# THE EFFECT OF CIRCUIT IMPEDANCE ON FIELD–COUPLED CROSSTALK

by

Thomas A. Jerse
Department of Electrical Engineering
University of Kentucky
(formerly with the Hewlett Packard Co.)

## 1. OBJECTIVE

To understand the effect of circuit impedance on the magnitude and type of field–coupled crosstalk.

## 2. EQUIPMENT

A. Sinusoidal oscillator with a nominal 50Ω source impedance and at least $10V_{p-p}$ open–circuit voltage at 1MHz.
B. Dual–trace oscilloscope with a minimum bandwidth of 20MHz.
C. Ohmmeter.
D. Standard appliance cord (2 sections, 2 meters long each).
E. 500Ω non–inductive variable resistor.
F. 330Ω carbon resistor (1/4 W).
G. 10Ω carbon resistor (1/4 W).

## 3. PROCEDURE

### 3.1 Electric–field coupling

1. Using figure 1a as a guide, fix one length of appliance cord flat to a non–metallic table. The far end of the cable should be left open circuited.
2. Solder the 10Ω resistor in series with the near end of the cable.
3. On the table, fix the second length of cord parallel to the first, placing them as close together as the insulation will allow.
4. Solder the 500Ω variable resistor across the far end of the second cable. Choose the resistor terminals such that a full counter–clockwise rotation of the shaft places the minimum value of resistance across the cable.
5. Solder the 330Ω resistor across the near end of the second cable.
6. Set the oscillator to a frequency of 1MHz and connect it to the 10Ω resistor at the near end of the first cable.
7. Connect the oscilloscope across the near end of the first cable and adjust the amplitude of the oscillator for a reading of $10V_{p-p}$.
8. Connect the other channel of the oscilloscope across the 330Ω resistor at the near end of the second cable.
9. Set the variable resistor to its minimum value by turning its shaft fully counter–clockwise.
10. Measure the net parallel resistance across the second cable with an ohmmeter. (The result encompasses the parallel combination of the 330Ω resistor with the variable resistor.)
11. Using the oscilloscope, measure the amplitude, $V_1$, of the signal at the near end of the first cable.
12. With the other channel of the oscilloscope, measure the amplitude, $V_2$, of the signal coupled to the second cable.

13. Compute the voltage transfer function $|V_2/V_1|$ and tabulate the result.

14. Turn the variable resistor shaft fully clockwise to set the net resistance to its maximum value and repeat steps 10 through 13.

15. With the variable resistor set for maximum coupling, place your hand over a section of the two cables so close that you touch the insulation. Take care that you do not alter the spacing between the cables. Note the change in the transfer function.

### 3.2 Magnetic–field coupling

1. As shown in figure 1b, modify the set–up of the previous experiment by twisting the leads at the far end of the first cable together to form a short circuit. In addition, move oscilloscope probe A to the other side of the 10Ω resistor.

2. Using steps 9 through 14 of procedure 3.1, measure the transfer function of the crosstalk for the minimum and maximum settings of the variable resistor.

3. Adjust the variable resistor for maximum coupling. As in step 15 of procedure 3.1, use your hand to cover a section of the two parallel cables without varying the cable spacing and record the change in the transfer function.

## 4. THEORY

The source in procedure 3.1 excited primarily electric fields because it drove an open circuit. Most of the energy was in voltage; very little current flowed at this test frequency where the cable is somewhat shorter than a wavelength. Electric–field coupling is a high–impedance phenomenon. It can be thought of as occurring through a small–valued mutual capacitor, $C_{12}$, between the lines. The mutual capacitance presents a large reactance at low frequencies. Because it is a high–impedance source, the electric field coupled from the first cable can be modeled as a frequency–dependent current source injected into the second cable. (See figure 2a.) The voltage produced by the current source maximizes when the net resistance to ground $(R_1 \| R_2)$ on the second line is largest.

Conversely, the source in procedure 3.2 excited primarily magnetic fields because the short placed at the far end of the first cable in step 1 forced most of the energy into current. Some of the magnetic flux produced cut through the loop of the second cable to generate a low–impedance voltage source in series with the line. (See figure 2b.) The mutual inductance, $M_{12}$, directly controls the coupling because it gauges the proportion of magnetic flux lines that flow through the loop of the second cable. The resulting current induced in the second cable is largest when the net resistance in that circuit $(R_1+R_2)$ is smallest. In this way, the largest voltage across the 330Ω resistor at the near end of the line appeared for the minimum setting of the variable resistor.

Covering a section of the cable with the experimenter's hand (a high–impedance element) essentially added another mutual capacitor between the two cables. This act had little effect on the magnetic–field coupling because this additional high–impedance path does not provide an effective avenue for the low–impedance magnetic fields. By contrast, the hand enhanced electric–field coupling because some of the field coupled from the source to the hand and subsequently to the cable. The mutual capacitance provided by the hand combined in parallel with the existing mutual capacitance to boost the overall coupling.

