Radiated emissions, predicted and measured, from a voltage source in a 0.15m section of wire, (simulating a common mode voltage in a PCB ground) and the effect of an attached wire.

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WireShortening.R&D.doc

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1) Introduction

When a wire or cable is connected to a PCB ground the common mode current flowing in the PCB ground continues to flow on the attached wire. At low frequency the wire length may be much less than a wavelength and this is referred to as an electrically short wire. As the frequency of the source is increased so the level of radiation from the wire increases. For a wire effectively disconnected from ground at both ends, which is the case studied here, the maximum radiation occurs when the wire is a resonant 0.5λ long. This configuration can be considered a half wave dipole shorted in the middle and this is discussed in reference 1. If the wire is connected to a PCB contained in a shielded enclosure and the wire exits the enclosure this can be modeled as a monopole above a finite ground plane (the enclosure) and maximum radiation occurs when the wire is a resonant 0.25λ long.
Thus for a 1m long cable attached to a PCB far removed from ground the maximum frequency of radiation is 150MHz. For a 1m long wire attached to a PCB enclosed in a metal enclosure the maximum frequency of radiation is 75MHz.

As data and clock speeds increase the frequencies radiated from attached cables also increase. The FCC in CFR 47, Part 15, section 15.33 requires that when the highest frequency generated or used in a device is 108-500MHz that the upper frequency range of the measurement is 2GHz. When the highest frequency is 500 – 1000MHz then the upper frequency range of the measurement is 5GHz and when the highest frequency is above 1000MHz then the upper frequency range of the measurement is the 5^{th} harmonic or 40GHz, whichever is the lower.
This report looks at the level of radiation when the attached wire is electrically long, equal to a wavelength or greater.
In the typical radiated emission set ups for commercial requirements contained in ANSI C63.4 and required by the FCC the use of a turntable is required. This means that the sections down the length of the electrically long cable as it rotates are either closer to or

farther away from the measurement antenna. The voltage source in this experiment is a constant frequency and the cable length is changed to obtain lengths of from 0.5λ to 5λ This report considers only the case when the wire is 3m distance from the antenna and the measurements and predictions are made either with the wire broadside on to the antenna, in the same plane, or the case where the wire and source is rotated, in which case the level of maximum radiation for any angle is measured.
Thus in one test the table is rotated and the maximum emission is measured. The length of the wire is then modified and the table again rotated to achieve a maximum level of radiation.
The angle of rotation is noted and the NEC program, 4NEC2 version 5.5.2 by A. V., is used to predict the level of radiation at this angle using the same level of voltage for the source.
One other variable is a potential impedance mismatch between the ground plane impedance and the impedance of the attached wire and this effect is also measured.

2) PCB simulation and test set up

Assume a logic driver connected in a microstrip PCB configuration connected to a load as shown in figure 2.1
As the driver changes state it drives the input impedance of the receiver which includes an input capacitance. Thus a current pulse is generated and flows back in the PCB ground. As described in reference 1 the ground impedance is dominated by the ground plane partial inductance and although reduced by the mutual inductance between the signal trace and the ground plane it is significantly higher than was predicted in early EMI textbooks.

