# EXAMINING THE ROLE AND CONTENT OF PHYSICS ELECTRONICS COURSES

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AAPT SUMMER MEETING
BOISE STATE UNIVERSITY
AUGUST 7, 2002

Introduction

Scope of talk

- A few personal reflections ("How I got this way") [Not included below]
- How the electronics courses at Gustavus have been evolving
- Questions about electronics course objectives, content, and implementation
- Ten useful points from the practice of electromagnetic compatibility
- Questions & discussion

How the electronics courses at Gustavus have been evolving

Dick Fuller hired me at Gustavus in 1979 with the charge to improve the labs and teach the two junior-year half-credit electronics and instrumentation courses, among many others. My first task was to pull together five lab stations from the rooms full of non-functioning test equipment. Of course, we had no technician, and the Dean paid me an overload to fix stuff.

I stayed with the Diefenderfer text through 1983, but its emphasis on discrete components was already becoming dated. Over the next decade, I used the texts by Higgins, Horowitz and Hill (in both editions), Fortney, Simpson, Diefenderfer & Holton's third edition, and Barnaal. In the late 1980's Chuck Niederriter and Steve Mellema got an NSF-CSIP grant to develop a required junior-year experimental modern physics lab to replace the lab component of the sophomore modern course. That required us to put the analog electronics half-course into the fourth semester, still with two lectures and one two-hour lab each week. The digital electronics half-course, with one lecture and one three-hour lab remained for juniors, and most students took both courses.

I found that Barnaal's book matched the level of our sophomore students (including the author's son) better than the other texts, although I did a lot of supplementing, and we had our own local lab manual. I skipped the microprocessors chapters since we had a separate self-taught course using the Heathkit microprocessor trainer, until we dropped that course about 1990. Chuck and Steve were using various forms of BASIC with IEEE cards and meters in the experimental modern course, which has grown to include two three-hour labs and one or two lectures each week, in two sections.

In 1992 I received an NSF-ILI grant which, with our overmatch, brought us $72K for 14 stations of new test equipment, including Tektronix 2212 scopes with attached Bubblejet printers, Leader function generators, and other equipment. The first course expanded to three lectures per week, and coverage was extended to digital logic, with a couple of lectures on electromagnetic interference issues. A required project was added to the second course.

In 1999, Tom Huber took over the sophomore electronics course, with a goal of including more digital topics, and he raised the lab to three hours per week. We offer two lab sections with enrollments of 8-12 each. That redevelopment has continued and he has tried the text by Storey, and the engineering book by Hambley, neither of which completely covers the mix of topics we agree we need. After considerable discussion and some compromises, we will add a fourth lecture this year to the first course, and cover more sequential logic and waveshaping. I am revising the second half-course, which has treated mostly digital and advanced analog topics, to include some introduction to RF and other elective topics. This course has seen declining enrollments in recent years, and it will only be offered during our one-month January Term in alternate years, primarily for staffing reasons.

With mixed feelings, we have added three weeks of LabView at the beginning of our experimental modern course. We expect the students to build on that exposure and their prior introduction to waveshaping and one-shots in some of the following experiments that require computer data acquisition and control. It is very much a work-in-progress at this point.

Questions about electronics course objectives and content (in some order)

1. What is the course preparing students for, both locally and globally, both immediately and long-term?
a) Other sequential lab courses
b) Specific research groups or experiences
c) Engineering B.S./M.S. and dual-degree options
d) Degree requirements or electives

2. What background in circuits, laboratory methods, and calculus is assumed? This tends to peg the level and define the prerequisites.

3. What student groups will take the course?
a) Physics majors and minors
b) Pre-engineering students (perhaps included in the above)
c) Computer science students
d) Chemists, biologists, other sciences
e) Communications, arts, etc.

4. What is the desired relative emphasis on circuits, devices, and instrumentation?

5. Are specific software packages (e.g. LabView, PSpice, Circuitmaker) or computer languages (Basic, C++) part of the course objectives, or are they necessary evils?

6. What kinds of background and priorities are desirable or required for the instructor? To what extent can the course(s) be taught well by more than one person?

7. What is the optimum (or possible) mix of course and lab time?

8. What available texts, lab manuals, and teaching materials can support the course objectives?

9. What is the laboratory space and equipment situation? Are there prospects for new equipment from local resources and/or external grants?

10. Is there a technician or lab specialist to support the course? Can upper-level students assist in the labs?

11. What fraction of the specific concepts, circuits, devices, instruments, and software used in the course have long-lasting pedagogical value, and how much is temporary technology?
12. What is the relative emphasis on core topics versus electives?

13. What is the project component, if any?

14. Is there a historical or Liberal Arts component, by design or otherwise?

15. What courses, both inside and outside the department, overlap in topics or compete for the same students?

(If you can come to a consensus on all of these, you are very likely a one-person department.)

<u>Ten useful points from the practice of electromagnetic compatibility</u>

Basics and terms first:

a) Coupling mechanisms between the source and the receptor are radiation and conduction. However, radiation doesn't necessarily mean plane waves, just coupling via E&M fields. We know this.

b) EMC = Electromagnetic compatibility: A design objective or condition in which equipment is not affected by external noise sources, and is not itself a source of noise. "Thou shalt neither an emitter nor a susceptor be."

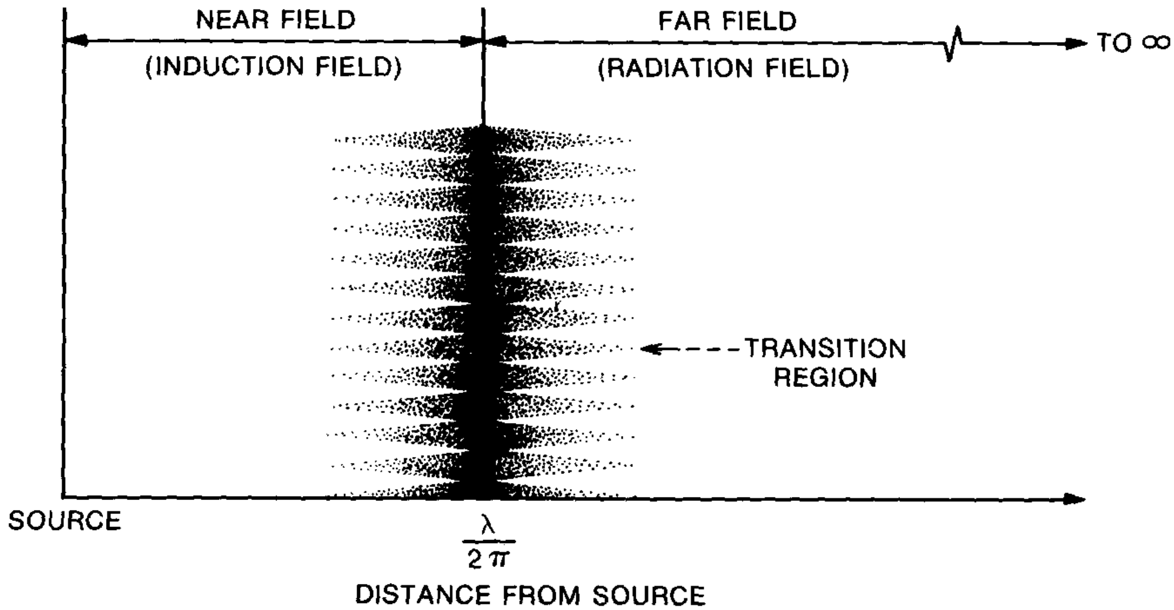
c) The inverse of immunity is susceptibility.

