Radio Wave Propagation and Direction Finding

Introduction:

Bang! Jim awoke with a start. He had been having the most wonderful dream about winning the yearly "Outstanding Technician" award at the upcoming company banquet. To his left sat Jerry, his heavily bearded face drawn out in a scowl. "What happened?" "Damn! We've lost the engine. Gonna have to set 'er down." The small plane was pitching downward into blackness; the only thing Jim could see out the rain-streaked window was the dim glow of a distant town. Jerry picked up the microphone. "Mayday, mayday, this is Charlie Delta one two four, we have lost engine power. We're going down! Our bearing is zero-four-five, fifty miles east of Carsonville, over." As the plane descended through the cloud cover, dark grey fields sped by in fast forward. It all seemed unreal. The plan landed with a crack; dust and debris filled the cockpit as the plane *thwacked* its way through the cornfield. Then all was still; the air reeked of fuel, dirt, and hot plastic. Jim then became aware of his weight pulling upward against his seat belt. *We're upside down in this thing in the middle of nowhere*, thought Jim... *we've got to get out of here!*

The above example, while probably overdramatic, illustrates a simple but important wireless application. Obviously, Jim and Jerry were able to use two-way VHF to radio their position to the control tower before they landed, but how will rescuers find them in pitch darkness? Fortunately, their small plane is equipped with an EPIRB (emergency position indicating radio beacon), which transmits audio "warble" tones on 121.5 MHz. The EPIRB will transmit a modulated RF carrier for up to about 38 hours after a hard landing, enabling crews to locate the craft.

In this first experiment you will get some hands-on experience with VHF signal propagation by doing a little direction finding or "Foxhunting." The equipment you'll use is very similar to that used in search and rescue operations. A portable low-power transmitter operating on 145.555 MHz (in the 2 meter Amateur Radio band) will be used as the "Fox."

Radio waves can travel from a transmitter to a receiver in several ways:

- Direct (space) wave: The signal travels directly through space to the receiver with no interference. Direct wave propagation occurs at all frequencies. It is limited by the radio line-of-sight distance between the two devices.
- Sky wave: The signal travels skyward, refracts or "skips" off the ionosphere back to earth, and reflects skyward again (or is received). Sky wave propagation is primarily limited to frequencies below 30 MHz (although "skip" up to 75 MHz is possible under limited conditions.)
- Ground wave: The signal follows the curvature of the earth and can travel beyond the normal line of sight (up to 800 miles is possible). Ground wave propagation is best below around 10 MHz; at VHF (above 30 MHz), it is not a useful propagation mode.

We can use several methods to find the location of a radio transmitter. Among these are:

- Directional antennas: We can rotate a directional antenna and observe the signal strength. Usually the bearing to the source is at maximum signal strength. This technique is useful at all frequencies but requires considerable operator skill. It is hard to apply from a moving vehicle.

- Triangulation: By using several fixed stations with directional antennas, we can combine the bearing information from the stations to develop a "fix." A fix is an area that likely contains the signal source. A search team then proceeds to the fix area.
- Doppler: Using an electrically rotated antenna system, phase modulation is impressed upon the incoming signal. By correlating the phase shift impressed on the incoming signal with the internal phase reference signal, a bearing can be developed. Doppler doesn't work well below about 50 MHz because the Doppler frequency (phase) shift diminishes with decreasing frequency. It doesn't work well with uncorrelated signals (such as SSB, CDMA, and so on).

The portable receiver we'll use relies on the Doppler method. It has two dipole antennas that are electrically switched at an 800 Hz rate. The resulting RF signal is passed into an FM receiver, which demodulates the signal as an 800 Hz audio tone, as shown in Figure 1.

