Dr. Norbert Cheung's
Lecture Series

Level 5 Topic no: 13

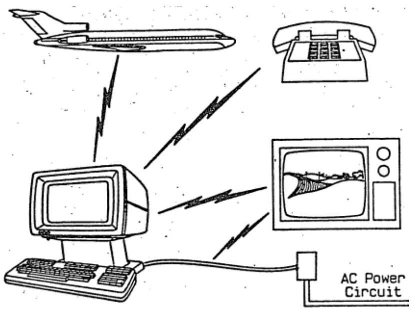
EMI/EMC in Motion Systems

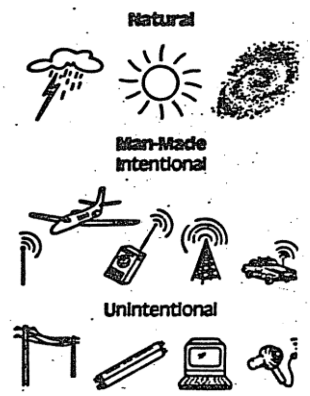
Contents

Email: norbertcheung@szu.edu.cn
Web Site: norbert.hk

1. The EMI/EMC Problem

1. Internal Problems
2. Susceptibility from the outside
3. Emission to the environment via equipment or cables





The EMI Problem and Sources of EMI (natural, manmade, and unintentional)

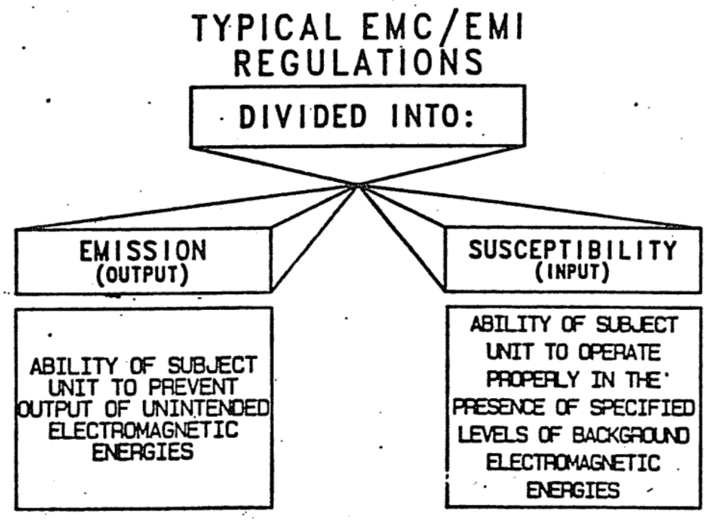
EMC Electromagnetic Compatibility – The ability of a device/system to operate normally, yet cause no deviations in the normal operation of other devices/systems in its intended electromagnetic surroundings

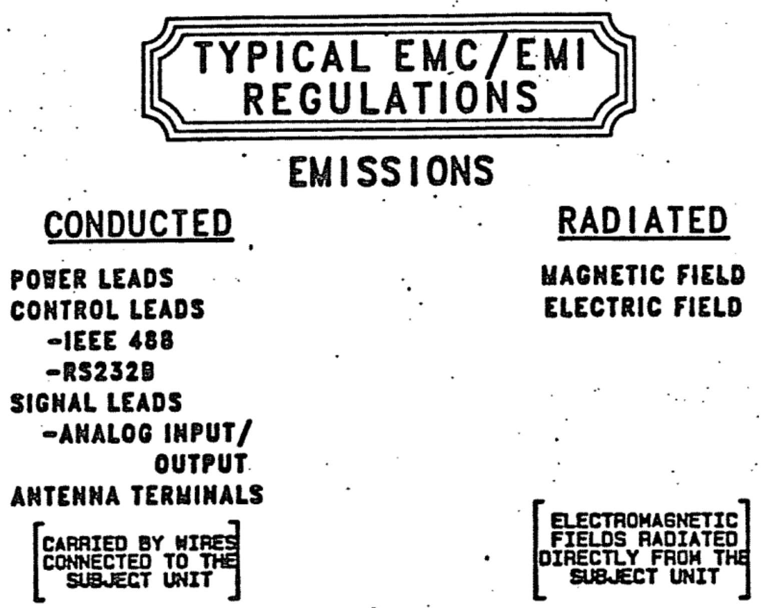
EMI Electromagnetic Interference – The disruption of normal operation of a device/system (victim) caused by the presence of undesirable or unintended electromagnetic energies emanating from another device/system (source).

Ambient – surroundings around equipment
E Field – Electric Field V/m
H Field - Magnetic Field T
Far field - $>30\lambda$
Near Field - $<30\lambda$

Frequency Bands

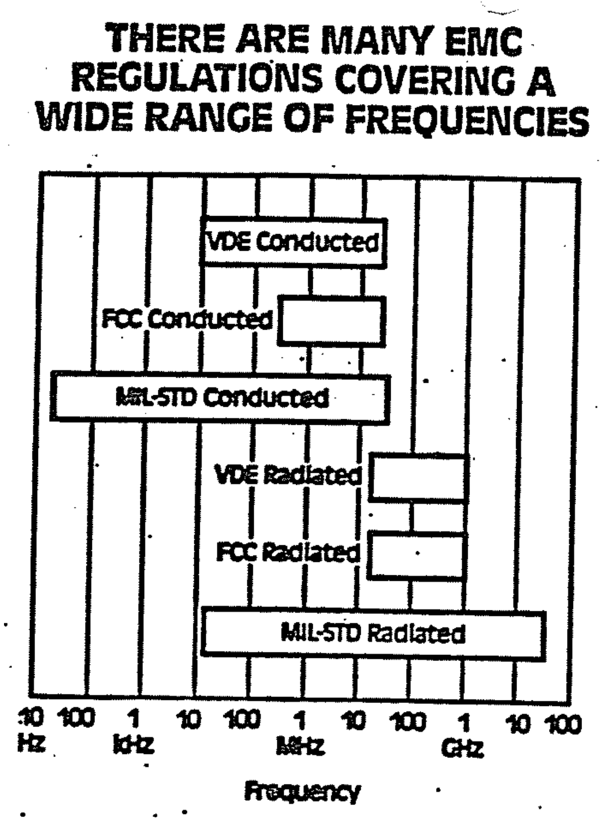
	SUB AUDIO	≡ LESS THAN 10 HERTZ
	AUDIO	≡ 10 TO 20,000 Hz
ELF	≡ EXTREMELY LOW FREQUENCY	≡ 30 TO 300 Hz
VF	≡ VOICE FREQUENCY	≡ 300 TO 3000 Hz
VLF	≡ VERY-LOW FREQUENCY	≡ 3 TO 30 KILOHERTZ
LF	≡ LOW FREQUENCY	≡ 30 TO 300 KHz
MF	≡ MEDIUM FREQUENCY	≡ 300 TO 3000 KHz
HF	≡ HIGH FREQUENCY	≡ 3 TO 30 MEGAHERTZ
VHF	≡ VERY-HIGH FREQUENCY	≡ 30 TO 300 MHz
UHF	≡ ULTRA-HIGH FREQUENCY	≡ 300 TO 3000 MHz
SHF	≡ SUPER-HIGH FREQUENCY	≡ 3 TO 30 GIGAHERTZ
EHF	≡ EXTREMELY HIGH FREQUENCY	≡ 30 TO 300 GHz
MW	≡ MICROWAVES	≡ 1 GHz TO 30 GHz
MMW	≡ MILLIMETER WAVES	≡ 30 TO 300 GHz