d) EMI = Electromagnetic interference

e) RFI = Radio-frequency interference (10 kHz-3 GHz originally, but higher now)

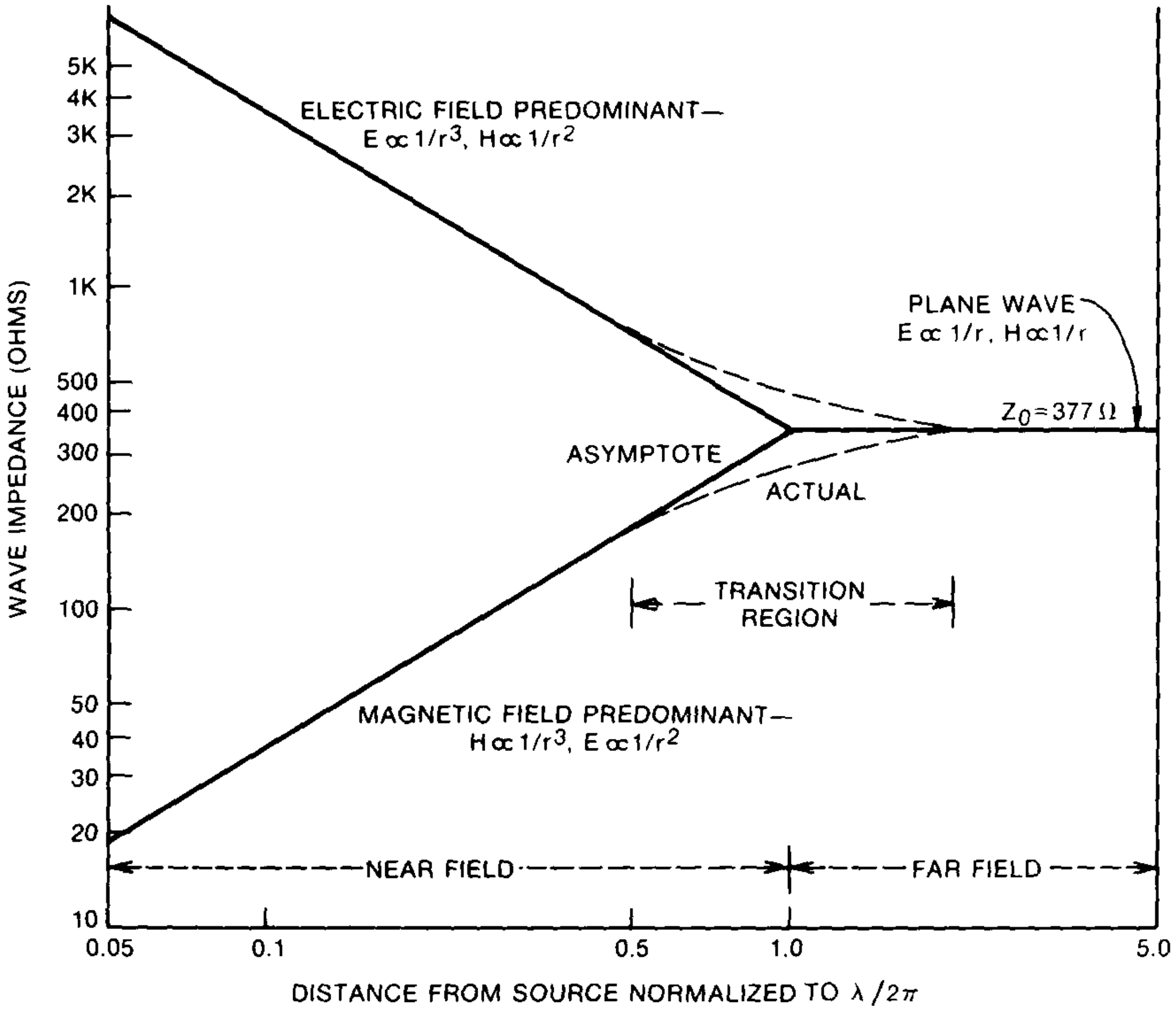
f) Grounding, filtering, and shielding are essential tools, but they must be applied carefully or they can be worse than useless.

1. Know your zone. The radiation zone (or far field) begins about $\lambda/2\pi$ away from the source. Closer than this is the induction (near field) zone, in which the E and H fields must be treated separately. [Ott Fig. 6-3]




Figures reproduced from Noise Reduction Techniques in Electronic Systems (Second Edition), Henry W. Ott, copyright © 1988 by AT&T Bell Laboratories, by permission of John Wiley & Sons, Inc. [This book should be on the shelf of every experimental physicist who works with electronics or instrumentation.]

a) The wave impedance Z = E/H is a useful way of characterizing the fields from different sources at different frequencies and distances. [Ott Fig. 6-4]




b) Other multipoles, if present, complicate the near-field case, but these have even faster fall-off with distance.