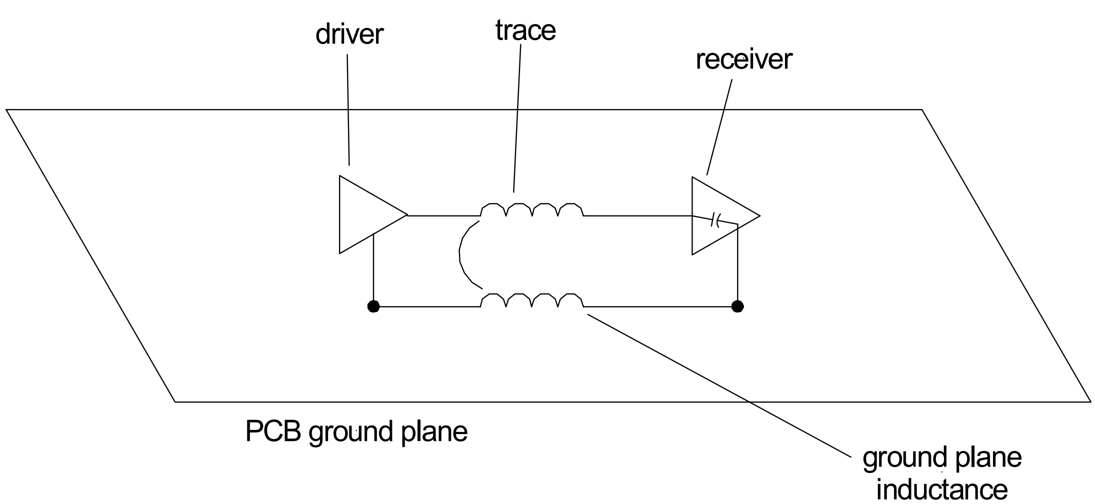

Figure 2.1 Logic driver and receiver connected in a microstrip
As the current flows in this impedance a voltage is developed in the ground plane and a common mode current flows. When a wire is attached to this ground the current continues to flow on the attached wire, as shown in figure 2.2.

The current flows in a very narrow area of the ground plane under the microstrip signal trace. This can be modeled as a voltage source in a short wire as shown in figures 2.3. If the voltage source is contained in a metal enclosure or has power supplied by a separate power line, then the displacement current flowing between the signal trace and this nearby conductive structures will alter the level of radiation. For this reason a small 1GHz voltage controlled oscillator connected to three watch batteries was mounted in the center of a 0.15m long 22AWG wire as shown in photo 1.

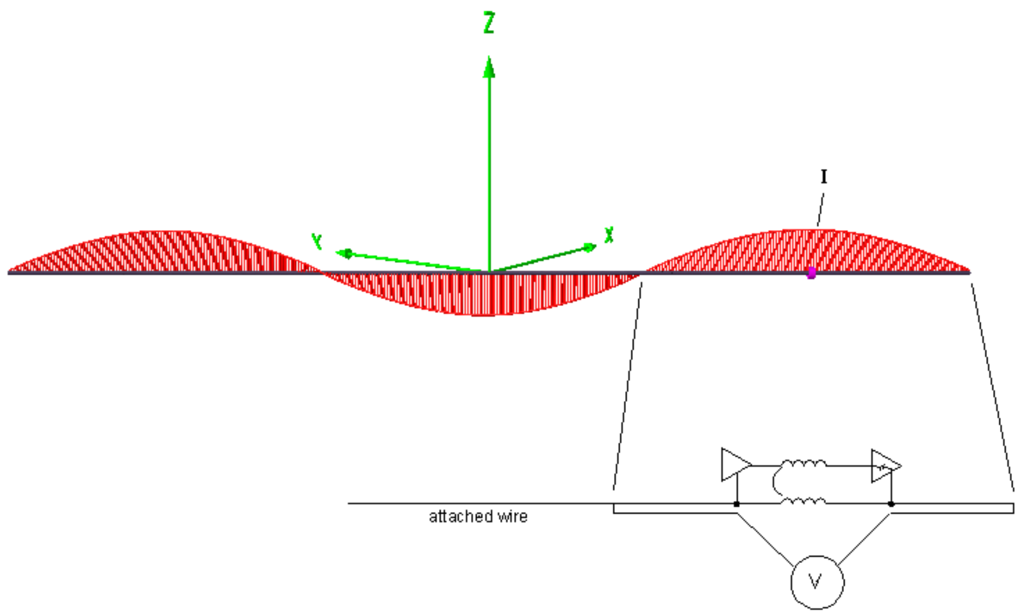

Figure 2.2 Current distribution on the wire and source with a total length of 1.5λ

The measurements were made using a dipole tuned to 1GHz on a free space range. The wire was raised 1m above a low conductivity floor which was covered in ferrite tile absorber. The area between the antenna and the wire was also covered in ferrite tile. Thus any displacement current between the wire and the floor is expected to be minimal and any ground reflection also minimal. The antenna was raised 1.25m above the floor.