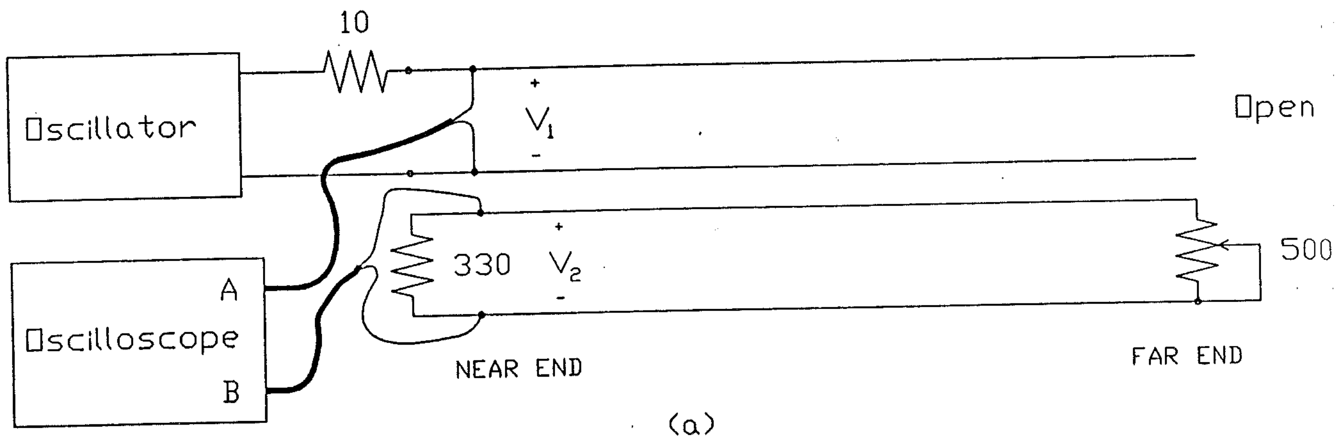
The simple coupling model illustrated in figure 2 applies to low frequencies where the coupled lines are somewhat shorter than a wavelength as was the case in this experiment. A more general model can be found in the referenced paper by C.R. Paul.

The relatively high characteristic impedance of the appliance cord limits the maximum frequency at which this experiment can demonstrate the difference between the electric and magnetic coupling. With the cable lengths specified, it is difficult in procedure 3.2 to make most of the energy in the first cable flow as current above 1MHz because the shorted cable presents a significant impedance to the generator.

## 5. REFERENCES


1. Ott, H.W., **Noise Reduction Techniques in Electronic Systems**, 2nd ed., John Wiley & Sons, New York, 1988, pp. 30–40.

2. Paul, C.R., "On the Superposition of Inductive and Capacitive Coupling in Crosstalk Prediction Models," **IEEE Trans. on Electromagnetic Compatibility**, EMC–24(3), pp 335–343, August 1982.