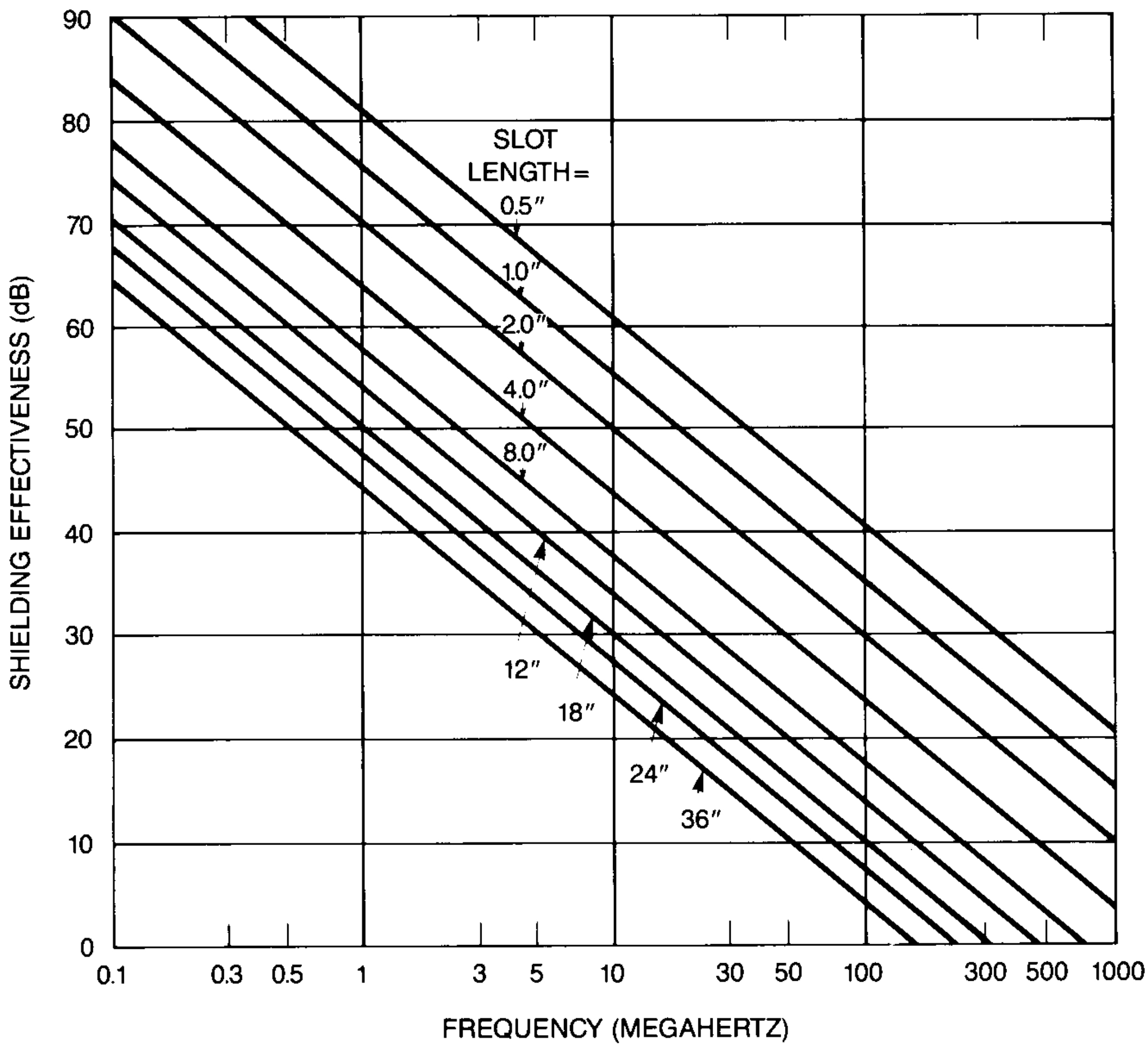
2. Every wire, coil, circuit board trace, or shield aperture can be an antenna, for both radiated emissions and pickup.

a) There are hidden schematics and antennas everywhere.

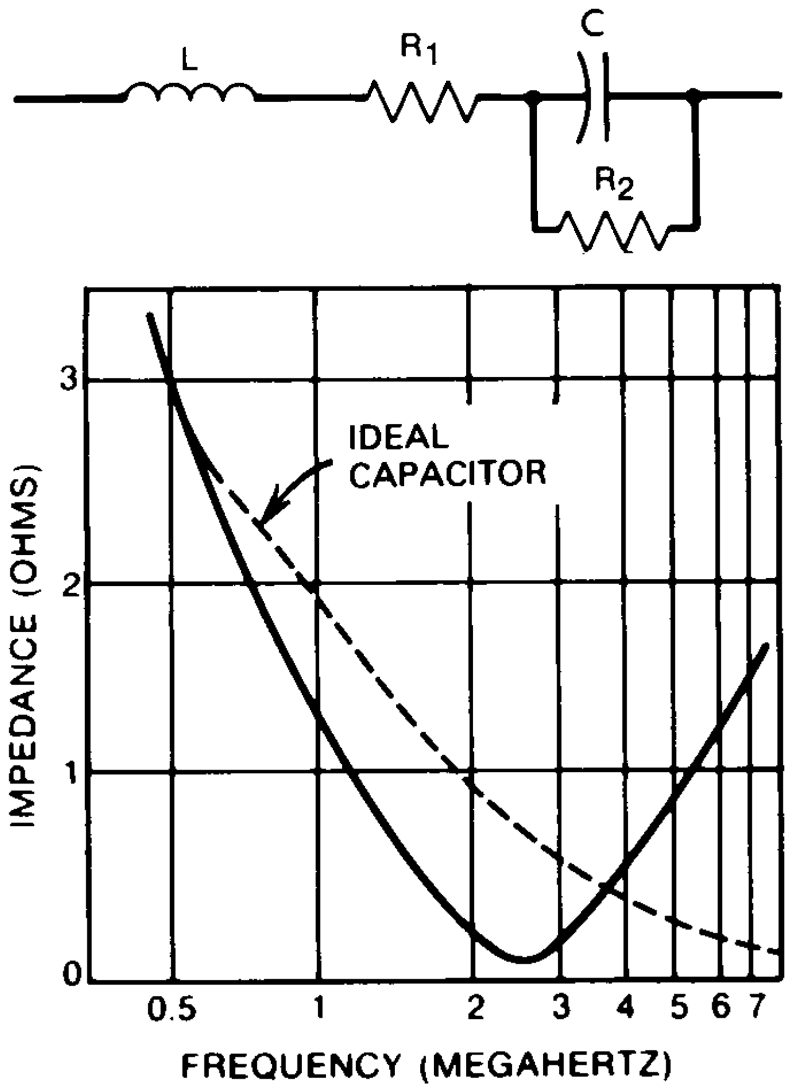
b) When the length of a conductor or the maximum dimension of an aperture in a shield gets close to λ/20, there will be radiative emissions and coupling.

c) Recall that digital signals have enormous concentrations of harmonics, and thus wavelengths much shorter than the fundamental.

d) Consider an opening in a metal enclosure the size of a 3.5" floppy disk. [Ott Fig. 6-25]



3. Discrete components and connectors are all a combination of resistance, capacitance, and self-inductance. Capacitors resonate at surprisingly low frequencies (a few MHz) and then turn into inductors above there. Inductors turn into leaky capacitors (and antennas), and resistors tend to become inductors at higher frequencies. [Ott Figs. 5-1 and 5-2]




4. "Ground" means a lot of different things. An ideal ground point is a source or sink of any amount of current at any frequency, without having its potential changed. (There are no such creatures in captivity.)

a) A signal ground is a low-impedance path for current to return to the source. Sources may be internal or external to the equipment.

