Matthew Spencer – Fall 2024

Lab 4: Near Field Measurements

In this lab you are going to use near filed probes to measure electromagnetic fields.

After this lab, you will be able to:

1. Calculate magnetic fields around some common structures.
2. Use near field electromagnetic pre-compliance measurements to infer circuit behaviors.

Theory Questions

1. A sinusoidal voltage source with a 50 Ohm output impedance is used to drive a Helmholtz coil with 75 turns and a radius of 1cm. What is the coil magnetic flux density, B, as a function of voltage amplitude, Vzp, and frequency, f?

   You will need to look up an expression for the flux in the Helmholtz coil to answer this question, and you should find an expression that assumes flux in the coil is constant (though technically it varies a little with position). Don't forget to account for the inductance of the coil, which you can readily calculate as flux/current once you've looked up a flux expression.

2. What is the magnetic field at radius R away from an infinitely long wire carrying current I? You can derive this from Maxwell by finding the integral form of the equations and taking a path integral, or you can just look it up.

Lab Instructions

This lab doesn't require any circuit simulations. Instead of comparing measurement, simulation and analysis for each problem, just compare measurement and analysis. We will use the HP 8665B signal generator, Agilent N9320B spectrum analyzer, Tekbox TBPS01 near field probes and Tekbox TBWA1 wide band amplifier. Datasheets are below:

- https://www.tekbox.com/product/TBPS01_TBWA1_Manual.pdf
- https://us.rs-online.com/m/d/72ff981d3a2821471f9c138fdea78d94.pdf
- https://www.keysight.com/us/en/product/8665B/highperformance-signal-generator-6-ghz.html

1. Familiarize yourself with the HP 8665B RF signal generator and the N9320B spectrum analyzer.
   a. Turn on both devices.
   b. Set the span of the spectrum analyzer to 2MHz and the center frequency to 4MHz.
   c. Set the output of the signal generator to the following settings, VERIFY THAT THE POWER LEVEL IS NEGATIVE DBM, connect the signal generator to the spectrum analyzer, enable RF signal output, and record the resulting spectra.
      i. -50dBm at 4MHz
      ii. -40dBm at 4MHz
      iii. -40dBm at 5MHz

   d. As a note: We'll dig into this more in a future lab, but beware that the spectrum analyzer is trickier than it looks. Keep your span fairly narrow (500kHz-2MHz, narrower if you are working at very low frequency), and ensure that you are only viewing positive frequencies on the screen (set center > span/2).

2. Calibrate the near field probes
   a. Assemble a test setup
      i. Find the Tekbox TBPS01 near field probes and Tekbox TBWA1 wide band amplifier. The amplifier is usually in the near-field probe box.
      ii. Connect a near field B probe to an SMA cable using a type-B to SMA adapter.
      iii. Power the amplifier by plugging it into a USB connection.
      iv. Connect the SMA cable to the pre-amplifier input
      v. Connect the amplifier output to an instrument you will use to measure the power produced by the near field apparatus. The N9320B spectrum analyzer from section 1 works well, but so does an oscilloscope or a multimeter.
      vi. Connect your signal generator, usually the HP 8665B from section 1 though other signal generators also work, to one side of a Helmholtz coil. We have two Helmholtz coils available in lab, but most teams use the 75-turn coil pictured in Figure 1. (The new, 100 turn coils are likely to perform better, but no one has used them yet.)
      vii. Connect a sense resistor from the other side of the Helmholtz coil to ground.
      viii. Connect a measurement tool to the sense resistor so that you can measure the current through the Helmholtz coil.
      ix. Put your probe in the Helmholtz coil, turn on your signal generator and do some basic checks: do you see a B field response at the frequency you are driving in? Does the B field response go away when you take your probe out of the Helmholtz coil? Does the power of the response change when you change the power of your input? Does the frequency of your response change when you change the frequency of your input?
   b. INFORMATIONAL: The probes need to be calibrated because our measurement equipment reports a power level (or a Voltage level depending on your measurement tool), but we want to know what field produced that power.
      i. We can do this by driving known H values into our probe, recording the power that the field produces, and making a plot with measured power on the x-axis and applied H field on the y-axis. When we measure a power in the future, we can use the plot to convert the power level back into an H field. We will call this a low-f field-power calibration.
      ii. There are also several frequency responses that can affect the measured field. First, our test circuit has a frequency response between the power we apply and the field it produces (this is captured in theory question 1). Fortunately, measuring current in the coil can sidestep this response; there is no frequency response that affects the relationship between coil current and B field. Second, each near field coil has a frequency response, which is depicted on pages 2 and 3 of the datasheet. We will call this behavior the coil frequency response.

