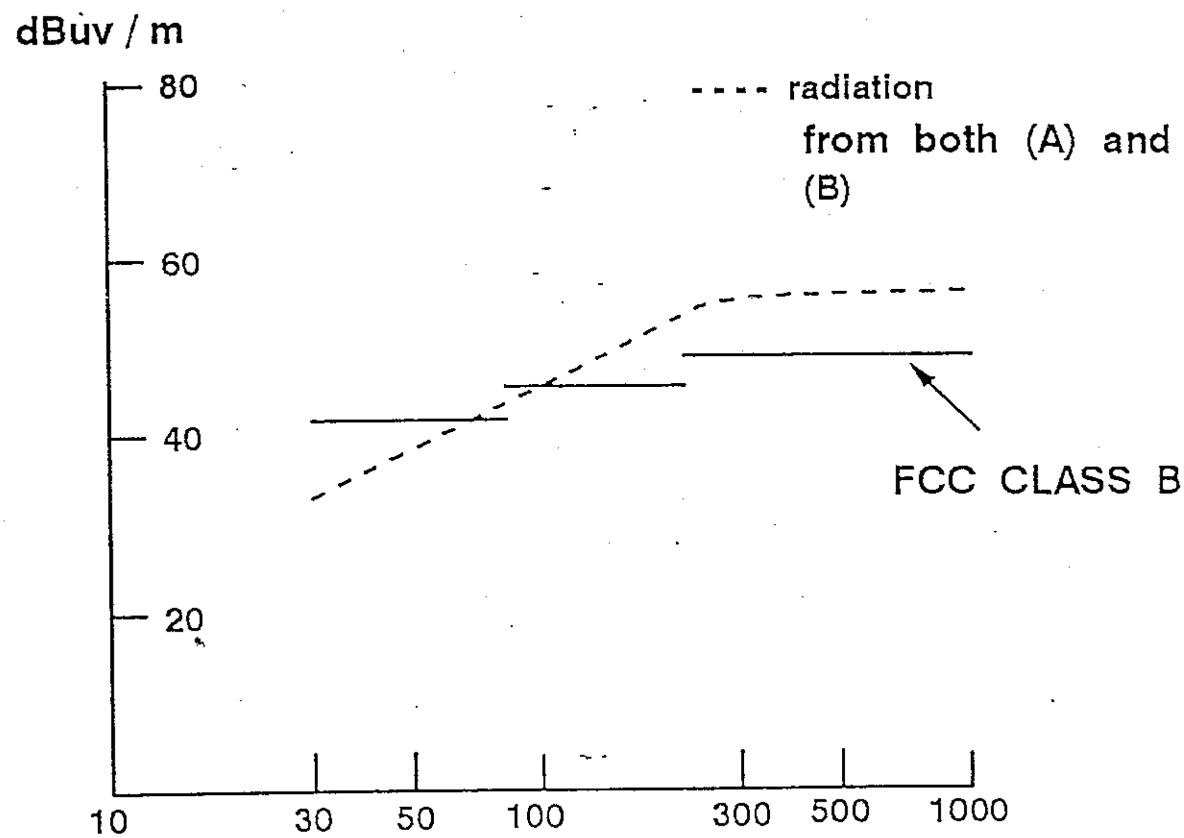
- Equation is accurate for small loop
  (perimeter << $\lambda / 4$) .

  E varies with location .

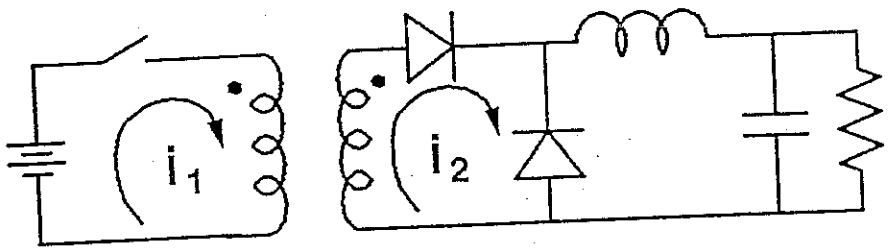
D.M. Radiation from Clock Signal

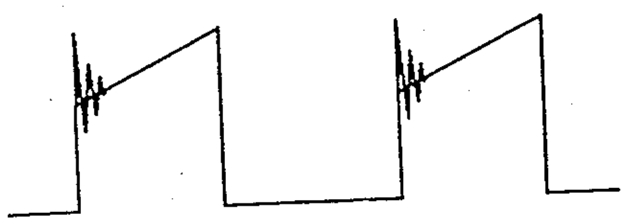
(A) 4" - long, 1/2" - wide trace carries 16 MHz
4 ns rise time, 35 mA clock signal
(PC - board trace)

or (B) 3' - long, 50 mil adjacent return, 4 ns,
35 mA (cable)



D.M. Radiation in Power Supplies





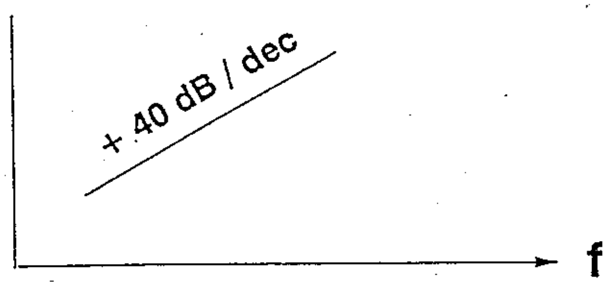
- Normally , i_2 is much large than i_1

- Ringing frequency ≈ 10 -- 30 MHz
  Without suppression or shielding ,
  P.S. cannot pass FCC regulation .

