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WIRING DESIGN FOR THE CONTROL OF ELECTROMAGNETIC INTERFERENCE (EMI)

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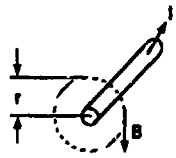
- **WIRING DESIGN IS ONLY ONE IMPORTANT ASPECT OF EMI CONTROL. OTHER IMPORTANT AREAS FOR EMI CONTROL ARE:**
  - CIRCUIT DESIGN
  - FILTERING
  - GROUNDING
  - BONDING
  - SHIELDING
  - OTHER AREAS LIKE; LIGHTING, ELECTROSTATIC DISCHARGE (ESD), TRANSIENT SUPPRESSION, AND ELECTROMAGNETIC PULSE (EMP).

- **A WIRE CARRYING CURRENT GENERATES MAGNETIC AND ELECTRIC FIELDS DESCRIBED BY MAXWELL'S EQUATIONS, AND FUNCTIONS AS AN ANTENNA. THE CABLE EFFICIENCY OF THE ANTENNA DEPENDS ON ITS LENGTH COMPARED TO THE WAVELENGTH OF THE SIGNAL.**

- **LOW FREQUENCY EMISSIONS ARE CONSIDERED WHERE THE LENGTH ~~OF~~ OF THE WIRE IS LESS THAN 10% OF THE SIGNAL WAVELENGTH, WHICH IS NORMALLY THE CASE WITH POWER CABLES.**

- **COUPLING MACHENISMS ARE:**
  - CONDUCTIVE, E.G., COMMON MODE NOISE
  - INDUCTIVE (RADIATING MAGNETIC FIELD), E.G., CURRENT IN A CABLE
  - CAPACITIVE (RADIATING ELECRIC FIELD), E.G.. HIGH TENSION LINES

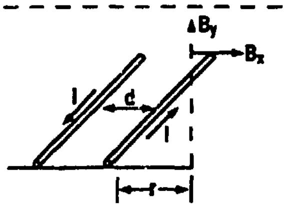
- **WIRE MAGNETIC FIELD EMISSIONS AT LOW FREQUENCIES**



SINGLE WIRE

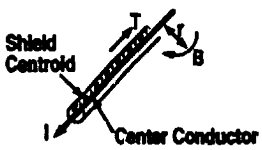
$$B = \frac{\mu_o I}{2\pi r}$$

B(Weber/m^2) - Magnetic Flux Density
$\mu_o = 4\pi 10^{-7}$ H/m



PARALLEL PAIR

$$B_{max} = |B_y| = \frac{\mu_o Id}{2\pi r(r+d)} \cong \frac{\mu_o Id}{2\pi r^2}$$

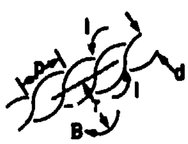


COAXIAL CABLE

Effective Eccentricity, δ

$$B_{max} = \frac{\mu_o I\delta}{2\pi r(r+\delta)}$$

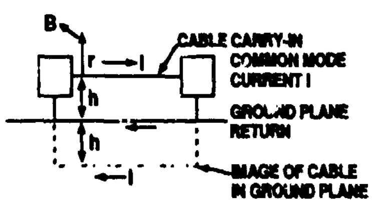
- **WIRE RADIATED MAGNETIC FIELD EMISSIONS AT LOW FREQUENCIES**



TWISTED PAIR CABLE

$$B_{max} = \frac{\mu_o I}{pr} \, q \, I_o(q) \, e^{-2\pi r/p} \qquad q = \frac{\pi d}{p}$$

$I_o(q)$ is a oth order modified Bassel function of 1st kind



COMMON MODE

$$B_{max} = \frac{\mu_o I2h}{2\pi r(r+2h)}$$

ELECTRIC FIELD PICK UP DUE TO MAGNETIC FIELD EMISSIONS

$$E = A \frac{dB}{dt}$$

A - loop area

WIRE DESIGN GUIDELINES FOR EMI CONTROL

- **WIRE DESIGN APPROACHES FOR EMI CONTROL**
  - PARELLEL WIRE PAIR
  - WIRE PAIR TWISTING
  - COAXIAL DESIGN
  - BALANCED LINES
  - FLAT CABLE