Photo 1. Wire and 0.15m section on the turntable.

The emissions were predicted using the MOM capability of NEC. The source was fixed in the center of a 0.15m length made up of 100 segments. The frequency was set to 1GHz, which made the 0.15m section equal to 0.5λ. This represents a resonant length PCB ground plane. A wire was attached to one end of the 0.15m section and this wire was increased in multiples of 0.25λ until the wire and the original 0.15m section were at a total length of 1.5m, or 5λ long.

Initial measurements were made with the wire in the same plane as the antenna and this orientation was not changed as the length of the wire was varied. The NEC measuring point and the dipole antenna were centered on both the 0.15m section of wire y=0.0 and at the center of the long wire y = -0.7543m. Figure 2.3 shows the results of modeling and measurements with the antenna at y = -0.7543m. The measuring point was set at a fixed distance of 3m broadside on to the antenna.

Figure 2.4 shows both a predicted and measured reduction in field as the length of the stationary wire is increased i.e. becomes multiple wavelengths long. This is intuitively what I expected and what I have observed in numerous measurements made on PCBs with and without attached wires (attached to the ground plane on the PCB). The major difference between the true PCB measurements on an Open Area Test Site and this experiment is that a good ground plane is present on the Open Area Test Site PCB measurements.

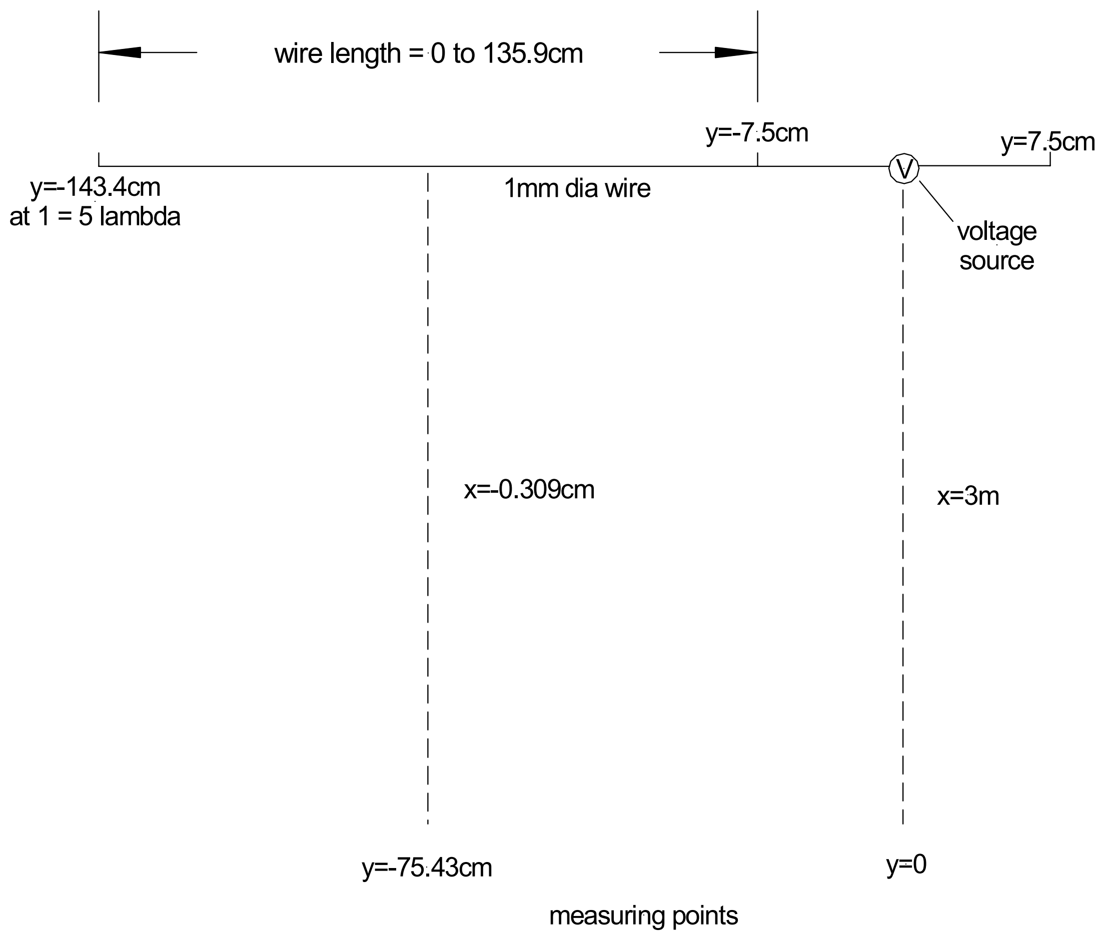

Figure 2.3 Geometry of the setup for stationary wire and source

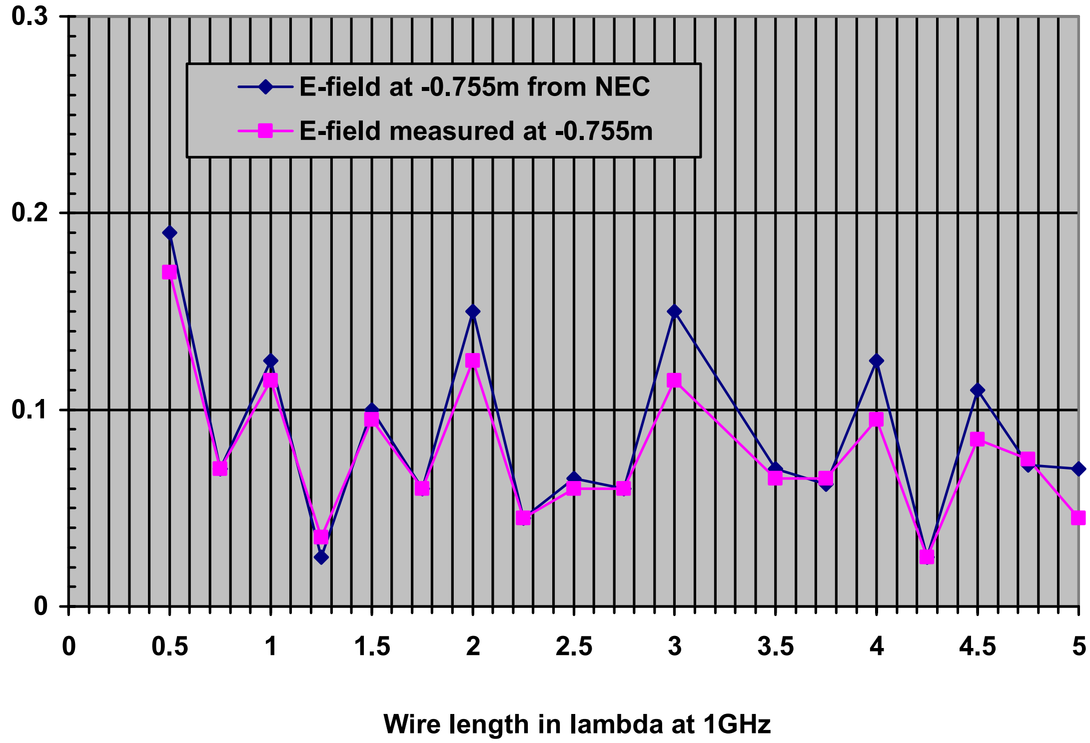

Figure 2.4 E field measured with the dipole antenna in line with the center of the 4.5 lambda (135.9cm) length of wire attached to the 15cm PCB. Compared to the NEC analysis with the measuring point at the same location i.e. at y = -0.755m.

For the second test, the rotation origin centered on the total length of the wire and 0.15m section. The NEC measuring point and the dipole antenna were set at a fixed distance of 3.365m to the wire and displaced from center by 0.43m. For each E-field measurement the wire and source were rotated with respect to the antenna until the maximum emission was observed. In the NEC geometry, the wire and source were oriented with respect to the antenna at the angles where maximum emissions occurred during measurements. Figure 2.5 depicts the test set up.