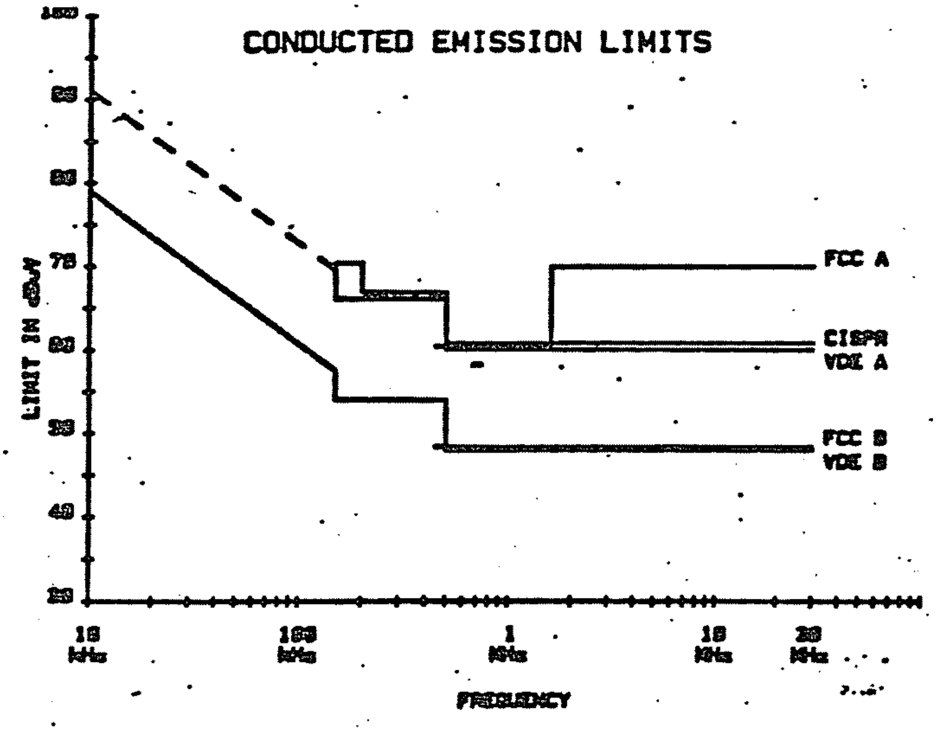




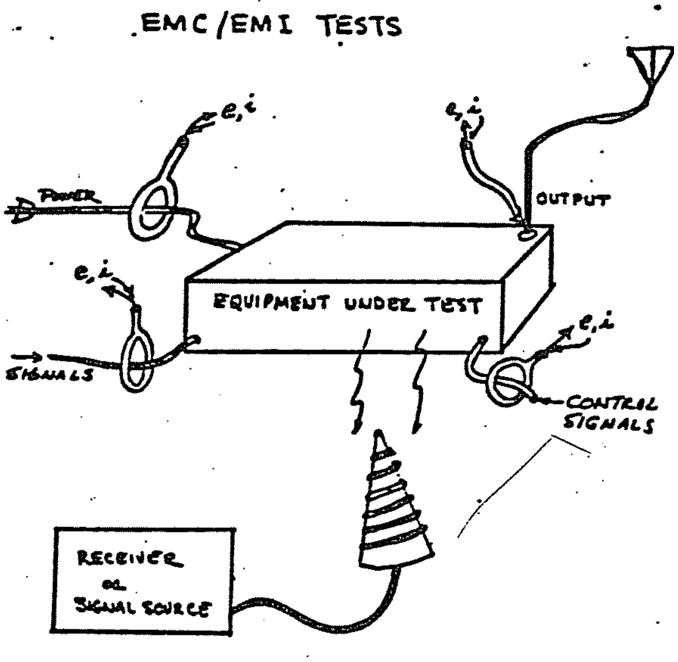
Who makes the rules?
FCC (US), VDZ (Germany), EN Standard (Europe) etc.

2. The Emission Standards





How to test the emission level of equipment?