- PARALLEL WIRE PAIR, ASSUMING THE CURRENT IS A PERFORMANCE REQUIREMENT AND CAN NOT BE CHANGED, AND THE DISTANCE "r" IS A GEOMETRICAL OR SPECIFICATION CONSTRAINT, THEN "d" CAN BE MADE AS SMALL AS THE WIRE INSULATION WILL ALLOW. THIS IS AN EFFECTIVE WAY OF REDUCING MAGNETIC FIELD EMISSION FROM A WIRE PAIR. IF r CAN BE CHANGED THEN ATTENUATION IS 40 dB PER DECADE OF DISTANCE CHANGE.

- IDEALLY THE COAX CABLE HAS NO MAGNETIC FIELD EMISSIONS, BUT BECAUSE OF MANUFACTURING TOLERANCES SOME ECCENTRICITIES "δ" WILL BE PRESENT. THE COAX CAN BE REPLACED FOR ANALYTICAL PURPOSES BY A WIRE PAIR SEPARATED BY THIS ECCENTRICITY "δ".

- THE SINGLE WIRE WITH A GROUND PLANE RETURN IS TYPICAL EXAMPLE OF DC POWER ON AIRCRAFT, WHERE THE AIRCRAFT SKIN FUNCTIONS AS THE RETURN. USING THE IMAGE THEORY THIS ARRANGEMENT CAN BE REPLACED BY A WIRE PAIR SEPARATED BYA DISTANCE "2h". CONTROLLING THIS DISTANCE, KEEPING IT TO A MINIMUM, WILL LIMIT THE MAGNETIC FIELD.

- FOR THE TWISTED PAIR THE DIRECTION OF CURRENT FLOW IN ADJACENT LOOPS IS OPPOSITE. AT AN OBSERVATION POINT, SITUATED SYMMETRICALLY BETWEEN THE LOOPS, THE MAGNETIC FIELD VECTORS FROM EACH LOOP CANCEL EACH OTHER. AS EACH LOOP CANCELS THE FIELD FROM ITS NEIGHBOR, THE ONLY UNCANCELLED LOOPS WILL BE AT THE EXTREME ENDS.
  - THE FIELD DROPS OFF AT A RATE OF 60 dB/DECADE CHANGE IN DISTANCE
  - AT CLOSE DISTANCE THE LOOP DIAMETER OR PITCH OF TWIST HAVE DOMINATE EFFECTS
  - PRACTICAL LIMIT IS 60 dB
  - AT HIGH FREQUENCIES ATTENNATION DROPS OFF WHEN THERE IS PHASE DIFFERENCE OF THE CURRENT IN THE WIRE.
  - HIGH FREQUENCY LIMITATION

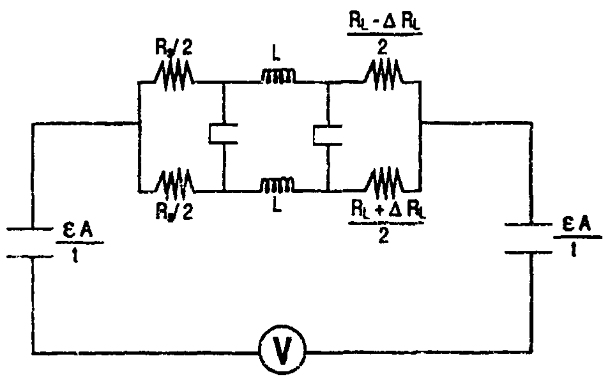
$$|H| = \frac{H_0}{N} \cdot \frac{\sin(\pi S/\pi\lambda)}{\cos(\pi S/N\lambda)}$$

H_0 - Magnitude of Field of Untwisted Pair
S - Length of Untwisted Wire

  - REDUCTION OF PICKUP DUE TO TWISTING COMPARED TO A PARALLEL WIRE PAIR IS EXPRESSED IN TERMS OF THE RATION OF THEIR AREAS
  - TWISTING HAS LITTLE EFFECT ON THE REDUCTION OF ELECTRIC FIELD EMISSIONS. THESE SHOULD BE SUPPRESSED BY AN OVERALL SHIELD.