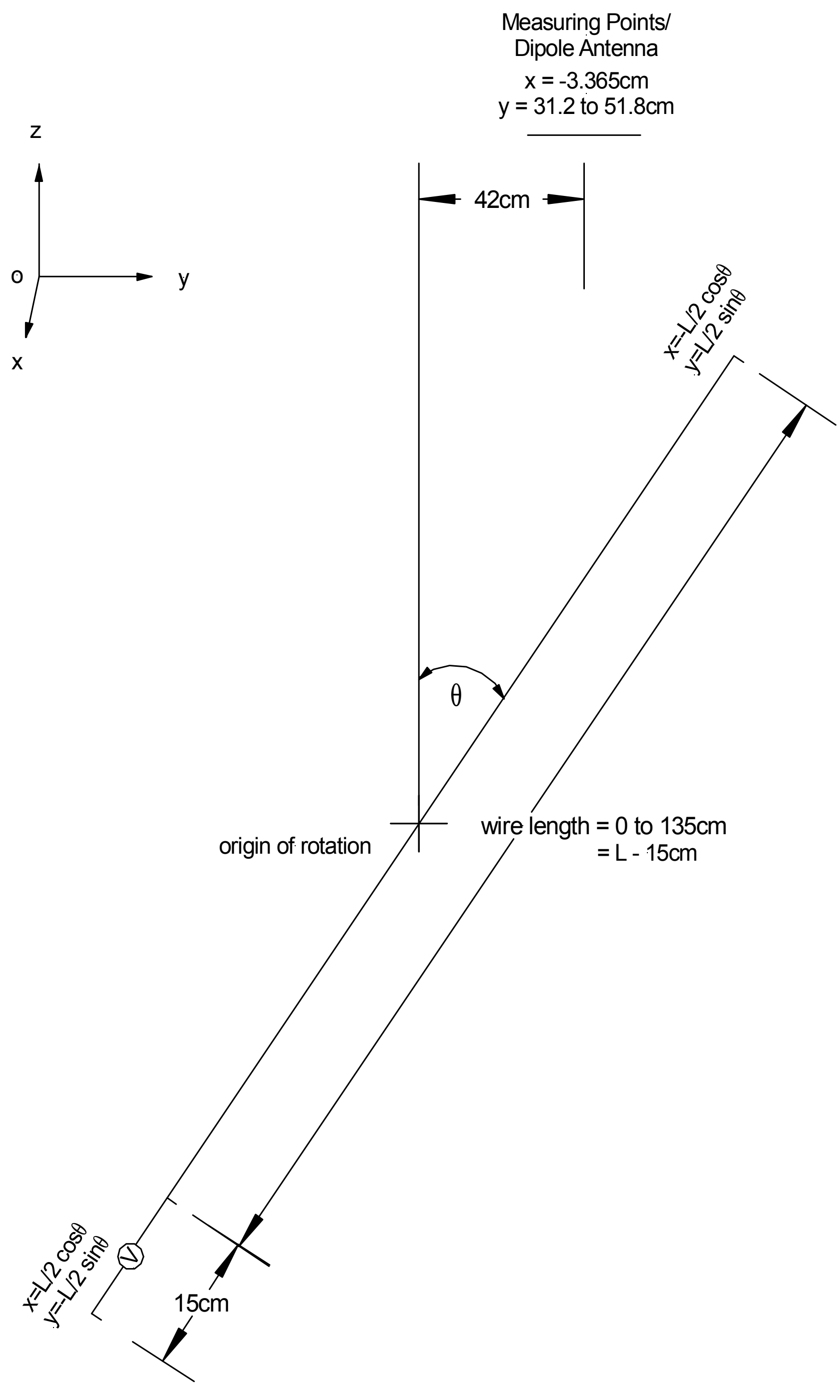

Figure 2.5. Geometry of the problem

Figure 2.6 shows the predicted and the measured fields as the length of the wire is increased. The previous investigation with a stationary wire and source, indicated that E-field levels measured at the antenna decrease as the length of the wire increases. This trend was not observed when rotating the wire and source. The trend observed in this investigation indicates a slight increase in E-field radiation as the wire length is increased. This can be explained if we take into account the constructive and