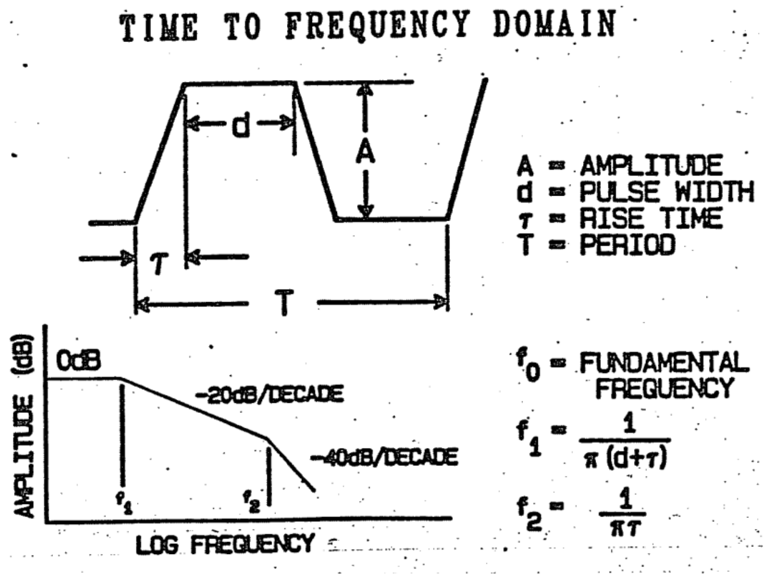
3. Digital Signal Interference

NOISE BANDWIDTH OF COMMON IC's

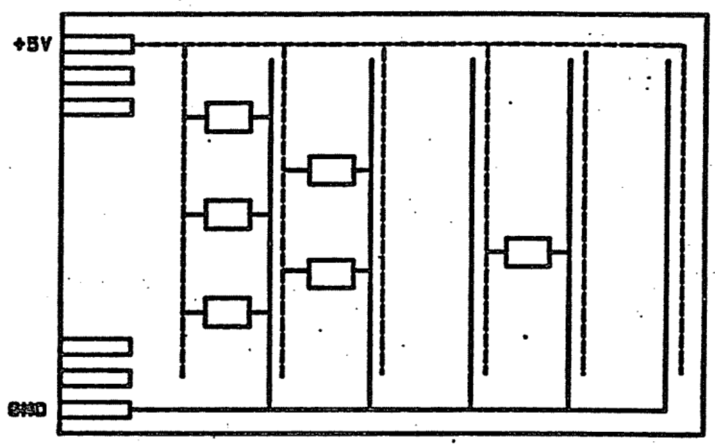
	RISE TIME v/ηs	INPUT CAPACITANCE pf	Δf 1/πτ mHz
CMOS	0.05	5	3
LP-TTL	0.2	5	21
TTL	0.3	5	32
LS-TTL	0.35	6	40
S TTL	1.0	4	120
ECL-10K	0.4	3	160

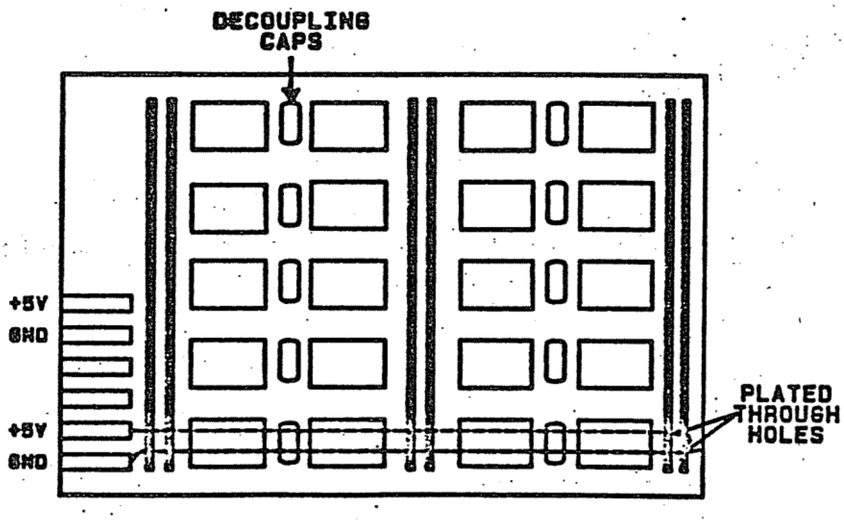
Different types of logic gates have different noise interference levels.

We can also (approximately) estimate the noise spectrum through the observation of the digital waveform.

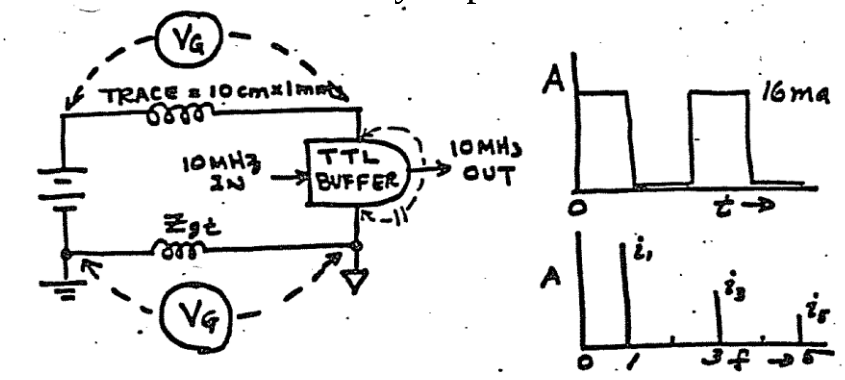


Therefore it is very important to properly layout the power and ground lines.





Each line on the PCB trace is very important.



TYPICAL TRACE: 1MM WIDE. @ 10 MHz, L = 7 OHMS
@ 50 MHz, L = 36 OHMS

IF I_1(PEAK) = 16 MA, FIFTH HARMONIC I_5(PEAK) = 2 MA,
THEN VG = 2 x 36 = 72 MV

LOOK UP CHART: 50 MHz/ 1CM/ 1A = +90 DBµV/M AT 10 M DISTANCE.

FROM CHART: 1MA = .001A = -60 DB
2MA = .002A = 6 DB = -54 DB

IF TRACE IS 10 CM, THEN = +20 DB

TOTAL EFFECTIVE SIGNAL = +56 DBµV/METER

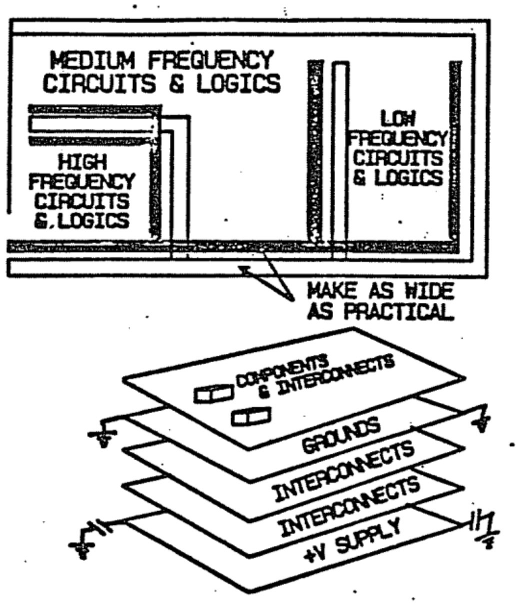
WHAT IS FIELD STRENGTH? +60 DBµV/M = 1 MV/METER.