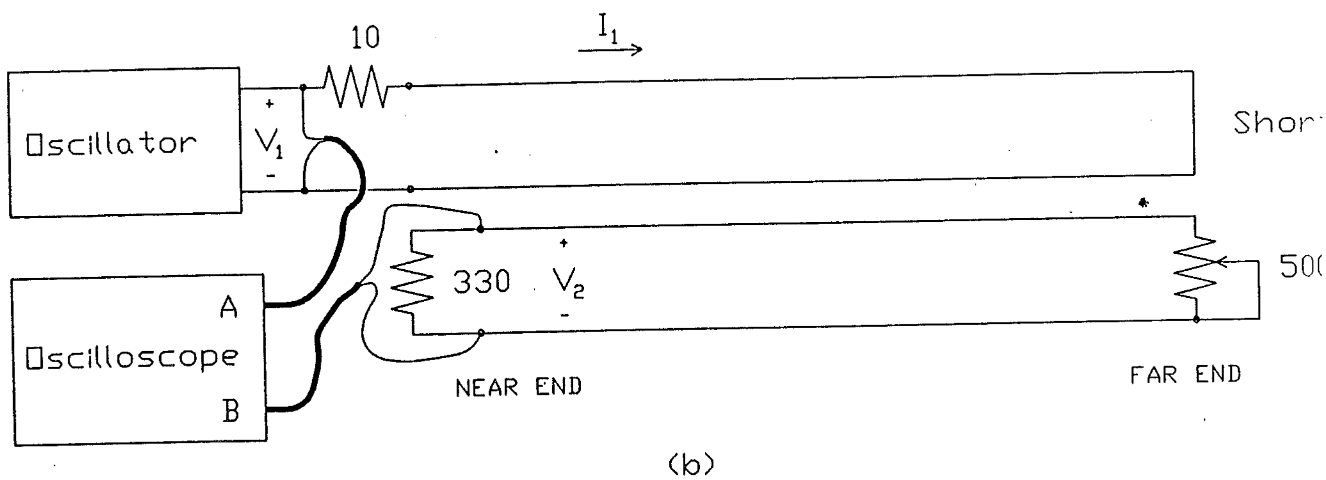




Figure 1. Set–up for coupling experiments. In (a), the first cable is open circuited so that electric–field coupling dominates. In (b), terminating the cable in a short circuit causes magnetic–field coupling to become the dominant mechanism.

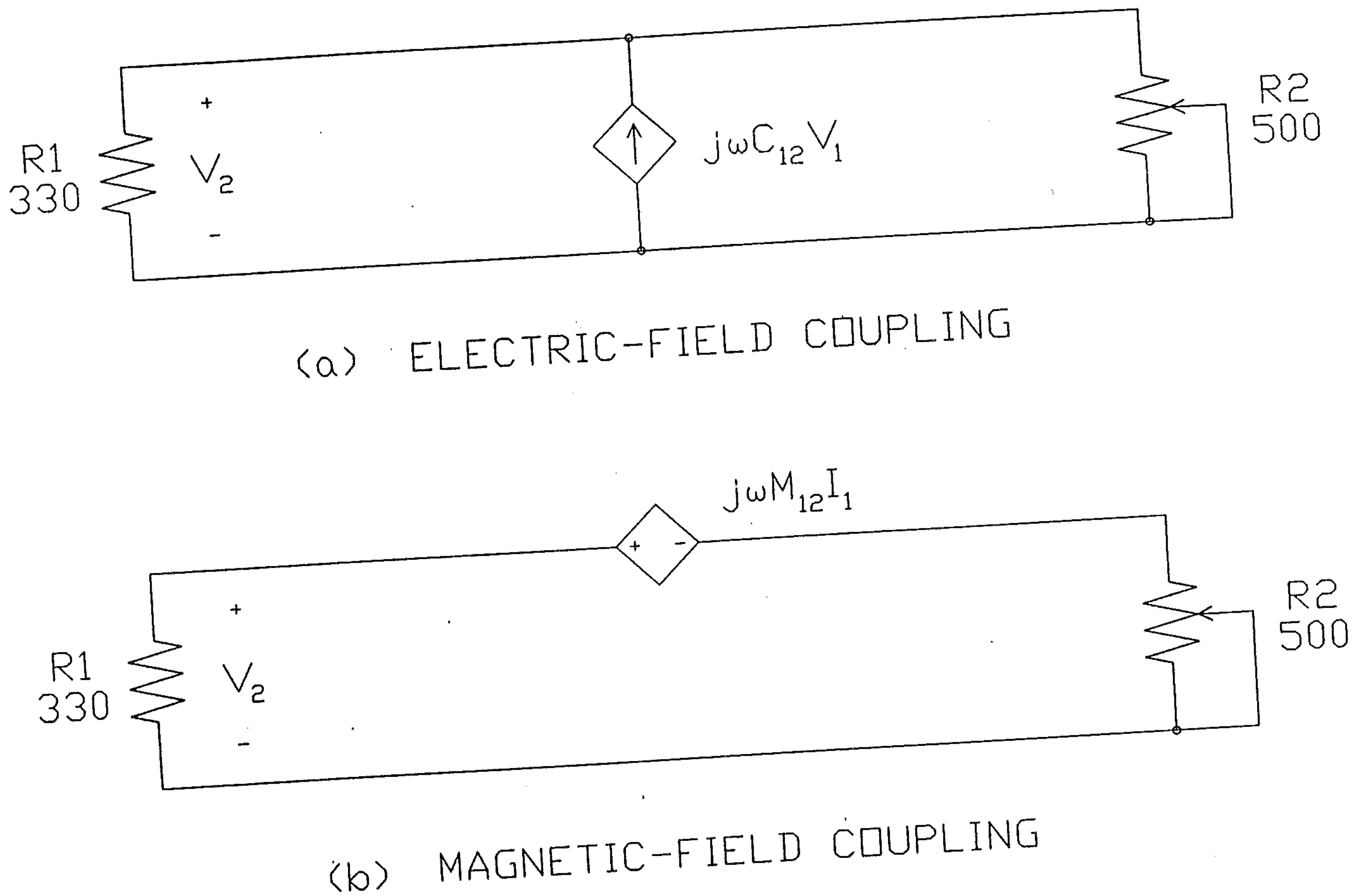



Figure 2. Equivalent circuits for low–frequency coupling into the second cable.