Reply to comments by Olhoeft et al.
May 7, 2001, ET Docket No. 98-153

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May 17, 2001

In my comments that I posted to the FCC web site, I described a test that I had made, which detected some interference from GPR transmissions on a nearby radio receiver. Olhoeft et al. have criticized my tests as follows:

> "Such anecdotal, non-quantitative and poorly documented tests as Sternberg's add little to these proceedings. Sternberg's description of possible interference is an example of how easily an observation can lead to misleading or unsubstantiated conclusions."

These comments are very surprising indeed, since on the next page Olhoeft et al. use the same type of test to support their own position.

> "Also, interference between a GPR and a cell phone was reported in a recent peer reviewed journal article (Olhoeft, 2000). In those tests, the GPR suffered operational inhibiting interference from the cell phone (it could no longer image a sewer under a concrete floor nor the thickness of the concrete with the cell phone in use that had been possible with the phone off)."

This test of the interference from a cell phone on a GPR record, which Olhoeft et al. used, appears to be virtually identical to the test that I performed (albeit in the reverse direction). I compared the reception on a handheld receiver with the GPR unit turned off, then turned on. I then recorded at what distances the GPR prevented comprehension of voice transmissions. I note that in the Olhoeft (2000) paper there are no quantitative measurements of field strength or radiation pattern from the cell phone antenna. Nor are there any numerical modeling studies of the potential effect of the measured field strengths on the GPR system, assuming various operational bandwidths, gain levels, detection thresholds, etc. The manufacturer and model, modulation type, polarization etc. of the cell phone are not documented. There is no discussion concerning possible digital signal processing to eliminate this interference from the record. Does the lack of quantitative data mean that this is a "misleading test?" Does the limited documentation of the details of the experiment lead to "unsubstantiated conclusions?" I would like to argue that this is actually a very useful, direct test of the effect of a cell phone on a GPR recording. I have to say that I wish the article had documented the distance from the cell phone to the GPR. Nevertheless, I presume that the operational conditions were that a cell phone user was standing near the GPR, using the cell phone in a normal talk/receive mode, and it caused interference to the GPR survey, which could have been engaged in a survey that would be of considerable importance to society. I do not understand how Olhoeft et al. can characterize my measurement of the effect of a GPR transmission on a radio receiver as misleading and then turn around and perform virtually the same test to show that a cell phone can interfere with a GPR. I suggest that both of our tests have been useful to show that there are important issues here that need to be addressed.

It is certainly reassuring that there have not been any reported cases of interference during operational GPR surveys. However, it is not clear that if someone had noted interference on their radio, whether they would have associated this interference with a crew that was performing a GPR survey in the vicinity. A GPR antenna typically looks like a box dragged along the ground and does not resemble what most people think of as a radar or radio antenna. During the 14 years that I have been running GPR surveys I have had countless curious bystanders ask, “What is inside that box?” None have asked, “What kind of radar antenna is that?”

In my comments that I posted to the FCC site, I also suggested that there might be alternatives to transmission of ultra-wideband signals for GPR surveys and other imaging applications. I pointed out that it is possible to record signals over a narrow bandwidth (e.g. in the bands reserved for Industrial, Scientific, and Medical or ISM), and then synthesize a wideband pulse. Olhoeft et al. in their comments responded that:

> "... such types of instruments have been studied and the mathematical requirements for them to work adequately require the availability of many frequencies per order of magnitude (commonly called a “decade”) in frequency. There are not enough frequencies available (allocated in the ISM bands or elsewhere) … "

On May 8, 2001, I sent a request to Olhoeft et al. asking for references, which support this statement. As of this date, I have not received any references, which show that one cannot synthesize a broadband response from narrow-band measurements. Of course, if one uses the response function only at the measured data frequencies, then many measurement points per decade may be required. There are in fact numerous published references that do discuss methods for extrapolating or interpolating a narrowband set of measured data to an effective wideband set of data. A few examples of these papers include: Miller and Burke, (1991), Miller (1998a), Miller,(1998b) Miller (1998c), Press et al. (1992), Pillage and Rohrer (1990), Baum (1976), Pflug (1998). Some of these papers show the accurate synthesis of a wideband response (including multiple resonance peaks) with just two frequencies and their derivatives. These papers are just a sampling of the techniques that we have been looking at for synthesizing broadband data from narrowband measurements. When these techniques are applied to measured data, the key is to obtain sufficiently accurate data in order to be able to apply these mathematical techniques. Producing the accurate derivatives of the measurements is extremely challenging, but may be possible using new and innovative techniques.