60 - 56 = 4 DB = RATIO OF 0.63, THEREFORE 56 DBuV = 0.63 MV/M

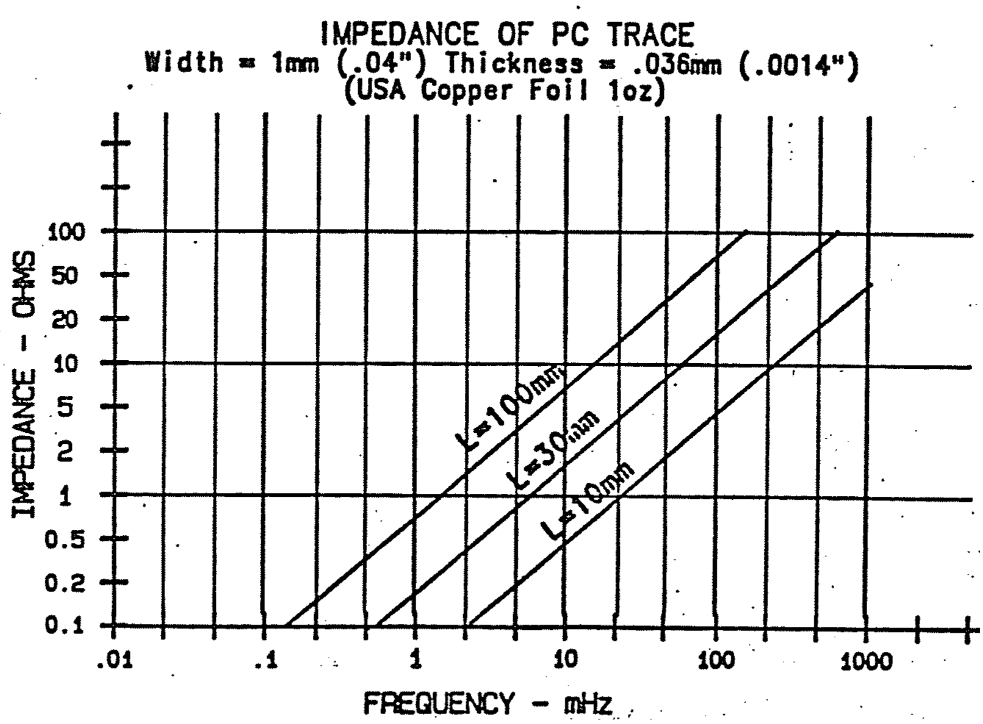
PCB design rules:

1. Avoid large loops in traces carrying current
2. Use separate grounds for large signals, make them wide
3. Run V+ and ground traces adjacent or on opposite sides
4. Use wide traces for V+ and grounds
5. On multi-layer boards, place EMI critical traces between Ground and V+
6. Cut corners to reduce reflections on traces carrying fast pulse
7. Choose as slow a logic component as possible
8. Use decouple capacitors between each pair of ICs. Keep leads short. Choose capacitors with high resonant frequency.
9. For switched mode power supplies, locate traces directly on opposite sides of the PCB to reduce the loop area.

PCB with low and high frequencies operation:



Trace impedance on the PCB

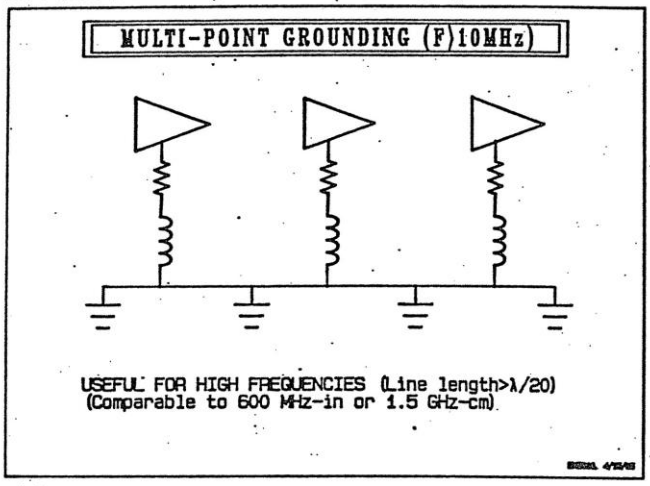


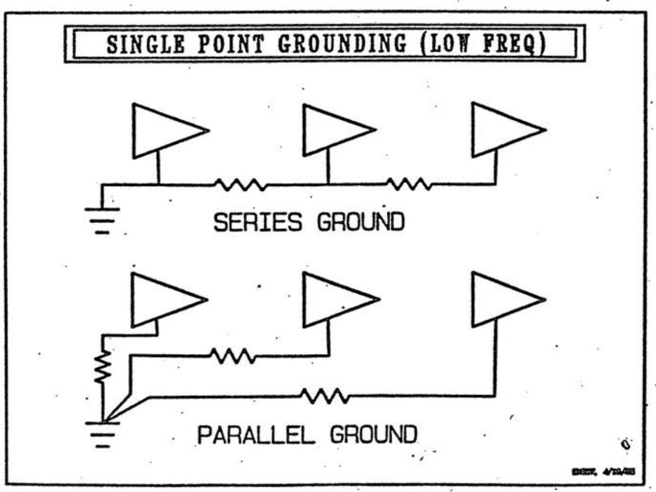
Checklist of Minimizing EMI on the PCB (especially for digital circuits)