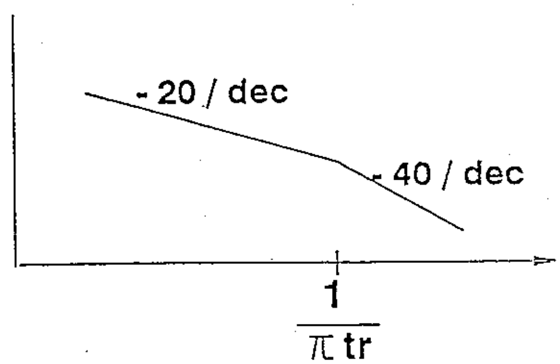
D.M. Radiation of Clock

$$E_{rod.} \propto f^2 \; I \; A$$

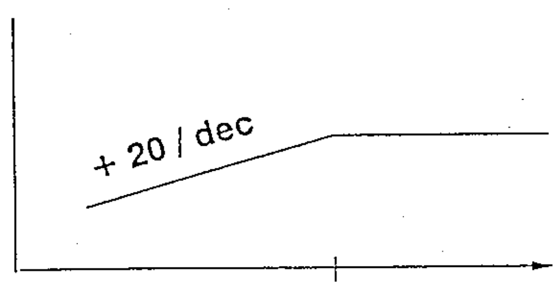
$E \propto f^2$



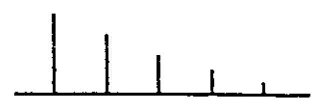
I



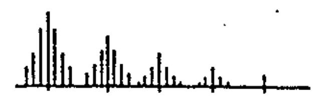
E radiated



Radiation Noise Sources in a Digital Circuit



Primary : Clock

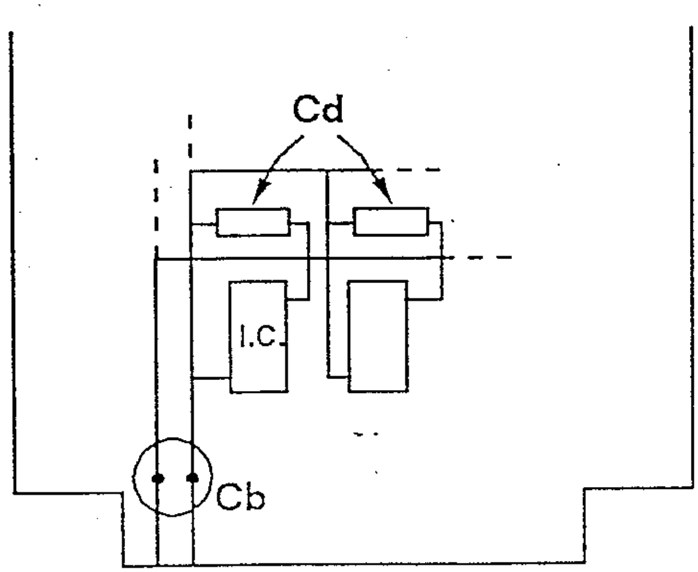


Line and Bus Driver

Secondary : Address Buses

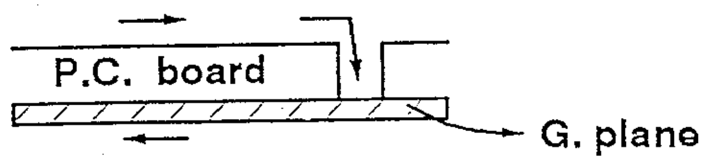
Data Buses

Power Supply : Transient Current

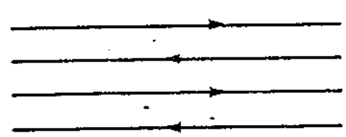


Controlling D.M. Radiation

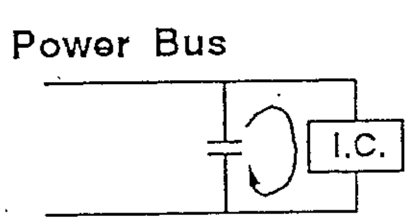
- Reduce Area of High - Frequency Loop
  - -- PC board layout
  - -- Use ground plane