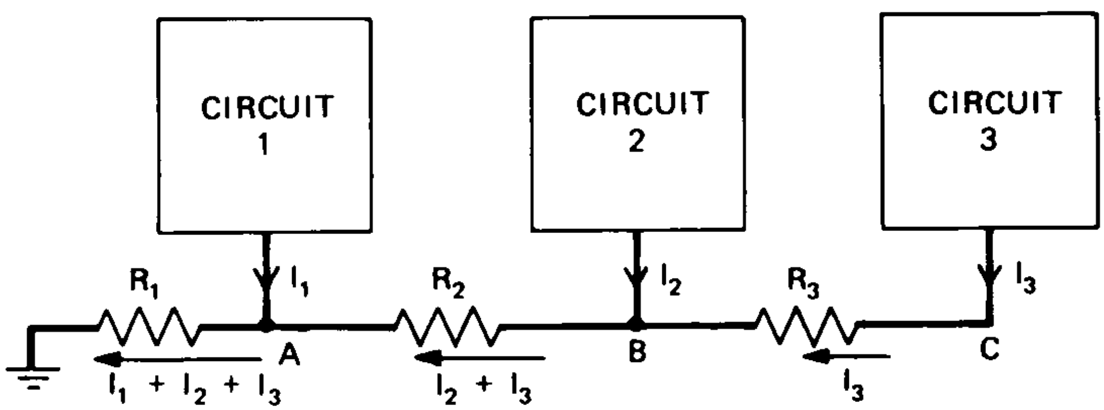
b) A safety ("green wire") ground is required by the National Electric Code in building wiring to provide a path for fault currents. Appliances with exposed chassis points require 3-prong plugs, per Underwriters Laboratory standards in the U.S.

c) Signal grounds and safety grounds are applied for different reasons and rarely have the same characteristics.

d) Guard wires and triaxial cable conductors are part of electrostatic shields and should not carry any current.

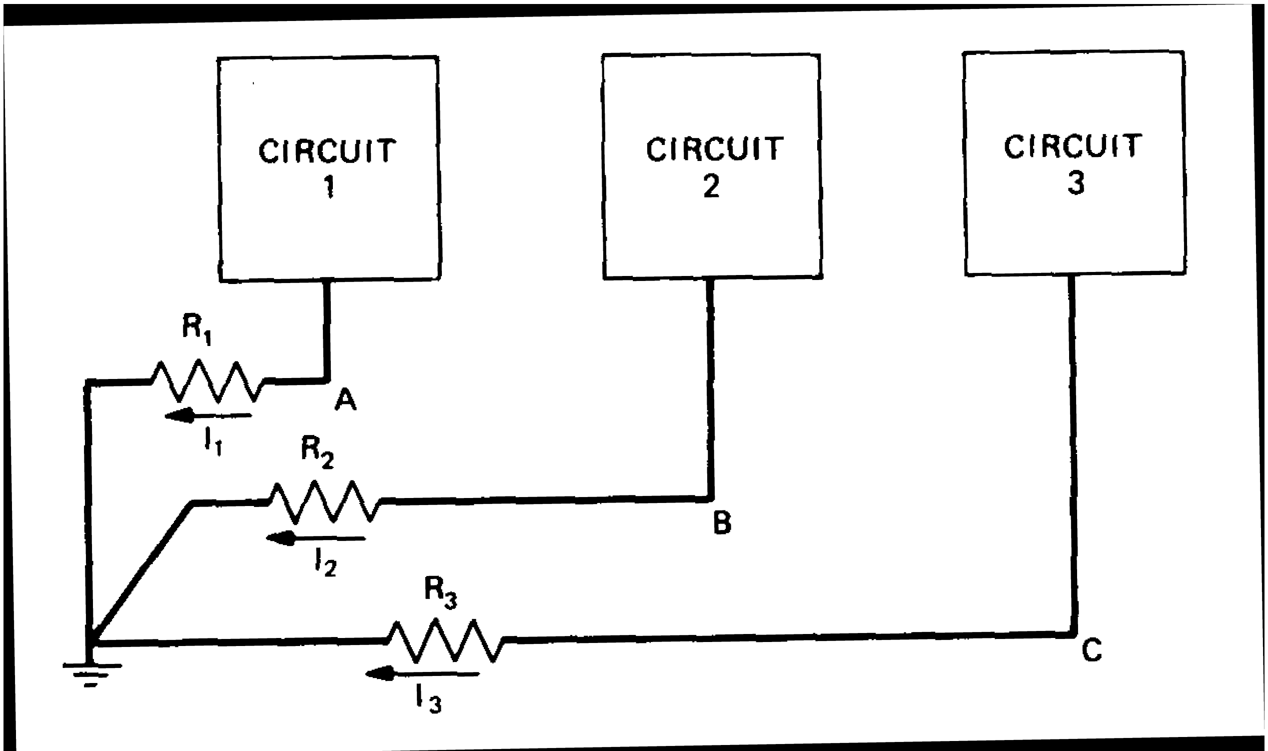
5. Signal grounding requirements:

a) Good grounding for analog signals requires single-point grounds to avoid ground loops (with their antenna-like behavior), and to avoid voltage drops between common ground points (which act as noise voltages at inputs). [Ott Fig. 3-6]

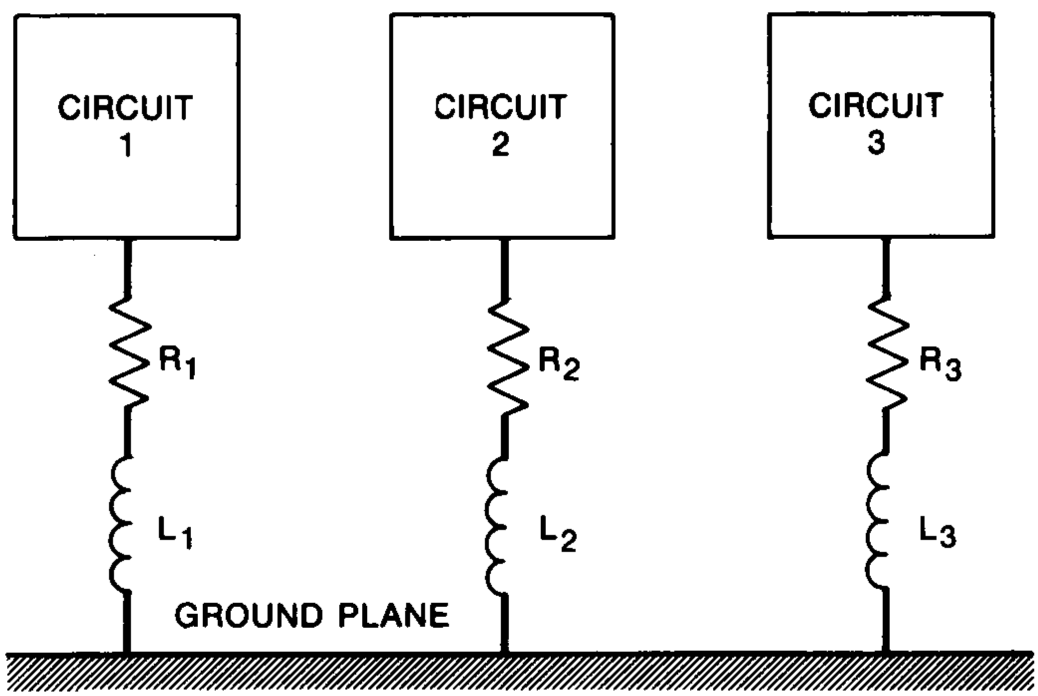



This series-type arrangement is common practice for the third-wire (safety) grounds in building wiring. Potential differences of tens of millivolts between different grounded receptacles within the same room are common, particularly if some of the equipment has power-line leakages.