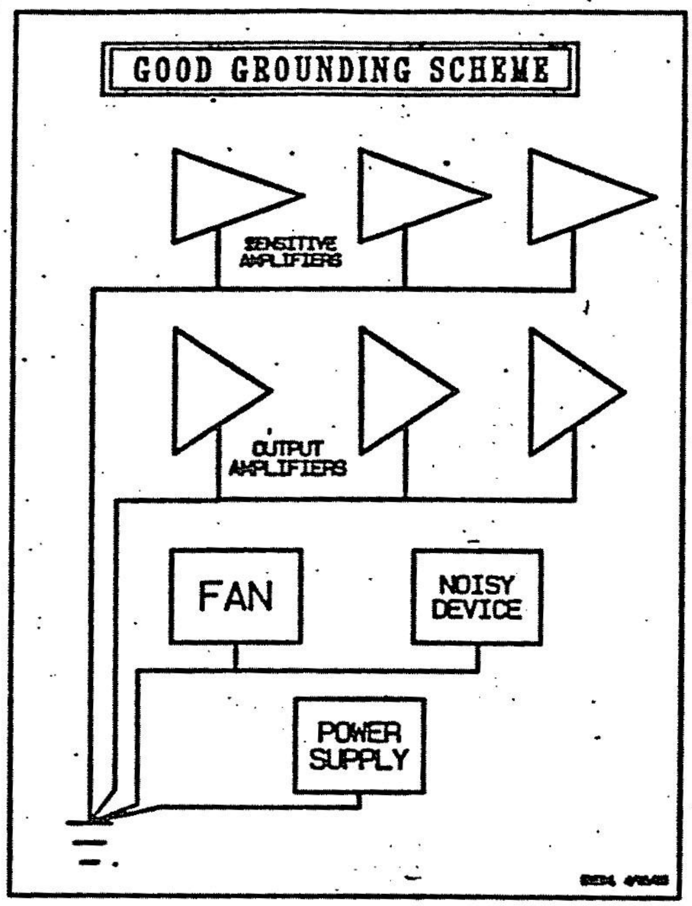
1. Elimination of Source
2. Isolation
3. Orientation
4. Shielding
5. Filtering
6. Grounding
7. Balancing
8. Impedance Level Control
9. Cable design
10. Cancellation techniques

4. Grounding and Filtering

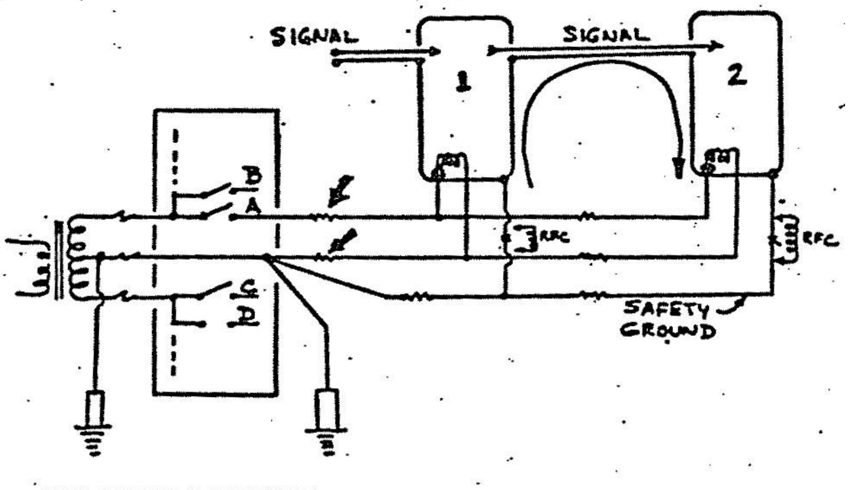
Different operating frequency requires different treatment





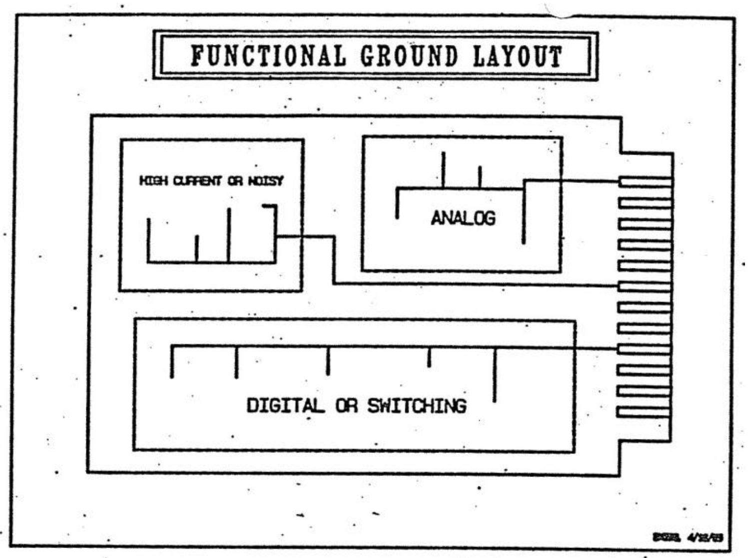


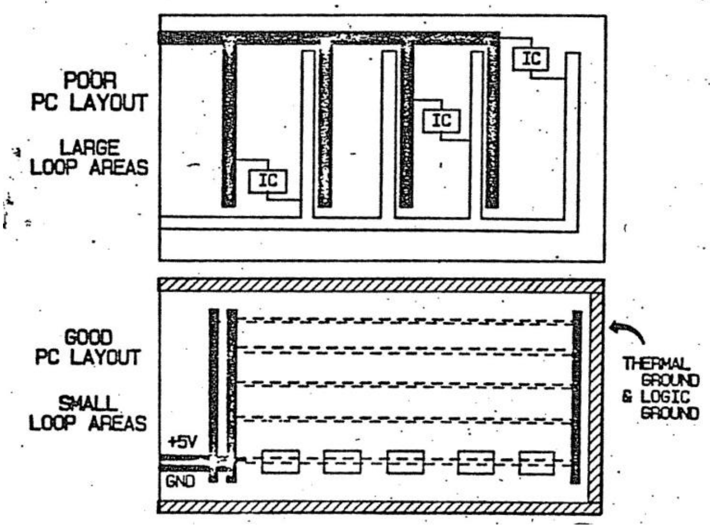
EMI CONTROL IN POWER MAINS



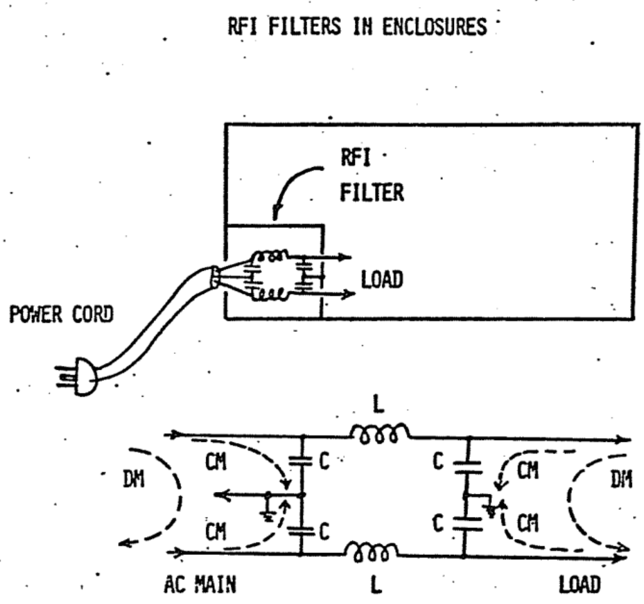
SOME POSSIBLE SOLUTIONS:

1. USE SEPARATE POWER LINES FROM BOX 2 TO A
2. " " " " " " " B
3. " " " " " " " C
4. PLACE FILTERS ON POWER LINES AT EQUIPMENT.
5. USE ISOLATION TRANSFORMER ON POWER LINES.
6. USE R-F CHOKES (INDUCTORS) IN SAFETY GROUND WIRE.