  - -- Alternate signal return in a ribbon connector

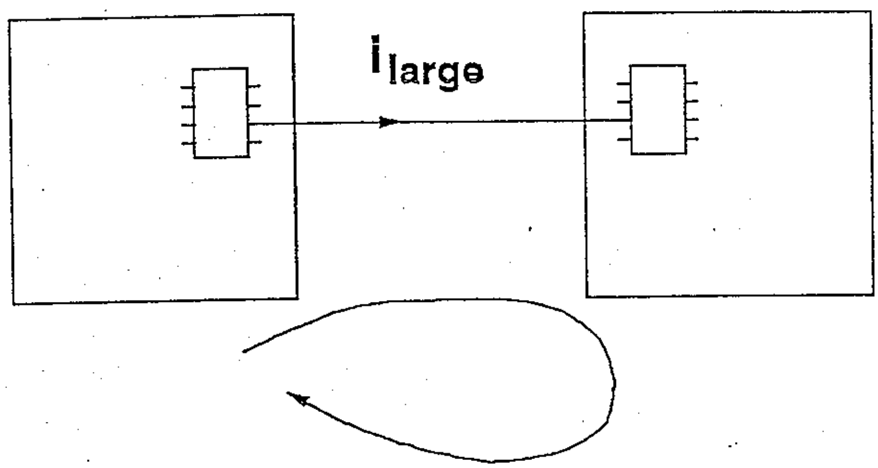


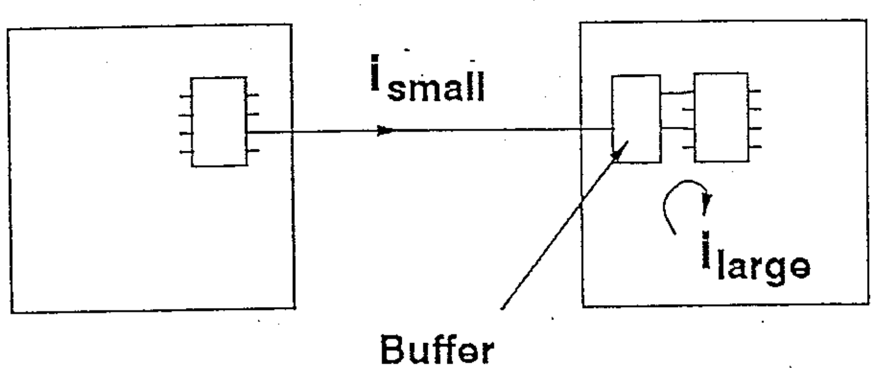
  - -- Use decoupling capacitor for each I.C.