   c. Use the Helmholtz coil and the parallel plate setup pictured in Figure 1 to calibrate your near field probes. You must calibrate one B field probe, though calibrating all four probes is worth a little extra credit. Your calibrations should include the following relationships.
      i. Two low-f, field-power relationships, one measured at 100kHz and the second at 5MHz. Measure this by relating measured power and applied field. (Note: our setup probably can't drive sufficiently powerful fields if f>30MHz.)
      ii. A coil frequency response that replicates the calibration curve on pages 2 and 3 of the near field probe datasheet. You probably won't be able to replicate the whole curve because our setup tops out at 30MHz, and the coil has a self-resonant frequency around 5MHz. Feel free to stop 1-5 MHz, and to increase input power levels as needed to improve the measured power.

3. Measure field around an "infinite" wire
   a. Use your calibrated probes and the function generator to measure the B field around the long wire on this breadboard. Compare your measured results to theory. You can measure the current in the wire using a sense resistor on the breadboard.
   b. The E field around this wire is poorly controlled, so we're not going to try to measure it. What do you expect the E field to look like from theory?

4. In this problem we are going to do some basic "pre-compliance electromagnetic testing". Pre-compliance electromagnetic testing is a form of near field testing that can help determine what parts of a circuit are radiating (and what field they radiate). We will do this by observing near field behavior in an example circuit:
   a. Find the test circuit pictured in Figure 3. It is comprised of a voltage regulator, a ring oscillator, a buffering inverter and a load resistor as shown in the schematic in Figure 3. It should be powered with at least 7V. Note that it has three types of nodes: the supply node, the digital nodes inside the ring oscillator, and the load node at the resistor. Inspect the circuit with your near field probes and use your measurements to answer the following questions.
      i. What types of nodes (supply/digital/load) emit strong B fields? Why?
      ii. What nodes (supply/digital/load) emit strong E fields? Why?
      iii. What is the frequency of the ring oscillator? If there is more than one peak in your measured spectrum, explain why.
      iv. Use your measurements to determine the value of the load resistor (which is currently hidden by tape).
   b. HINT: some details of how near field probes work are scattered around the videos
      i. Lecture 15 video 4 points out that E field probes form capacitive dividers and B field probes form transformers. That means these probes can't measure DC signals, only dV/dt and dI/dt.
      ii. Lecture 15 video 1 points out that E is linear in dV/dt and H is linear in dI/dt. (Take a derivative of the integral on slide 4.) The useful point is that bigger dV/dt or dI/dt will create bigger fields.
      iii. Lecture 17 video 1 points out that, in the very near field, E/H=V/I of the field-emitting circuit node. (This is buried in the text on slide 4) This is different than the behavior of propagating waves in free space, which have E/H=377Ohm.