destructive interference that occurs due to the phase of the currents flowing on the wire. At some orientation the composite field radiating from the wire will be maximally constructive and at some angle they will be maximally destructive, canceling each other out. When we do not rotate the wire we see the effects of destructive interference and therefore do not observe the maximum field strength produced by the wire.

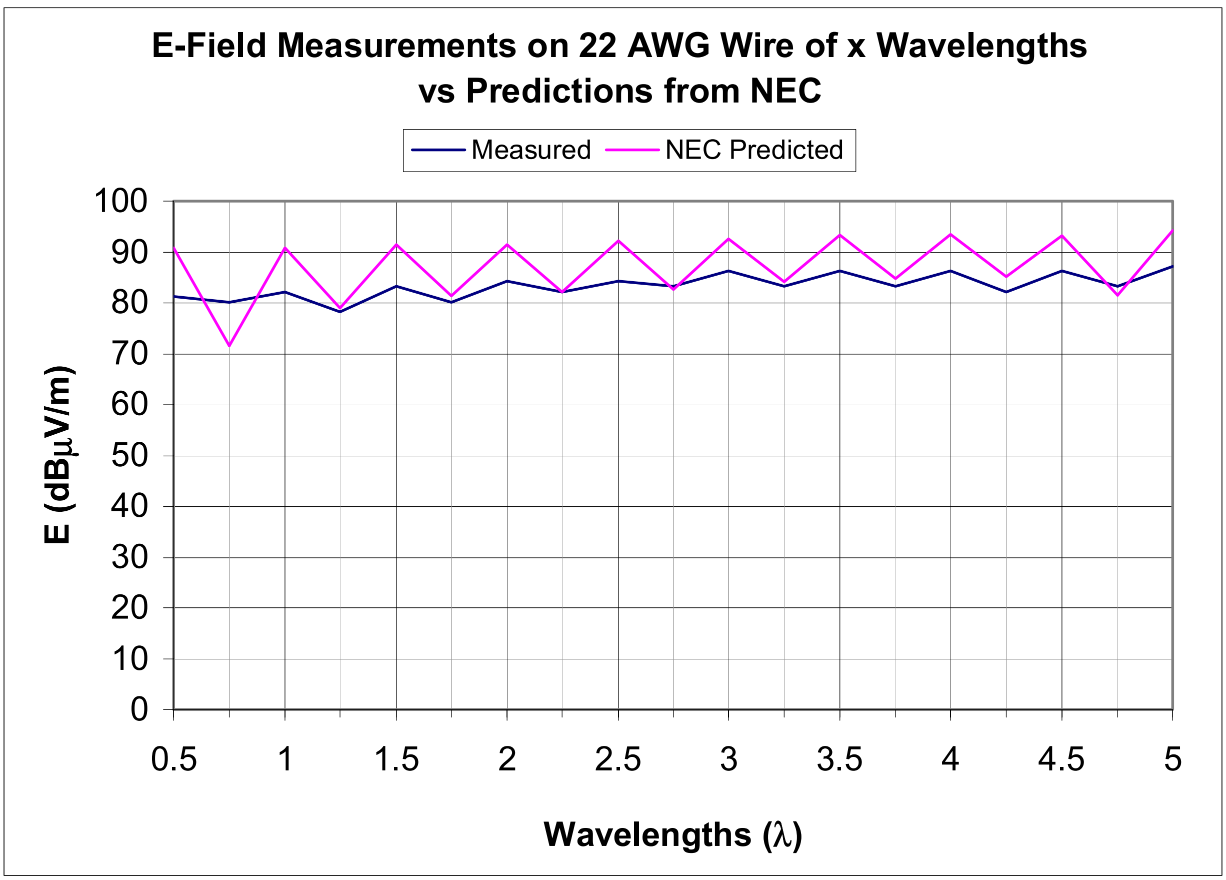

Figure 2.6 Comparison of the measured E-field at the dipole versus the E-field predicted by NEC for the same conditions.