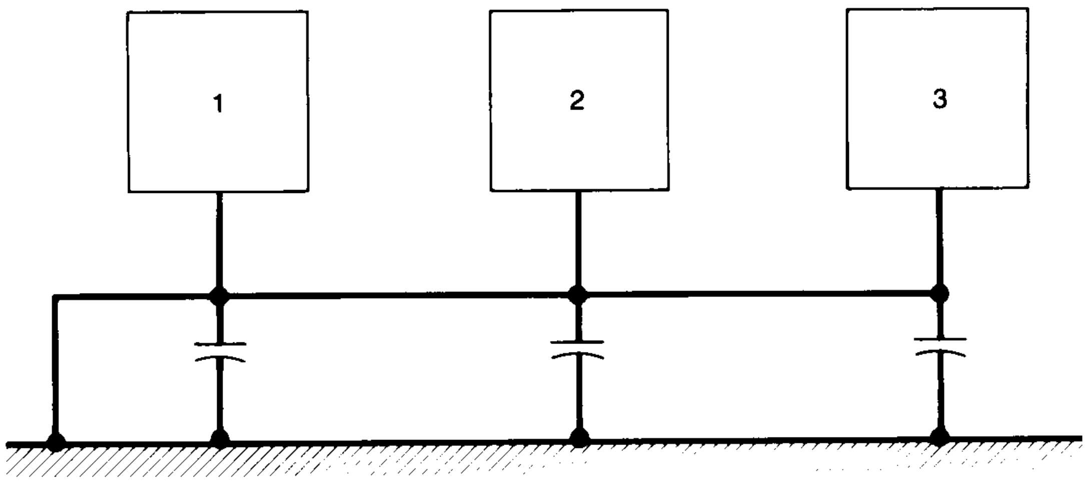
b) A better system, although it may require more wire and may add inductance, is the parallel-type of single-point grounding. [Ott Fig. 3-7]




c) Good grounding for digital signals and high-frequency analog signals requires multipoint grounding so that wire inductance (and therefore impedance) for harmonics and transients remains low compared to other paths. For digital and RF circuits one need lots of short, fat ground connections. [Ott Fig. 3-8]



d) Hybrid grounds can be used where both low and high-frequency grounds are needed. The grounding system below consists of three circuits connected by cables (whose inductance is present but not shown) and three capacitors. This hybrid behaves as a single-point ground at low frequencies and a multipoint ground at high frequencies (at least below the capacitors' self-resonance points.) Yes, it looks weird if you don't recognize the wiring inductance. But we often find small ceramic capacitors in parallel with large electrolytic capacitors to deal with the high effective series resistance of the latter. [Ott Fig. 3-9]



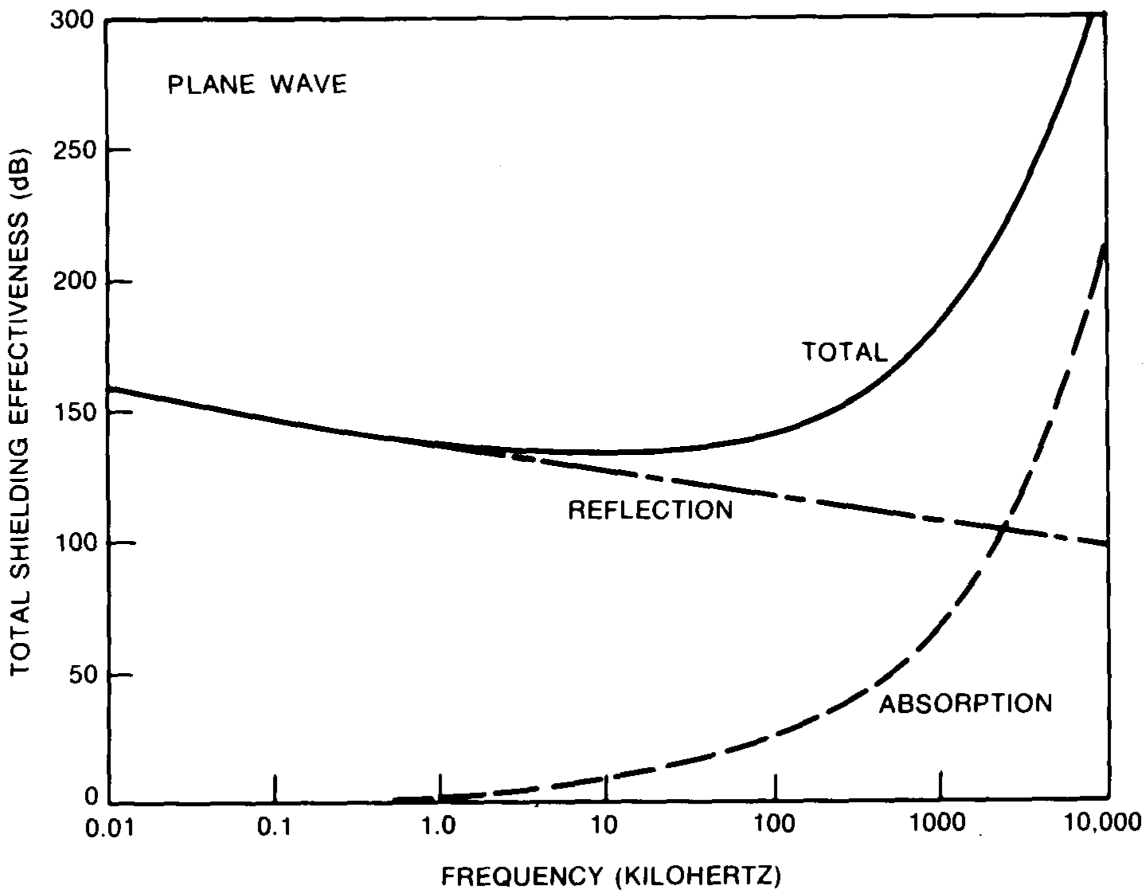

6. In an environment with both analog and digital sources and receptors, the most troublesome case is usually the combination of low-level analog inputs (where the physics is happening), which are being interfered with by radiative/field coupling from digital sources.

a) Computers and microprocessors make terrible neighbors for analog, non-cable television receivers. So do induction furnaces and sputtering chambers. Recall the rich harmonic spectrum of rectangular signals, plasmas and arcs, and how sensitive (i.e. microvolts) communications receivers and instrument amplifiers are.

b) Example: The old Apple II-series had a clock frequency of about 1 MHz. A shortwave receiver and antenna within 20 meters would pick up strong, modulated signals every MHz throughout the lower TV bands (50-80 MHz). For years, computer evesdropping made use of this unintended radiation. TEMPEST standards followed.