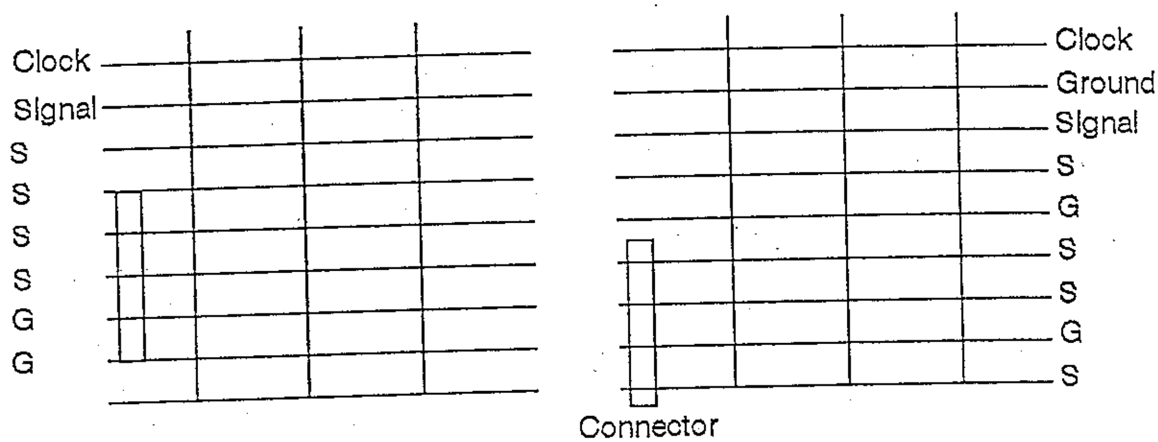
  - -- Use coaxial if necessary

Avoid Large Current Flowing in a Long Wire



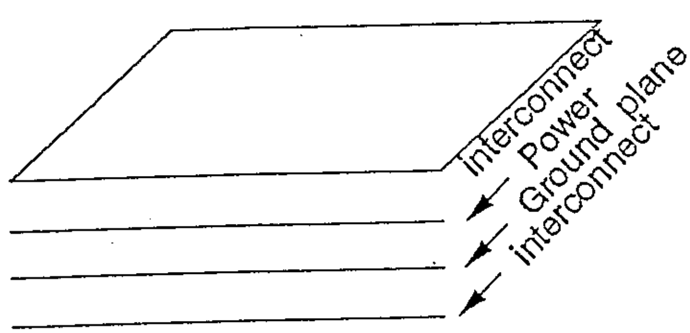


Backlpane Layout

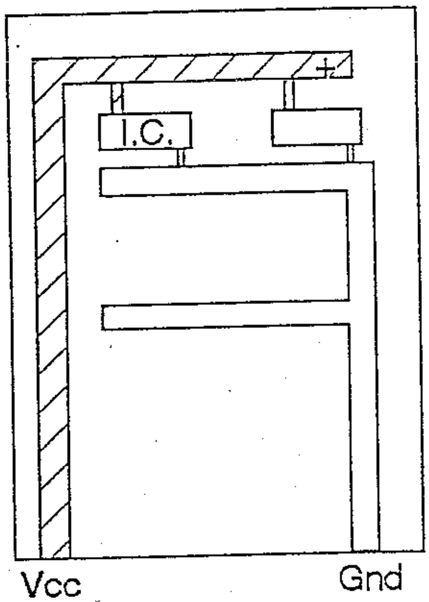


Bad

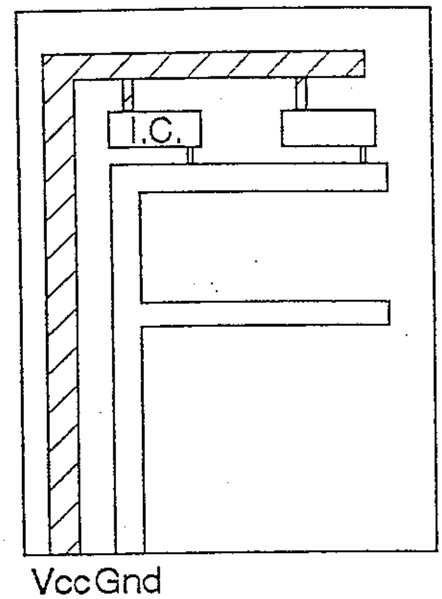
Better



Multilayer Board



Bad



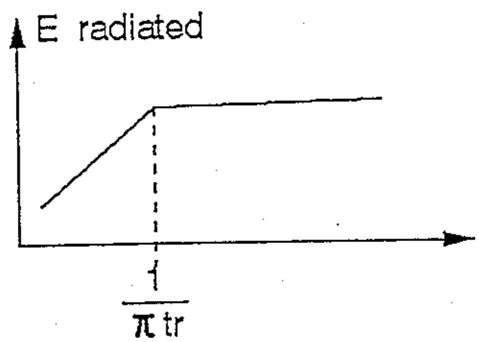
Good

Trace Length $l < \frac{\lambda}{20}$

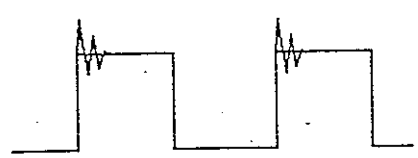
100MHz ----> $l = 15$ cm

- Reduce High Freqency Current

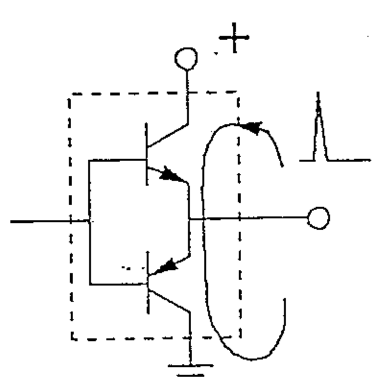
-- Slow down switching rise time tr



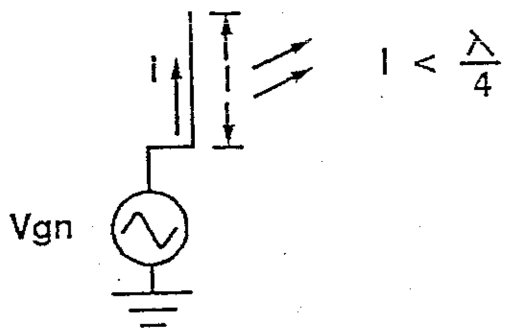
-- Avoid high freqency ringing



-- Avoid cross conduction of transistors



Common - Mode Radiation

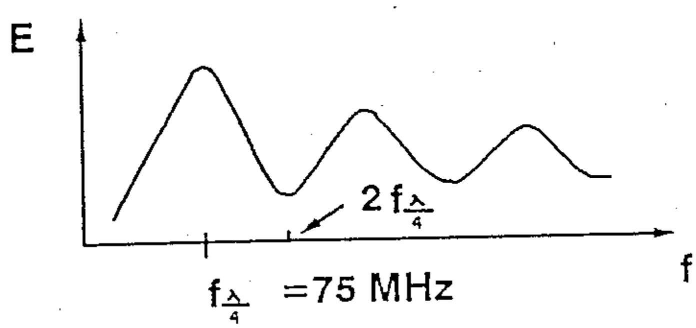


L,r : meter
I : Amp.
E : v / m

$$E_{max} = 12.6 * 10^{-7} \ (f L I) * \frac{1}{r}$$

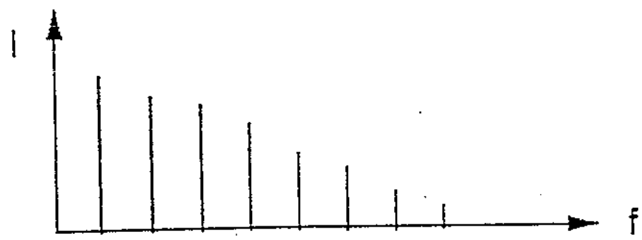
- At f = 30 MHz , L = 1 m , I = 100 mA
  r = 3 m , $E_{max} = 500 * 10^3$ uv / m >> FCC Limit

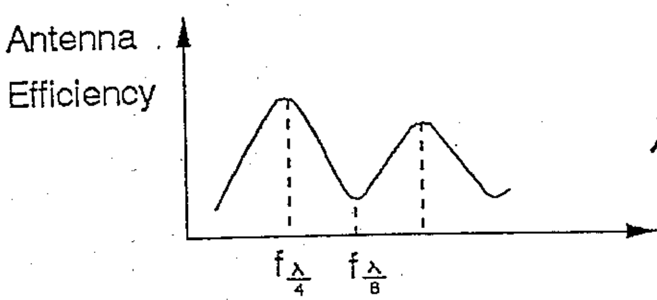
  $E \propto f$ if $l < \frac{\lambda}{4}$, E_{max} occursat $\frac{\lambda}{4}$