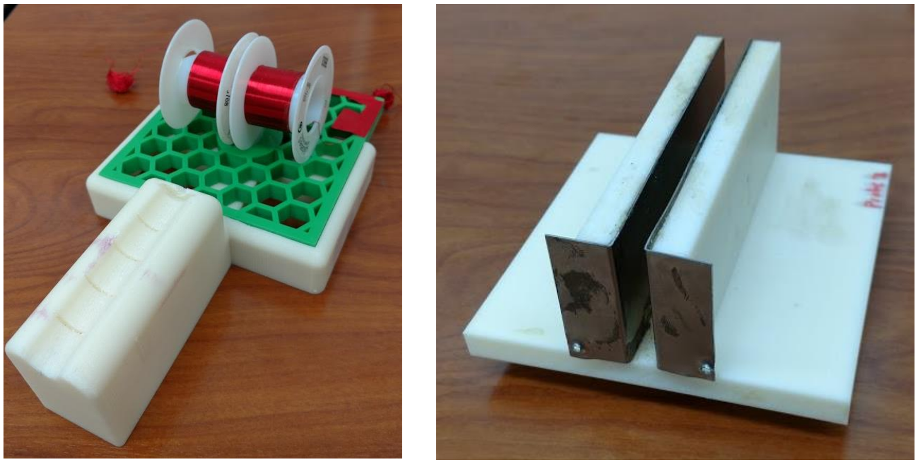

Fig 1

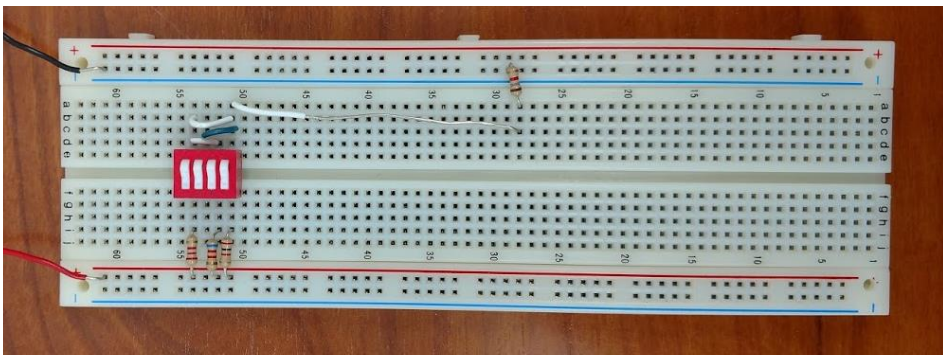

Fig 2

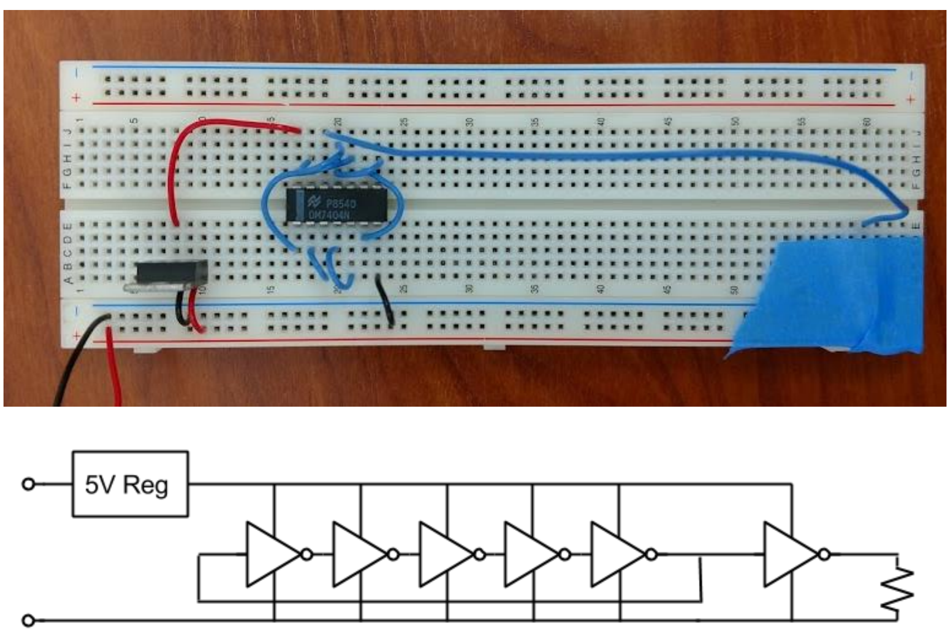

Fig 3

Required data in lab notebook:

- Spectra from familiarization exercise
- Power vs. Field calibration curve curves for at least one near field B probe, including calculations that relate voltage applied to Helmholtz coil to field strength.
- Power vs. frequency calibration curves for at least one near field B probe
- B Field vs. distance measurements for infinite wire. E field discussion for infinite wire.
- Representative field spectra for a few nodes in the example circuit
- Detailed explanation of oscillator frequency extraction, with calculations if necessary
- Spectra and calculations for load resistor extraction