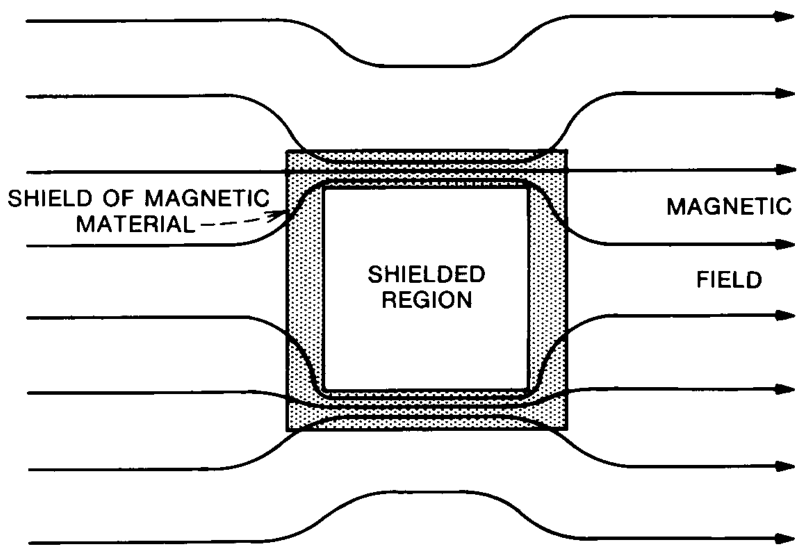
7. Shielding effectiveness depends on the impedance of the shield relative to the wave or source impedance.

a) Ideal shields transmit zero intensity. Both reflection and absorption mechanisms are at work in shields, but one or the other usually dominates in applications. Multiple reflections can contribute in thick shields. [Ott Fig. 6-15]




b) Good conductors make good shields for E-field sources and plane waves. Recall that the skin effect limits the field penetration at high frequencies, but absorption still dominates in this range.

c) Low-voltage, high-current (i.e. magnetic) sources in the near field present the greatest shielding challenge. Such shields must have both high permeability to enhance H-field "ducting", and high conductivity to enhance eddy-current absorption. The latter rises as sqrt(f), however. Traditional reflection is negligible in such cases. Hysteresis losses are a bonus in metals, but are the key mechanism in microwave absorbers. [Ott Fig. 6-16]




8. Filters are the chosen weapon for conducted noise. They work by absorbing or cancelling a part of the spectrum relative to some other part. We often teach something about the theory of high-pass, low-pass, bandpass, notch, passive, and active filters in introductory electronics courses. However, we rarely deal with commercial filters used to mitigate standard interference problems.

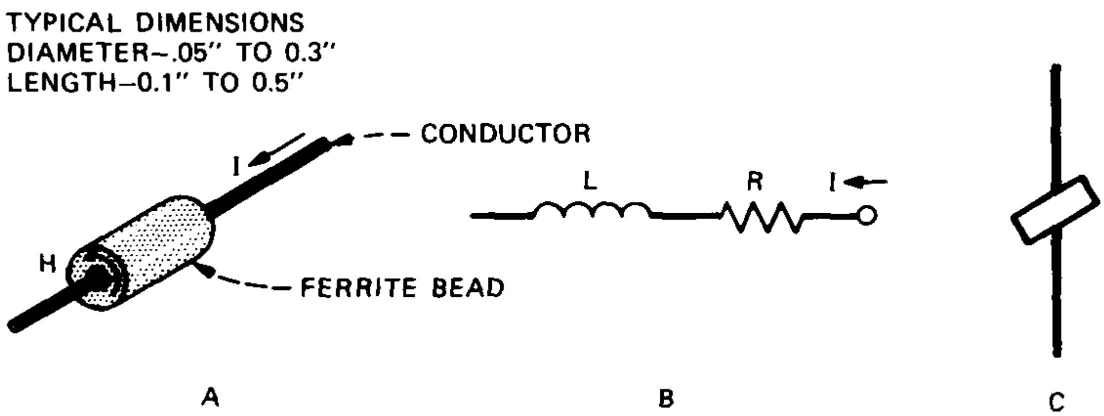
a) A filter must be considered in relation to the impedance of its connections.

b) A filter can become ineffective (or worse) when improperly installed, or used outside its frequency range. Recall the limitations of discrete components, and the behaviors of wires and circuit board traces.

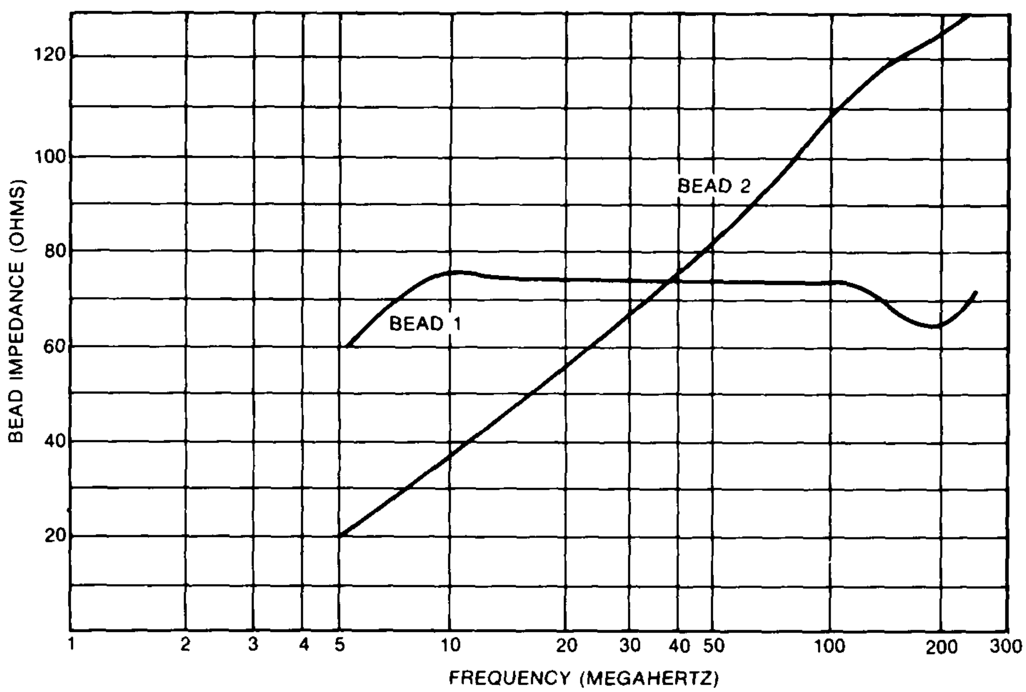
9. Ferrites can be your friends. Do you know what that bulge in the cable to your CRT monitor or SCSI peripheral is? You know, the thing that looks like the cable snake swallowed a film cannister. Have you noticed the small beads on the wires to the contact brushes on an electric shaver or other motor? These are ferrites, used to block the conduction and emission or pickup by wires of radio-frequency noise.

a) They are inert at DC and below about 1 MHz. The loss mechanism is hysteresis.