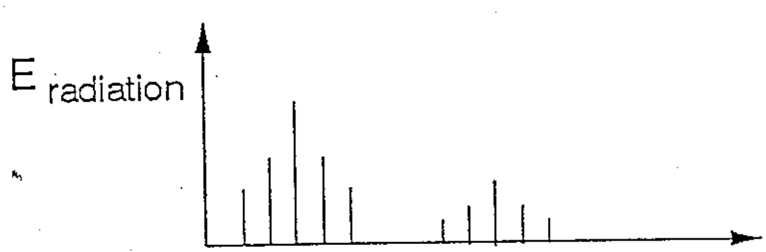
- C.M. radiation >> D.M. radiation
  (in general)

Radiation Efficiency

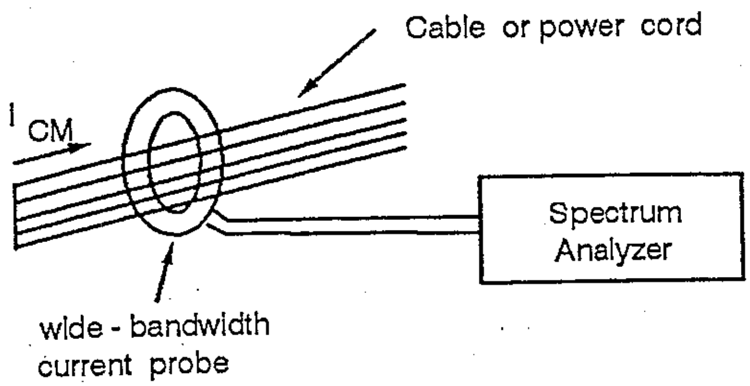




$$\lambda = \frac{3 * 10^{10} cm}{f}$$



Measurement of C.M. Current



- $I_{max} = \dfrac{0.8\, Es\; r}{f\; L}$ $r = 3$ m, Es = Spec. of FCC or VDE

  $I_{measure} < I_{max}$

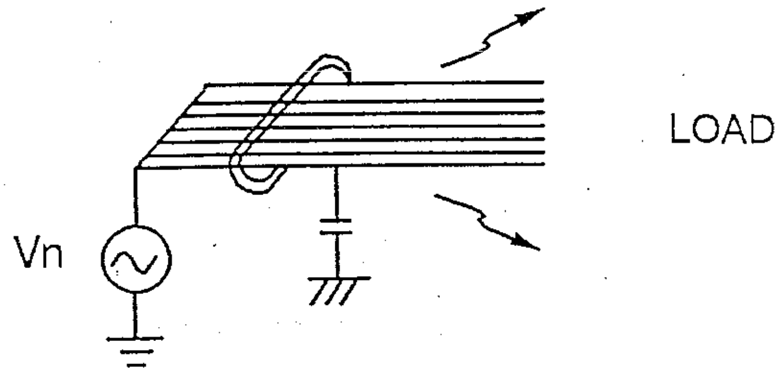
  For FCC CLASS B, at 50 MHz, $L = 1$ m

  $I_{max} = 5$ uA

- Good diagnostic test in the Lab.

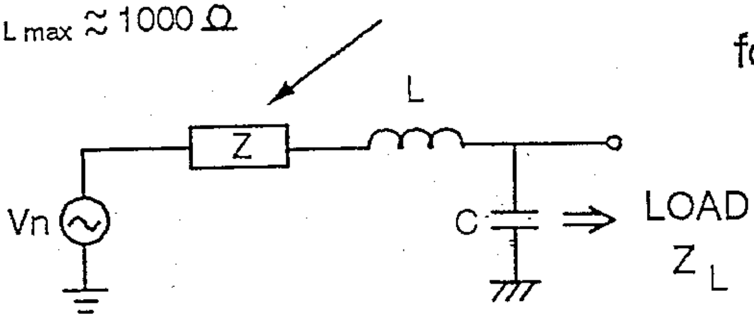
- Only milivolts of ground potential ---> $I > 5$ uA