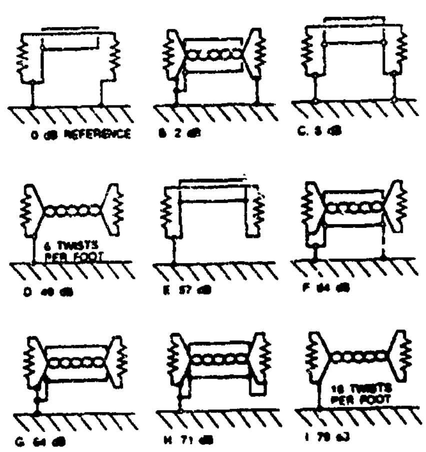
WIRE DESIGN GUIDELINES FOR EMI CONTROL

- BALANCED WIRE PAIRS, EFFECTIVE IN LIMITING COMMON-MODE PICKUP AND EMISSIONS
  - BALANCED SYSTEMS CAUSES EQUAL VOLTAGE DROPS ON EACH WIRE CANCELING EACH OTHER
  - DEGREE OF UNBALANCE IS CHARACTERIZED BY $\pm \Delta R_L$ WITH THE FOLLOWING EQUIVALENT CIRCUIT



$$CMRR = 20 \log \left(\frac{V_{CM}}{V_{DM}}\right)$$

- FLAT CABLE, BASIC CHARACTERISTIC RELATIVE TO EMISSION IS THAT IT ACTS AS LOW PASS FILTER, NOT ALLOWING CURRENT AT HIGH FREQUENCIES AND ASSOCIATED REDUCTION IN MAGNETIC FIELD EMISSIONS



*PREFERRED CIRCUIT FOR HIGH FREQUENCIES
VALUES GIVEN ARE FOR CIRCUITS 1" ABOVE GROUND PLANE BUT ARE ABOUT THE SAME FOR OTHER DISTANCES FROM GROUND PLANE

A. BASELINE REFERENCE, GROUND PLANE AS THE RETURN

B. UNBALANCED TWISTED PAIR

C. SHIELD GROUNDED AT BOTH ENDS

D. TWISTED PAIR

E. CO... INTO A BALANCED LOAD

F. TWISTED BALANCED PAIR

G. TWISTED PAIR

H. SIMILAR TO G

I. TIGHT TWIST

RELATIVE SUSCEPTIBILITY TO MAGNETIC INTERFACE

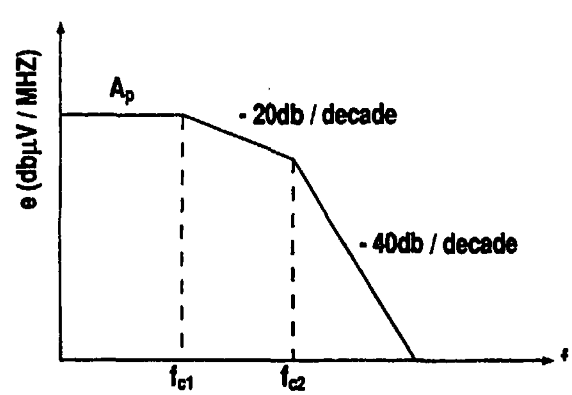
HIGH FREQUENCY EMISSIONS FROM CABLES

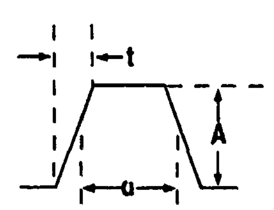
- AT HIGH FREQUENCIES SOURCES OF RADIATION ARE DIVIDED INTO TWO BASIC TYPES, ELECTRIC DIPOLE AND MAGNETIC DIPOLE
- ELECTRIC DIPOLES HAVE HIGH IMPEDANCE, LOW CURRENTS, WHERE MAGNETIC DIPOLES HAVE LOW IMPEDANCE, HIGH CURRENTS
- THE ELECTRICAL DIPOLE STRENGTH IS PROPORTIONAL TO 'CVL', WHERE 'C' IS THE CAPACITANCE BETWEEN THE ELEMENTS OF DIPOLE, 'V' IS THE VOLTAGE DRIVING THE DIPOLE, AND 'L' IS THE DISTANCE BETWEEN THE DIPOLE ELEMENTS.
- THE MAGNETIC DIPOLE STRENGTH IS PROPORTIONAL TO 'IA', WHERE 'I' IS THE CURRENT THROUGH THE MAGNETIC DIPOLE AND 'A' IS THE AREA OF THE MAGNETIC DIPOLE LOOP.