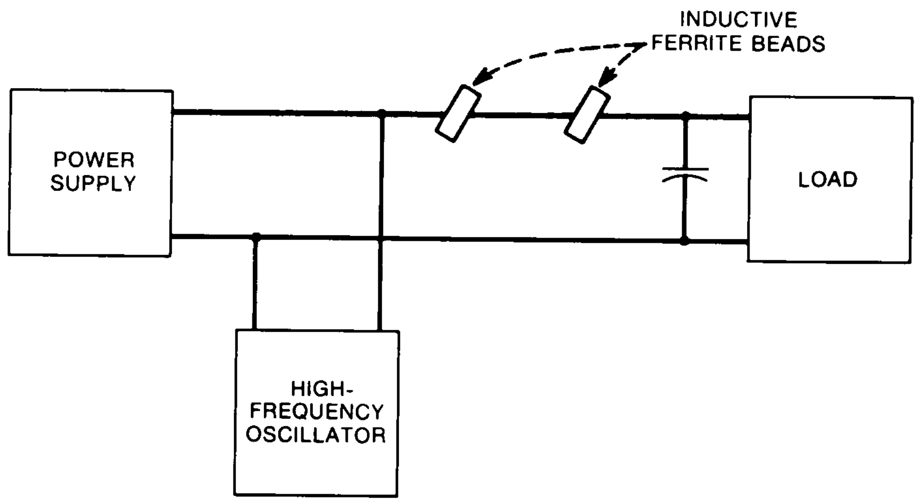
b) The equivalent circuit is series RL, but the behavior is often non-linear in the MHz range in which they are used. [Ott Fig. 5-15 and Fig. 5-16 on next page]



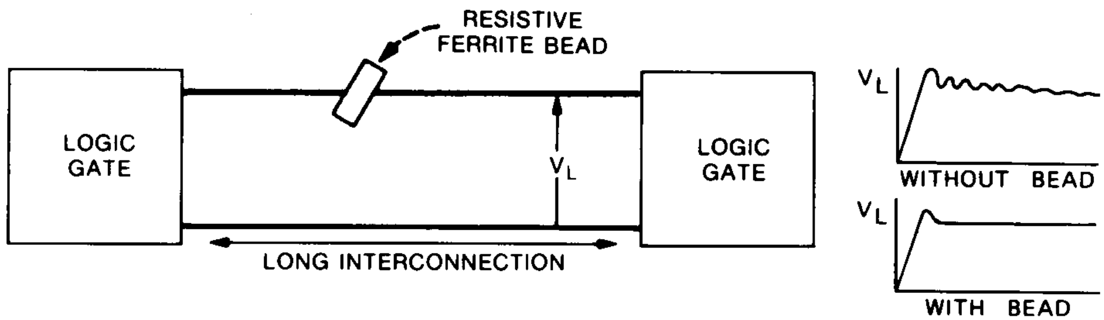

c) Ferrites are chosen for their attenuation over some frequency range, and may be combined to suit the need.




d) They are most often used in classic RFI situations. [Ott Fig. 5-17]




e) They may also be used to dampen "ringing" in digital circuits, or to kill off parasitic oscillations due to unintended feedback. [Ott Fig. 5-18]



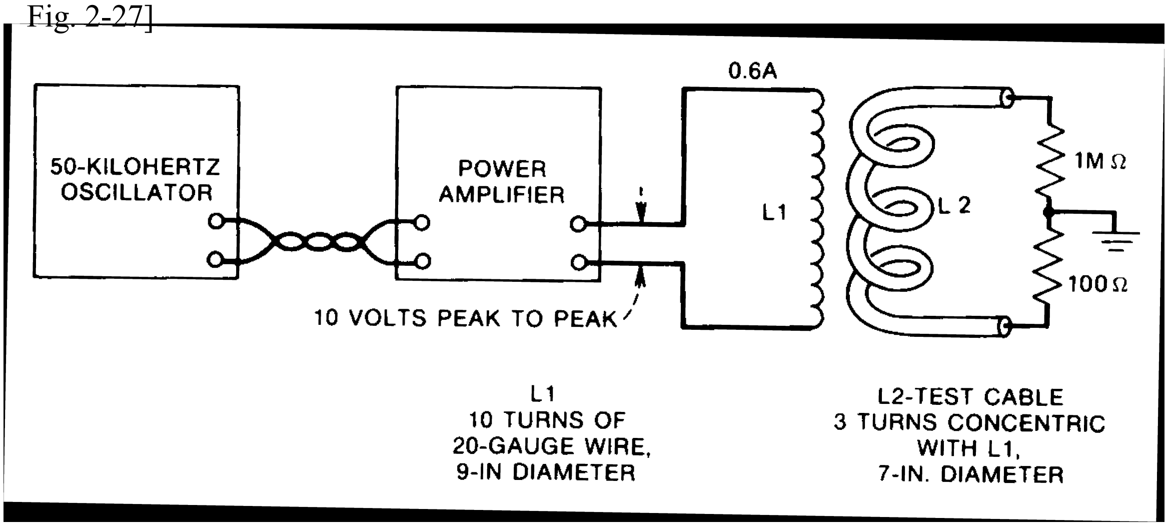

f) I recently prescribed a dose of ferrites to eliminate FM broadcast interference with the magnetic phono and microphone inputs of campus audio systems that were being interfered with by a very close 25 kilowatt commercial station. The station had been about 3 KW.

g) Why were audio amplifiers acting as detectors and rectifying the FM signals? Non-linearities inherent in any active device will do this to some extent. We even picked up the signals strongly on simple AM crystal radios. Tuning had no effect.