Effectiveness of C.M. Choke



$Z \approx 200\,\Omega$

$Z_{L\,max} \approx 1000\,\Omega$

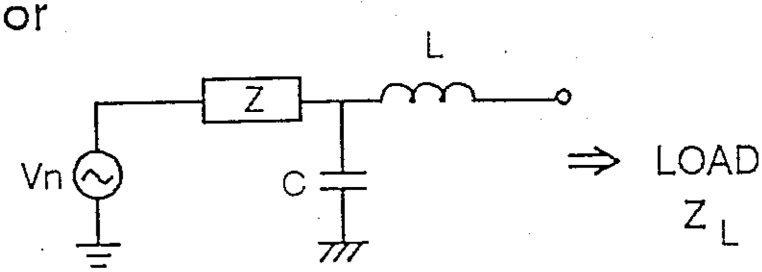


for

$wL >> Z$

$\frac{1}{wc} << Z_L$

or

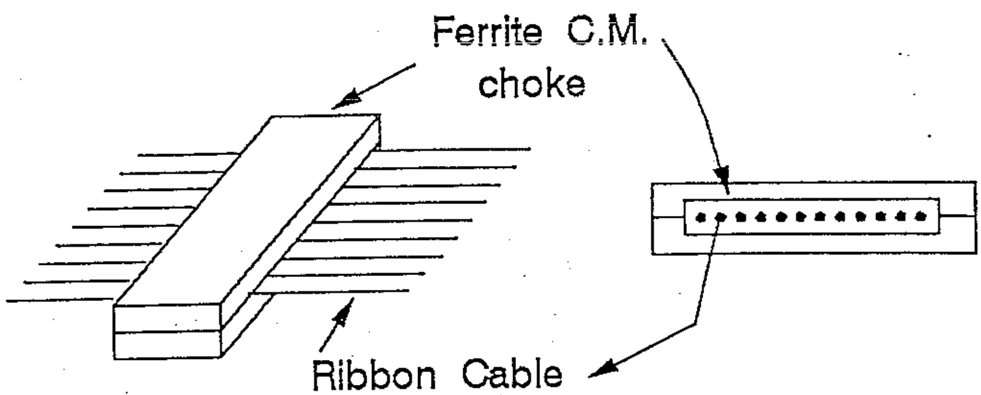


$\frac{1}{wc} << Z$

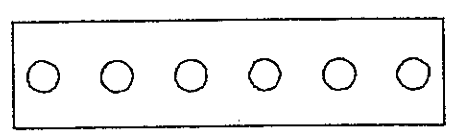
$wL >> Z_L$

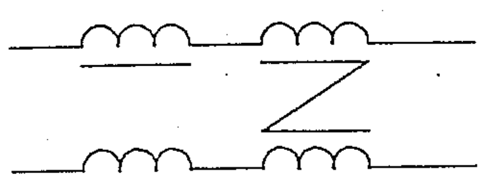
- Filter is effective for ESD protection also .

Ferrite Chokes for Filtering



Ferrite C.M. + D.M. chokes





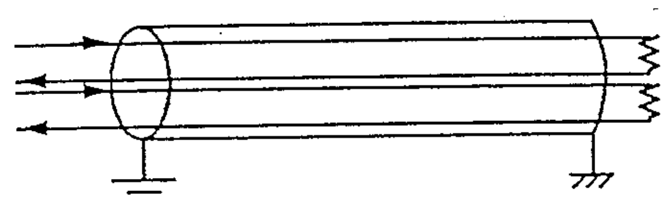
Controlling C.M. Radiation from a Cable

- Reducing Ground Noise Vn
  Use ground plane , ground grid ,
  Separate ground for I / O

- Decoupling by Low ESL Capacitor

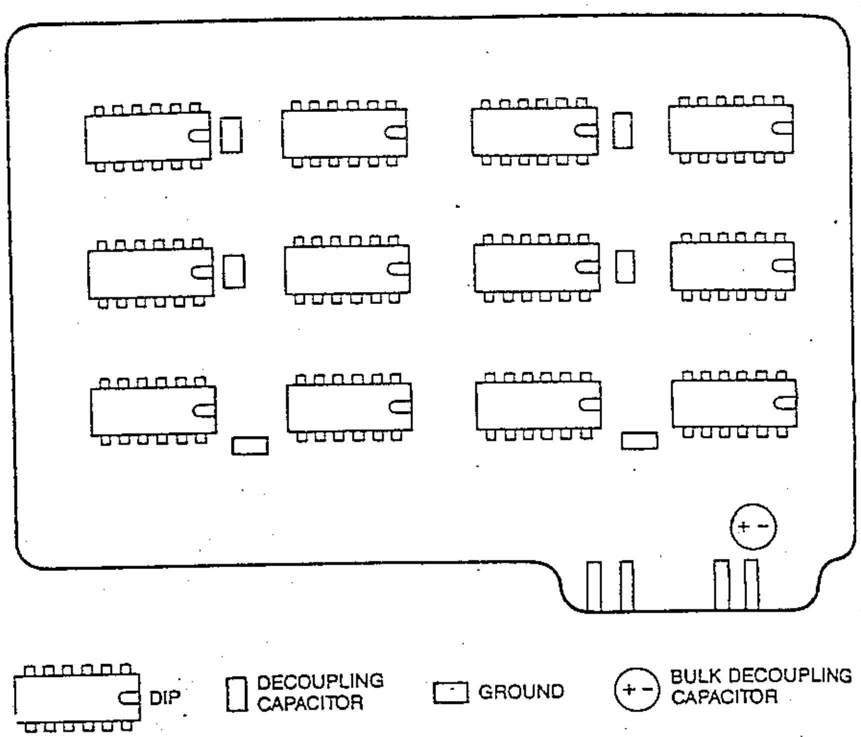
- Using Common - Mode Choke

- Using Shielded Cable (or Tri - lead)