As an adjunct to this investigation, an additional test was performed wherein the attached wire was substituted by ½" braid wire to simulate the effects of a larger diameter cable. The braid wire produced more radiation. See figure 2.7 for a comparison of the braid wire to the 22AWG magnet wire. This effect of a mismatch between the smaller diameter wire and the larger diameter braid simulates a mismatch between the PCB ground plane impedance and the attached wire and requires more investigation to quantify it.

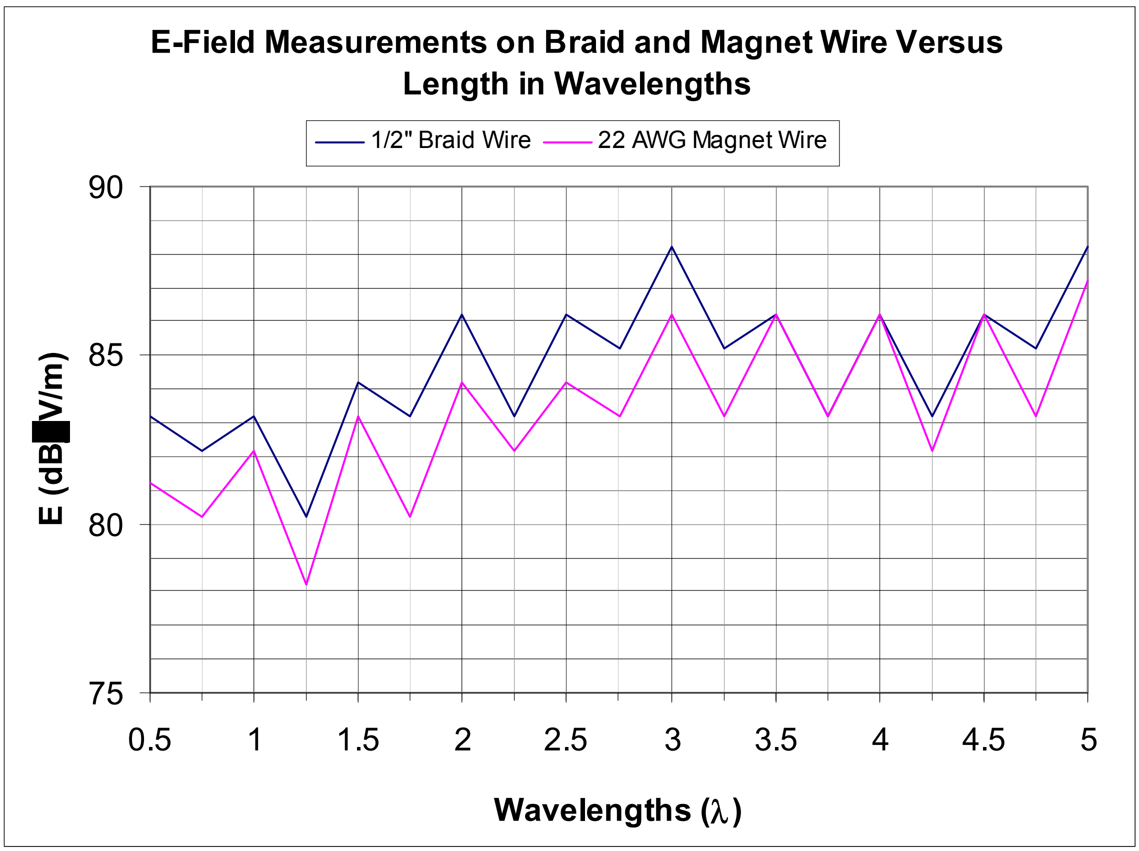

Figure 2.7. The effect on the radiated E-field of increasing the wire diameter.