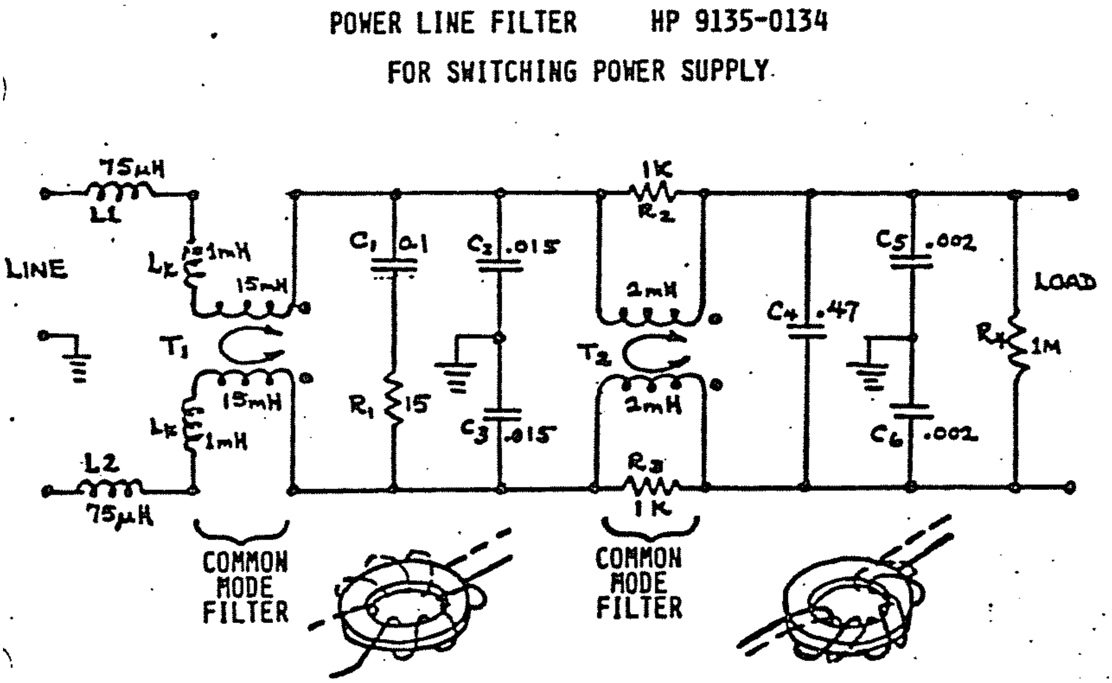


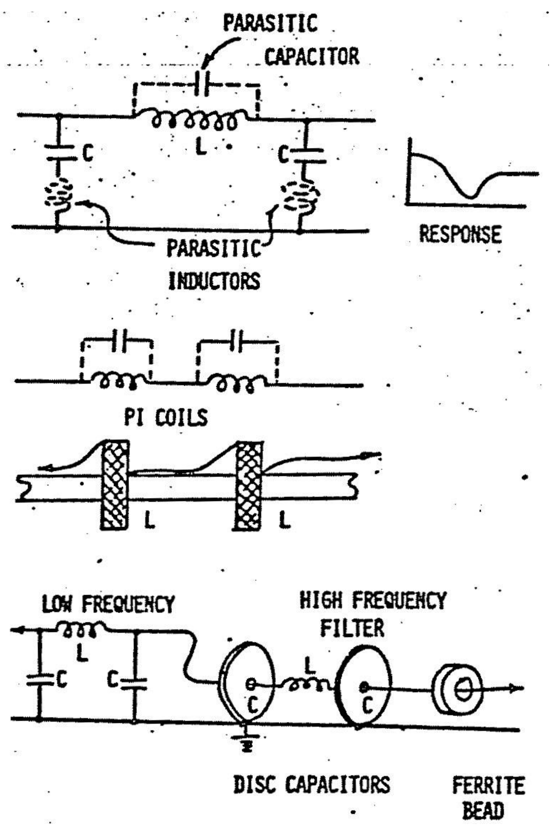


It is very important to put the filter in the right location



The filter should filter out the differential noise as well as the common mode noise.

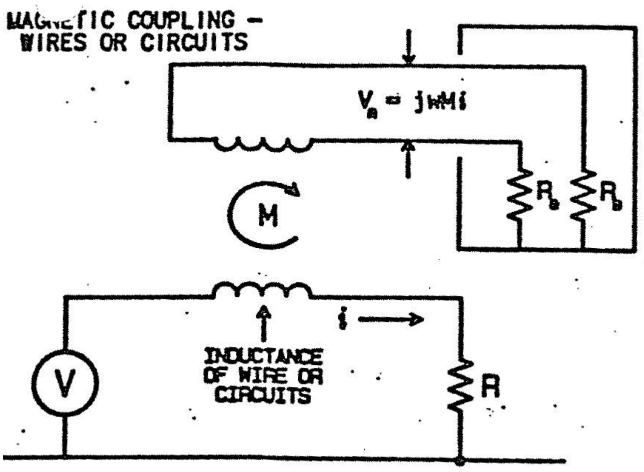




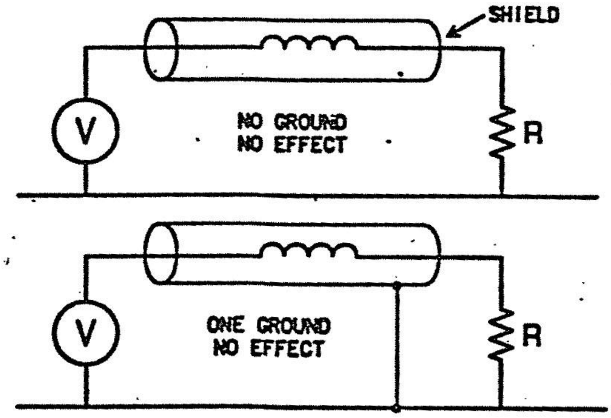
Differential Mode Line Filter at different frequencies