Ground both ends and terminate completely

Ground Grid in PC Board



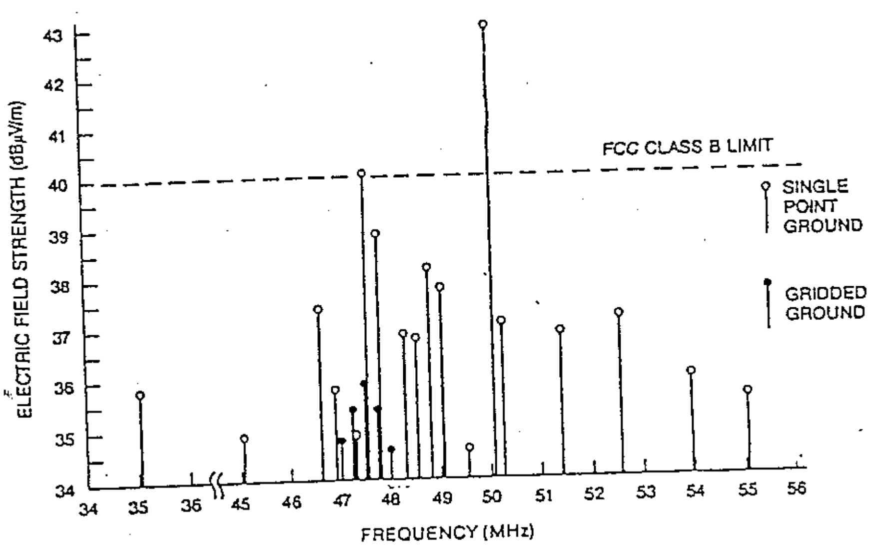
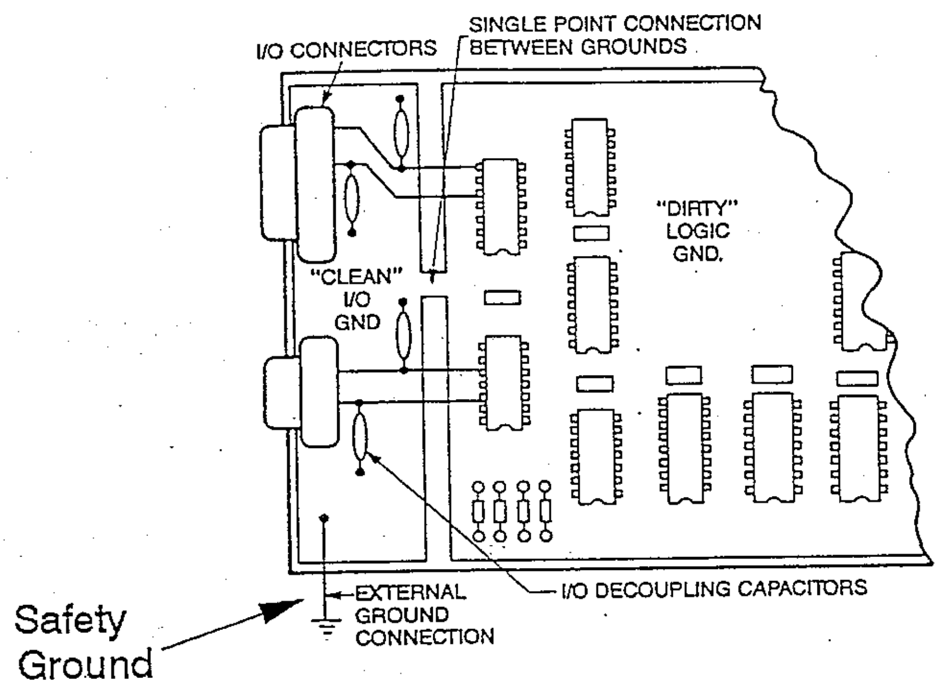


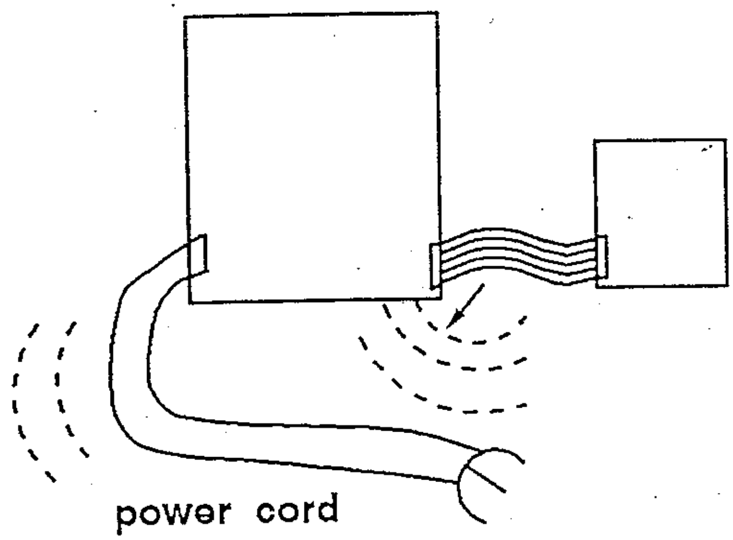
Figure 11-15. *Measured radiated emissions from a printed wiring board, with and without a gridded ground (from German, 1985).*