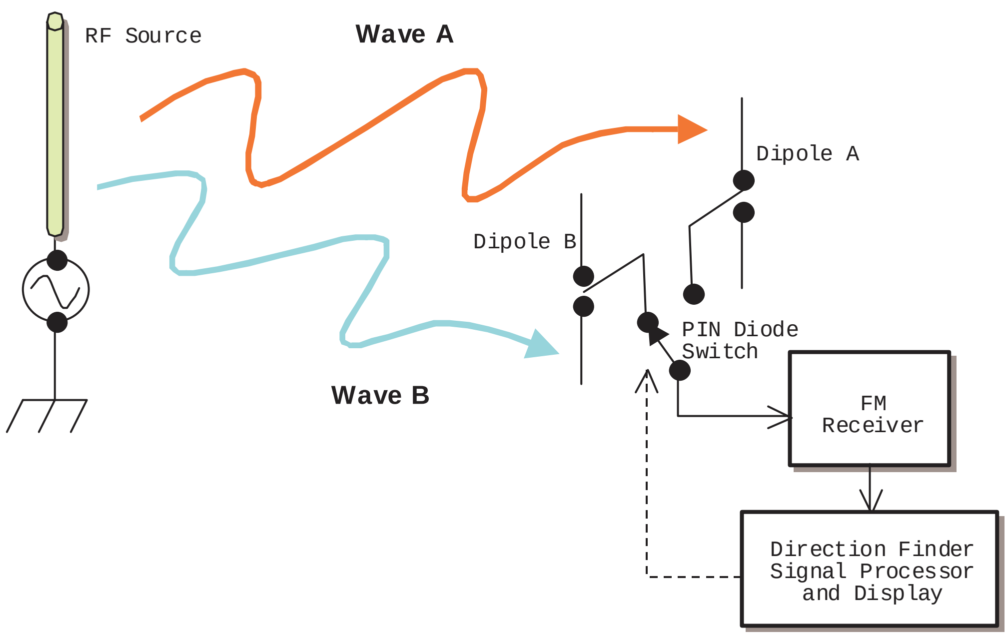

Figure 1: Doppler method with two antennas

The direction finder relies on the time of arrival of the signal at its two dipole antennas. Consider Wave A and Wave B in the figure. If they both arrive at the same time (phase angle) at the antennas, the electrical signals from the antennas will also be in phase with each other. In other words, when the distance from each antenna to the RF source is equal, the output signals are in phase and the direction finder will see a "null" (minimum audio) at the FM receiver output.

If Wave A travels a shorter distance, Dipole A produces a signal that *leads* the signal from Dipole B. The rapid (800 Hz) switching between these two different signals now phase modulates the incoming signal with an 800 Hz tone, which becomes audible in the speaker. The signal processor then indicates "right" on its display. The opposite happens when Dipole B is closer to the source.

Remember this when operating the DF unit: When the 800 Hz audio signal tone "nulls" (becomes minimum), you are either directly facing the RF source, or facing away from it. Use the directional indicators to guide your search; the RIGHT LED means you should turn right, and the LEFT LED means you should turn left.

Laboratory Procedure:

1. The transmitter will be hidden somewhere on the University campus. Before coming to lab, generate an accurate map of the campus. Try using `http://erraserver.microsoft.com` to get a satellite image. You'll use the map to collect quantitative data collected during the hunt. Import this map into a word processor (Sun OpenOffice, Microsoft Word, etc) as a drawing.

2. Divide your class into two or three groups (no more than 6 persons per group). Each group is responsible for finding the hidden "fox" transmitter once. Once a group finds the hidden transmitter, it will hide it for the next group to find.

3. Have someone hide the transmitter somewhere on the premises. (Please have this person keep the unit in sight to prevent it from being lost!) As a group, use the direction finding equipment to locate it. All groups must start at a common location (the steps to the student parking area are a good starting point).

   Plot the course you have taken to locate the transmitter on the map produced in step 1. Use the drawing features of your word processor, plot this course on the map image.

   If you have access to a compass and GPS receiver, provide the coordinates and bearing at each point you measured.

   If you have access to *MapPoint* (or similar software), you can import the GPS data to directly produce maps of the search.

4. Collect the map data from *all* other groups once the experiment has been completed.

5. From the data collected by all the groups, generate a master map that will contain the location of the transmitter each time it was hidden, plus the routes taken by each group to find it. This map will be a pictorial view of VHF radio wave propagation on the campus.

   In the data set, it will be very useful to indicate locations where ambiguous readings were obtained (such as due to multipath reception, reflections, and so on.)

6. Write a conclusion based on the recorded data. Be sure that your report has the following information:

   a) A description of the activities that your group performed;
   b) A list of the persons in your group;
   c) The maps (raw data);
   d) The conclusion based on the data and your own observations.

   Each person must write their own report.

Using the Portable Doppler Direction Finder

- Turn on the receiver and tune it to the Fox's frequency. Adjust the volume at least halfway up.
- Extend and adjust the antennas for 146 MHz (use the printed scale).
- Listen to the 800 Hz tone and watch the indicator LEDs. The *right* and *left* LEDs light to indicate the correct direction for walking. The *center* LEDs flash when your bearing to the transmitter is true (or if there is no signal). You will also notice that the 800 Hz tone nulls when you're either facing directly towards or directly away from the Fox.

Using a Handheld Receiver to Check Direction

Hold the receiver against your body and slowly turn. When the signal becomes weakest, the Fox is likely to be directly *behind* you. Move several meters away and repeat the measurement to make sure of the direction.

Helpful Information

Reflections can fool all direction finding equipment. For example, you may get a bearing that sends you in an "impossible" direction; or you may be unable to get a clear direction indication. Move a few meters away from the spot and try repeating the measurement.

Make all bearing measurements in the most open area available (away from buildings, vehicles, and other persons) to minimize reflections.

If you lose track of the Fox's signal (it becomes very weak), you may be moving in the wrong direction. Backtrack until you have a useable signal again. If you can't hear the signal, you can't DF it!