5. Cables and Coupling Problems

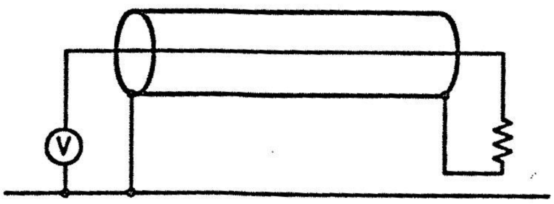
Effect on magnetic coupling through large current loops:



MAGNETIC COUPLING – WIRES OR CIRCUITS

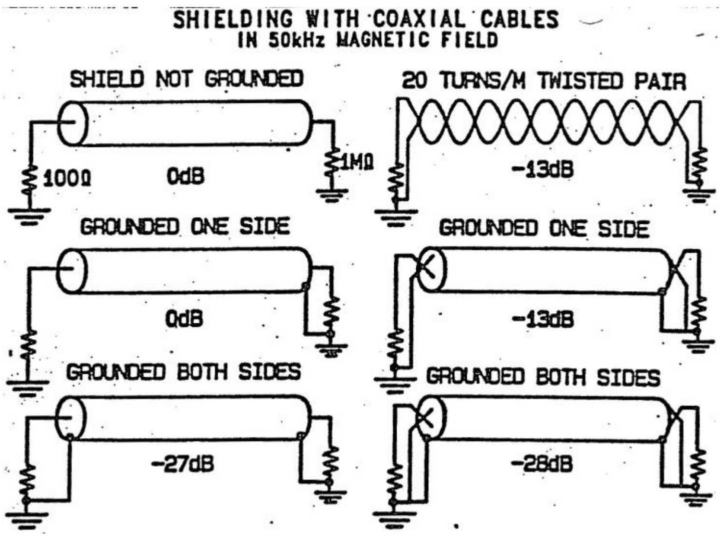


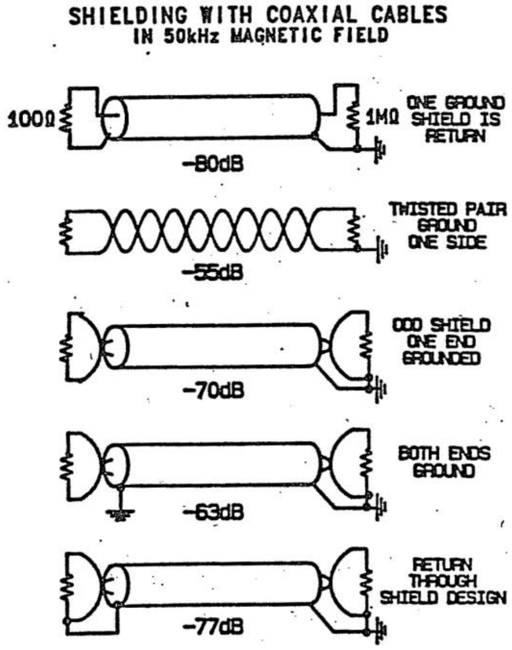
CURRENT RETURN THROUGH SHIELD

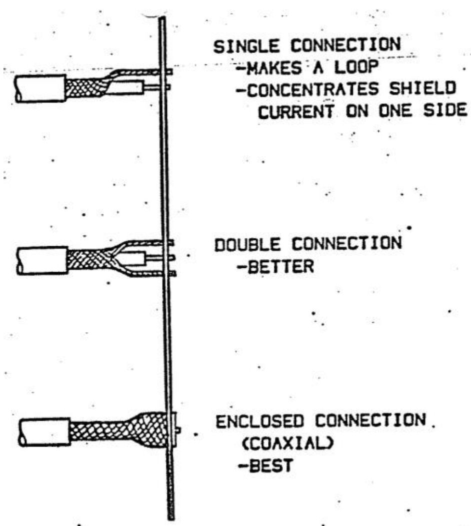


NO CURRENT THROUGH GROUND
NO LOOP TO RADIATE

To shield the magnetic field, we must apply special technique. The effectiveness of each technique is shown on the diagrams on the next page

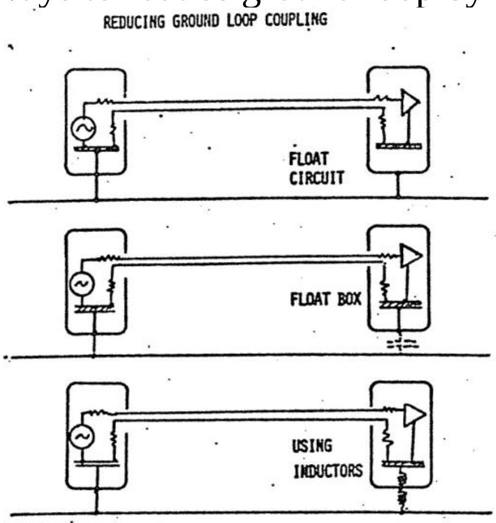


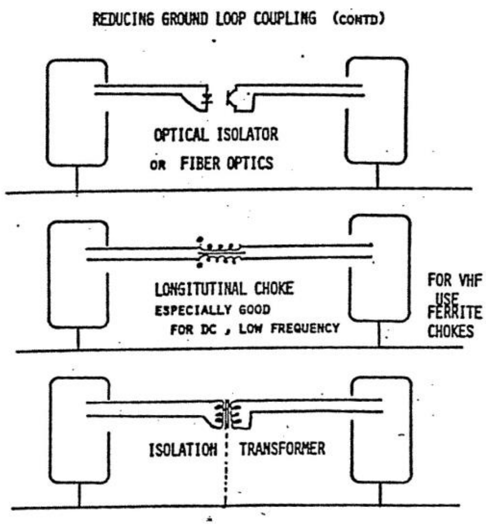




SHIELD GROUNDING TECHNIQUES

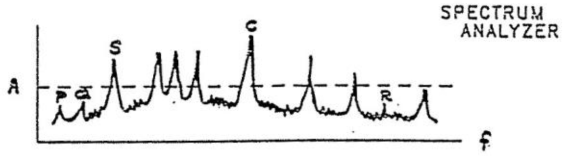
Ways to reduce ground loop by special coupling arrangement:





SUMMARY
GETTING STARTED – SOLVING AN EMI PROBLEM

MEASURE:

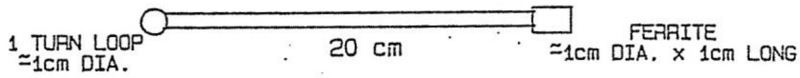


ANALYZE:

WHICH ARE INTENTIONAL (USEFUL) SIGNALS? S,C,P,Q,R
WHICH ARE NON-INTENTIONAL (NOT USEFUL) SIGNALS?
- ARE SOME NON-COHERENT (NOISE, BB) SIGNALS?