Controlling C.M. Radiation



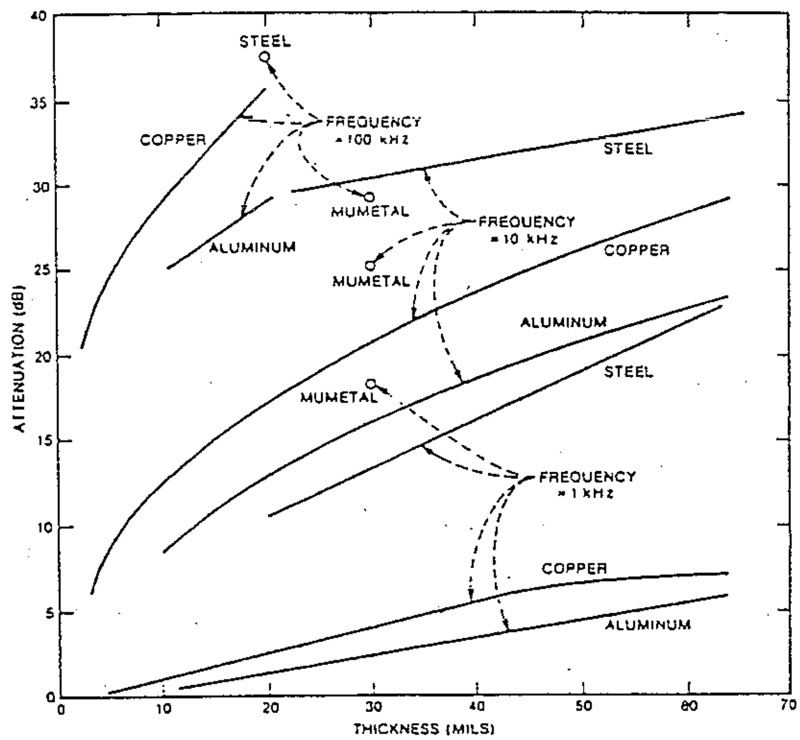
- I / O requires clean ground.
- All I / O s should be decoupled to clean ground before leaving system.

Conducted Vs. Radiated



- Radiated noise may couple into Conducted measurement
- Conducted noise may couple into radiated measurement
- Both types of noises need to be taken into consideration at the same time

Experimental Data on Magnetic Field Attenuation (Near Field)



- At Low freq. , Mumetal is most effective in reducing magnetic field .
- At high freq. , conductor make better shield than magnetic shield .
- At 100 KHz , Steel is only slightly better than copper .
- Permeability of magnetic material decreases with freq. Mumeatl changes with freq. in a much drastic manner than steel .

General Comments

- Using solid shield , it's relatively easy to obtain 90 dB of shielding effectiveness except for L.F. magnetic field .

- Shield discontinuity (holes , seams) has more effect on EMI than matreial .

- The amount of leakage depends on
  - --- max. linear dimension (not area) of opening
  - --- frequency of source
  - --- wave impedance

- Discontinuity has more effect on magnetic field leakage than electrical field leakage

Controlling Leakage

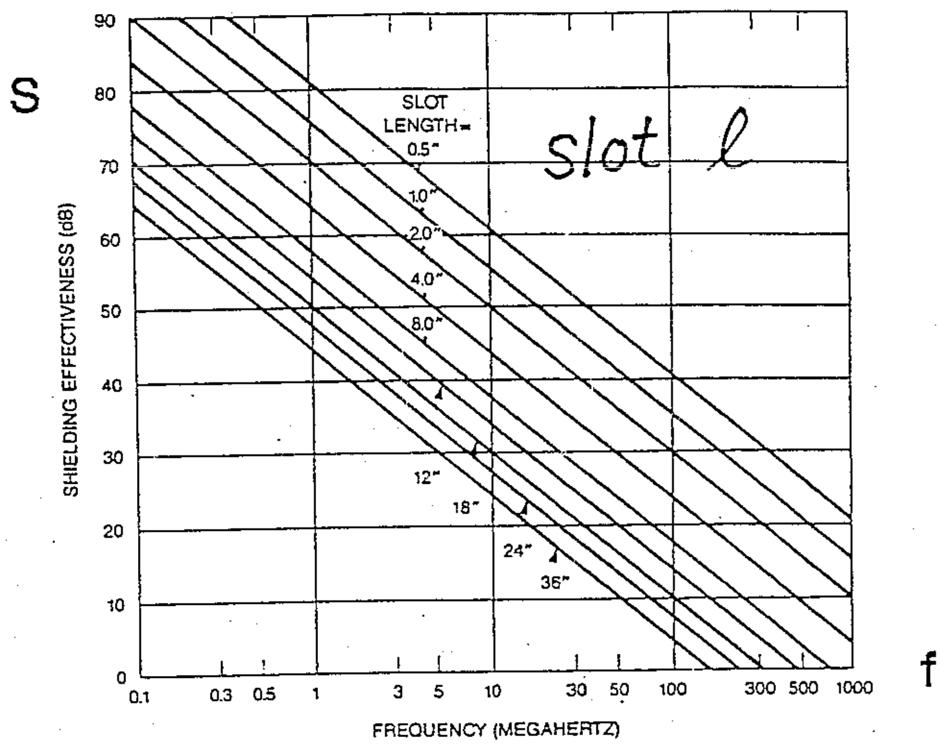
- Large number of small holes produce less leakage than one long hole

- Avoid opening greater than 1 / 20 of λ
  (this provides at least 20 dB)

MHz	max . length (in)
30	18
100	6
500	1.2

- Avoid having large number of holes on the same side

Shielding Effectiveness of Slot



$$S = 20 \log \frac{\lambda}{2l}$$

- Applies if $\frac{\lambda}{2l} > 1$ $\left(\text{when } \frac{\lambda}{2l} < 1 \quad S = 0 \right)$

- Single slot