REDUCING THE STRENGTH OF THE ELECTRIC DIPOLE IS IMPORTANT TO MINIMIZE ITS AREA (LENGTH OF WIRES AND THEIR SPACING) REDUCING THE AREA OF THE MAGNETIC DIPOLE RESULTS IN REDUCTION IN EMISSIONS. IN ADDITION REDUCING HIGH FREQUENCY COMPONENTS OF 'V' AND 'I' REDUCES EMISSIONS BECAUSE BOTH DIPOLES ACCENUATE HIGH FREQUENCY. THE DISTANCE FROM THE DIPOLE IS ANOTHER CONTROL PARAMETER.

PULSE FREQUENCY SPECTRA

- DECREASING HIGH FREQUENCY COMPONENTS IN THE CABLE VOLTAGE BY INCREASING PULSE RISE TIMES OR INSTALLING FILTERS IF THAT IS AN OPTION





DATA SIGNAL: $A_p = 20 \log (2Ad \cdot 10^6)$ $\quad f_{c1} = 1/\pi d$, A - in μV

CLOCK SIGNAL: $A_p = 20 \log \left(\frac{2Ad \cdot 10^6}{T}\right)$ $\quad f_{c2} = 1/\pi t$

ELECTRIC DIPOLE | **MAGNETIC DIPOLE**

$\beta \cdot r \ll 1$

NEAR FIELD

Electric dipole		Magnetic dipole	
$H_\phi = \frac{f \cdot C \cdot V \cdot L}{2 \cdot r^2}$	$\theta = \frac{\pi}{2}$	$E_\phi = \frac{f \cdot \mu \cdot I \cdot A}{2 \cdot r^2}$	$\theta = \frac{\pi}{2}$
$E_r = \frac{C \cdot V \cdot L}{2 \cdot \pi \cdot \varepsilon \cdot r^2}$	$\theta = 0$	$H_r = \frac{I \cdot A}{2 \cdot \pi \cdot r^3}$	$\theta = 0$
$E_\theta = \frac{C \cdot V \cdot L}{4 \cdot \pi \cdot \varepsilon \cdot r^3}$	$\theta = \frac{\pi}{2}$	$H_\theta = \frac{I \cdot A}{4 \cdot \pi \cdot r^3}$	$\theta = \frac{\pi}{2}$
$\frac{E\theta}{H\phi} = \frac{1}{2 \cdot \pi \cdot f \cdot \varepsilon \cdot r}$		$\frac{E_\phi}{H_\theta} = \omega \cdot \mu \cdot r$	

$\beta \cdot r \gg 1$

FAR FIELD

Electric dipole		Magnetic dipole	
$H_\phi = \frac{\pi \cdot f^2 \cdot C \cdot V \cdot L}{v \cdot r}$	$\theta = \frac{\pi}{2}$	$E_\phi = \frac{\pi \cdot f^2 \cdot \mu \cdot I \cdot A}{v \cdot r}$	$\theta = \frac{\pi}{2}$
$E_r = \frac{f \cdot C \cdot V \cdot L}{v \cdot \varepsilon \cdot r^2}$	$\theta = 0$	$H_r = \frac{f \cdot I \cdot A}{v \cdot r^2}$	$\theta = 0$
$E_\theta = \frac{\pi \cdot f^2 \cdot C \cdot V \cdot L}{v \cdot \varepsilon \cdot r}$	$\theta = \frac{\pi}{2}$	$H_\theta = \frac{f^2 \cdot \pi \cdot I \cdot A}{v^2 \cdot r}$	$\theta = \frac{\pi}{2}$
$\frac{E\theta}{H\phi} = 120 \cdot \pi$		$\frac{E\phi}{H\theta} = 120 \cdot \pi$	

$\beta = 2 \cdot \pi / \lambda \qquad v = 3 \cdot 10^8$ m/sec