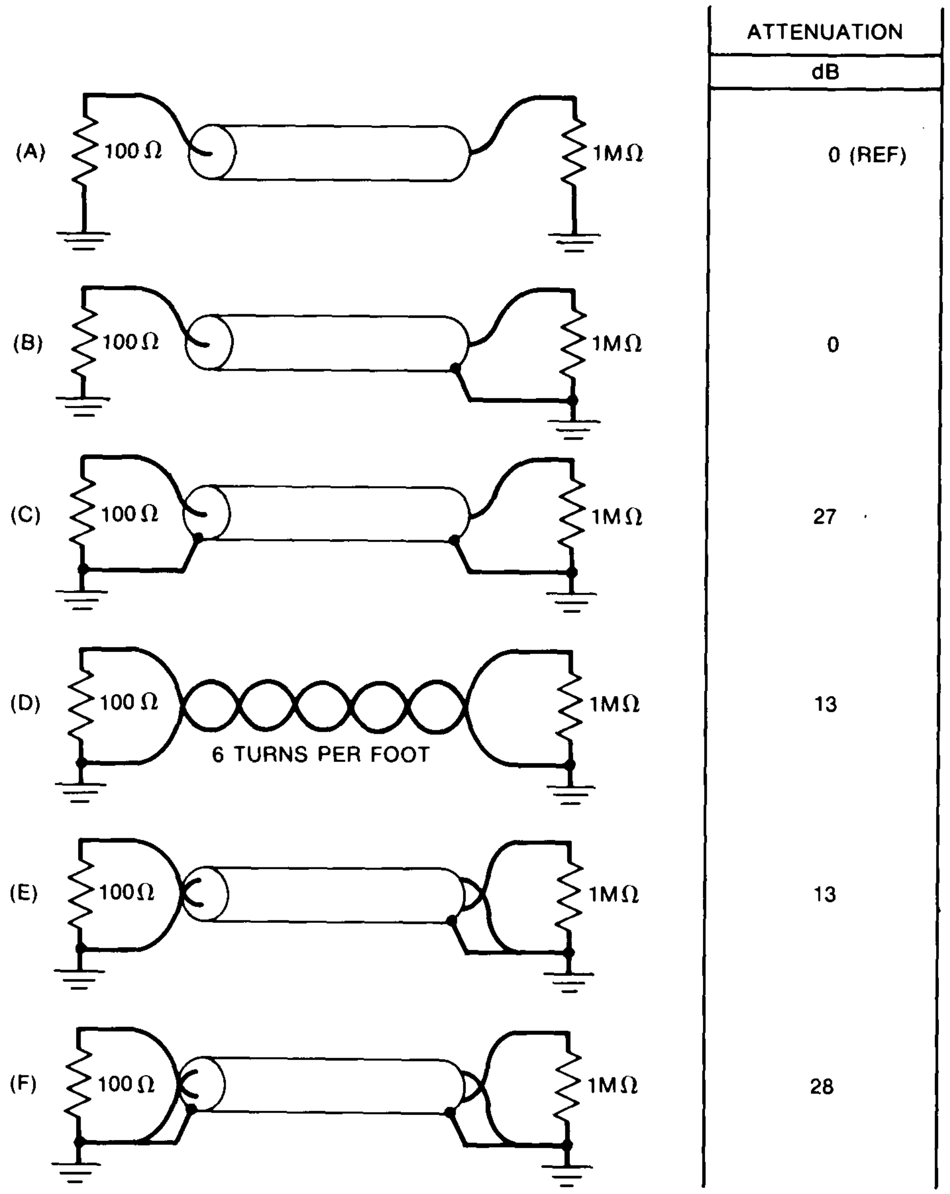
10. In troubleshooting an interference problem in a cable-connected system that has amplifier inputs, try changing the impedance of the input circuit.

a) If *lowering* the input impedance makes the problem *smaller*, the coupling is mainly via *E*-fields. If *lowering* it makes the problem *worse*, the coupling is via *H*-fields. Pursue the sources and remedies accordingly.

b) It pays to learn about the relative merits of shielded twisted-pair cable versus coaxial cable in specific situations. Ott reports tests using the following setup to measure the large differences in performance that arise depending on the many different ways of connecting the shields. [Ott Fig. 2-27]

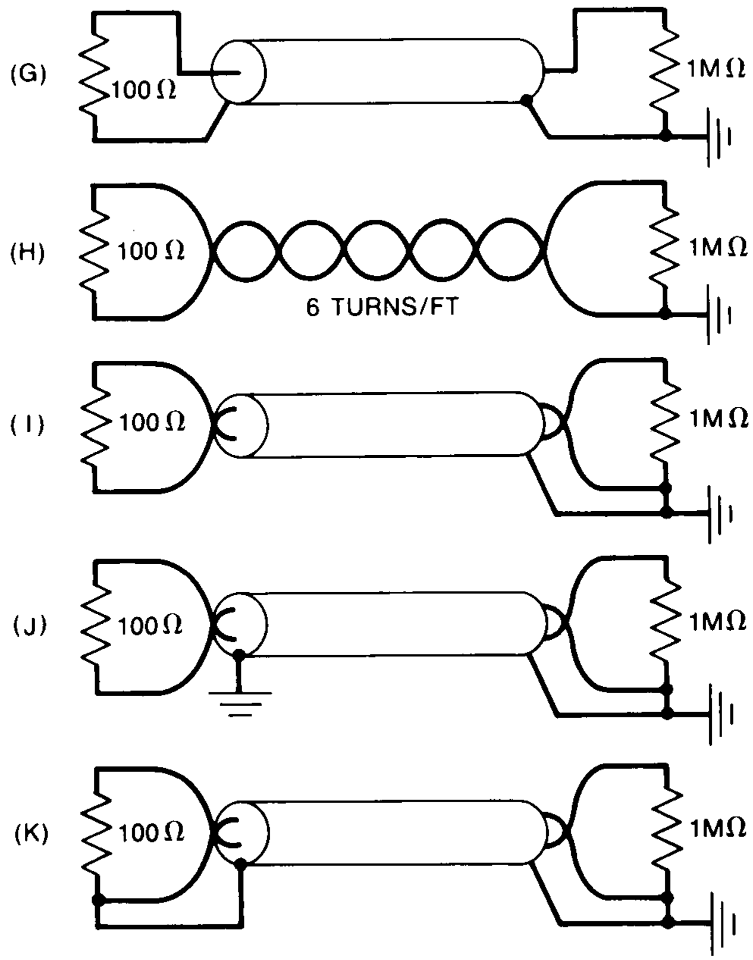



c) In the cases below, the circuit was grounded at both ends, in various ways. Note that the frequency was 50 kHz, which is higher than that used in many test circuits in undergraduate labs. At lower frequencies, the shielding attenuation is even worse. [Ott Fig. 2-28] d)




FREQUENCY = 50 KILOHERTZ FOR ALL TESTS

e) In the final five cases, the circuit was grounded at the amplifier end only.




| | ATTENUATION dB |
|---|---|
| (G) | 80 |
| (H) | 55 |
| (I) | 70 |
| (J) | 63 |
| (K) | 77 |

FREQUENCY = 50 KILOHERTZ FOR ALL TESTS