FIND/IDENTIFY:

TURN SOURCES ON/OFF AND WATCH SPECTRUM ANALYZER
TURN ON/OFF/SHORT MIXERS, BUFFER, DIVIDERS, CLOCKS, FLIP-FLOPS, GATES, ETC.
PROBE NEAR COMPONENTS WITH EMI USING LOOPS, FERRITE;



EMI REDUCTION CHECKLIST

REDUCING NOISE AT THE SOURCE

- MINUMIZE LOOPS CONTAINING PULSE CURRENTS
- SHIELD NOISE SOURCES AT THE MODULE LEVEL
- FILTER LEADS LEAVING A NOISY MODULE
- USE TWISTED WIRE PAIRS TO CANCEL NOISE
- USE SHIELDED WIRES WHERE NECESSARY
- USE PULSES WITH SLOWEST POSSIBLE RISE TIME

REDUCING NOISE COUPLING

- ROUTE LEADS WITH LOW LEVEL SIGNALS NEAREST CHASSIS
- USE TWISTED WIRE PAIRS
- USE COAX CABLES AT THE HIGHER FREQUENCIES & GROUND BOTH ENDS
- USE COAX CABLES AT LOWER FREQUENCIES WITH ONE END GROUNDED
- USE SEPARATE GROUNDS FOR HIGH AND LOW LEVEL SIGNALS
- USE SEPARATE PINS ON CONNECTORS FOR SIGNAL GROUNDS
- ON RIBBON CABLES, PLACE NOISY SIGNAL ON EDGE NEXT TO A GROUND

REDUCING GROUND COUPLING

- MAKE GROUND LEADS SHORT AS POSSIBLE
- SEPARATE NOISY AND QUIET GROUNDS
- AVOID GROUND LOOPS
- INSTALL CIRCUIT GROUNDS SEPARATE FROM CHASSIS GROUNDS
- USE STAR LOCK WASHERS TO BREAK PAINT FOR GROUND ON CHASSIS
- FOR HIGH FREQUENCIES, USE A SINGLE GROUND
- MOUNT COMPONENTS SECURELY TO PREVENT ACCIDENTAL GROUNDS
- USE BALANCED CIRCUITS WHERE NECESSARY TO AVOID GROUND LOOPS

OTHER REDUCTIONS

- INSTALL LOW IMPEDANCE LINES FOR POWER LINES
- KEEP SENSITIVE LEADS SHORT
- PLACE SENSITIVE CIRCUITS INSIDE A SHIELDED ENCLOSURE
- FILTER LEADS TO SENSITIVE CIRCUITS IN AN ENCLOSURE
- LEADS BEYOND THE CABLE SHIELD SHOULD RE SHORT AS PRACTICAL

REDUCING NOISE TO A RECEIVER OR SENSITIVE CIRCUITS

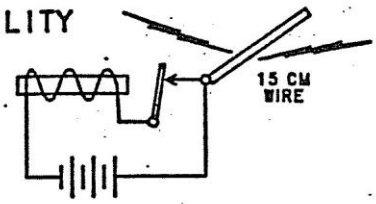
- LIMIT BANDWIDTH ONLY TO THAT NECESSARY
- SEPARATE SENSITIVE AND NOISY CIRCUITS
- DECOUPLE THE POWER SOURCES
- USE A SMALL BYPASS CAPACITOR IN PARALLEL WITH ELECTROLYTICS
- CONNECT CASE OR OUTSIDE FOIL END OF CAPACITORS TO GROUND
- IF NECESSARY, USE SHIELDED ENCLOSURE
- USE FREQUENCY SELECTIVE FILTERS WHERE PRACTICAL

SUMMARY STEPS

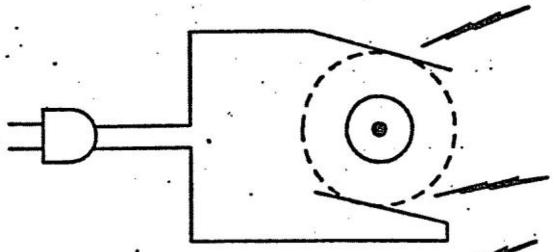
1. ELIMINATE
2. ISOLATE
3. REORIENT
4. SHIELD
5. FILTER
6. GROUND
7. BALANCE/CANCEL
8. IMPEDANCE CONTROL
9. CABLE DESIGN
10. MINIMIZE LOOPS
11. PC TRACE REDESIGN
12. MINIMIZE/MOVE RESONANCE
13. ELIMINATE NON-LINEAR DEVICES

SOURCES FOR TESTING SUSCEPTIBILITY

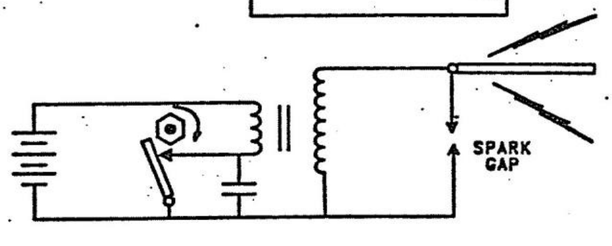
1. CHATTERING RELAY WITH 15 CM ANTENNA



ELECTRIC APPLIANCE WITH BRUSH TYPE MOTOR, ESPECIALLY GOOD FOR CONDUCTED EMI (i.e. SHAVER, ELECTRIC DRILL)



3. IGNITION COIL



--- END ---