As I mentioned in my original comments on the FCC web site, I feel these techniques hold promise for providing effective GPR imaging, using narrow-band measurements. I must stress, however, that considerable research is needed in order to make this a viable technique for GPR soundings. I also wish to argue that this approach can have potentially significant advantages to the geophysical community, such as the possibility of using larger transmitter power without risk of interference.

Olhoeft et al. requested additional information on the interference tests that I performed with the GPR and the radio receiver. The handheld, portable radio receiver that I used was an AR8000, manufactured by AOR, Ltd. of Tokyo, Japan. This receiver can scan frequencies continuously from 100 kHz to 1.9 GHz, with the exception that cellular telephone frequencies in the 800 MHz band are blocked. The receive mode can be selected as AM, NFM, WFM, USB, LSB, or CW.

The GSSI Model 3200 antenna was a standard, unmodified antenna, and was used with a GSSI SIR-8 control console and GRORADAR software. The antenna, control console, and control computer were used in a standard-operating mode for these tests and were operated according to the manufacturers specifications. The transmit and receive antennas were parallel, separated by 3 meters, and laid directly on the ground. Antenna center frequencies of 16, 20, 32, 40, and 80 MHz were used. I note that there is no shielding above this antenna since it is generally considered impractical to effectively shield GPR antennas that have center frequencies below approximately 200 MHz. The SIR-8 and the GRORADAR computer were remote from the antenna and did not contribute to any measured interference. The equipment was in excellent working condition. On the days of these tests, we had been recording images of buried pipes and other targets at depths of 1-to-3 meters.

The tests were run at our Avra Valley Geophysical Test Site, which is located approximately 30 km southwest of Tucson. The tests were conducted on November 1999 and May 14, 2000. The electrical properties at this site are described in Sternberg and Levitskaya (1998), Sternberg and Birken (1999), and Sternberg and Levitskaya (2001). This site had received little or no rain during the previous several weeks and the surface layer (approximately the top ½ to 1 meter) was very dry, with a conductivity of approximately 0.001 S/m at tens of MHz and a relative electric permittivity of approximately 5 at tens of MHz. Below 1-meter depth, the conductivity was approximately 0.1 S/m at tens of MHz due to increased natural moisture content, which is typical of desert soils in the southwestern U.S., and the electric permittivity was approximately 20 at tens of MHz. This lower layer represents a high-loss soil and is not an ideal environment for GPR. I note, however, that we have conducted GPR measurements in many basins throughout the southwestern United States (including Arizona, New Mexico, and Nevada). All of these basins, at least where we have conducted our GPR surveys, have similar electrical properties to Avra Valley (i.e. low conductivity and low-loss at the surface, high conductivity and high loss at depths greater than a meter or so), yet we have obtained very useful information from the GPR surveys for archaeological investigations, geotechnical surveys, and environmental studies at depths up to several meters. The existence of the large electrical property contrast at a depth of about 1 meter could lead to increased energy reflecting back up to the surface, and could potentially lead to an increased chance of interference. We have also seen a similar large contrast in electrical properties between a surface layer and a layer at depth in many other situations, for example, when a subsurface high-conductivity clay layer is encountered at depth in an otherwise low-loss soil. Another example is using GPR to map buried conductive targets, such as buried metal barrels (a favorite GPR target). If the surrounding soil is very low loss, GPR energy may be reflected back up to the air by such highly reflecting targets.

A fiberglass tape was laid out in-line to the GPR antennas and signals were measured at various distances along this line. The tape was then laid out perpendicular to the antennas and the measurements were repeated. At each distance, a frequency scan was performed with the receiver, the receiver antenna orientation was varied, and all receiver-operating modes were checked. I looked for frequencies where there was sufficient interference to prevent normal reception of voice transmissions. The GPR transmitter was toggled on and off repeatedly. A student operating the transmitter called out the changes from on to off. I recorded interference only if there was a clear correlation between the GPR transmitter on and off cycle and interference on the radio station signal. This eliminated any misinterpretation of interference due to the station not transmitting or propagation conditions changing.

The center frequency of a GPR antenna is highly dependent on the nearby soil electrical properties. I noted substantial changes in the primary interference frequencies as the GPR antenna location was changed. In addition, most stations were useable for only a short time period, after which they apparently stopped transmitting. I then had to search for other stations that were affected by the interference.

From all these measurements, I concluded that interference can occur, for this unshielded low-frequency antenna, for some radio stations, and for the soil conditions at this site, at distances up to 128 m. I emphasize that only some radio stations were interfered with. Other stations within the bandwidth of the GPR antenna did not receive any detectable interference at distances of a few meters away from the GPR antenna, in part because of the much greater signal strength of these radio stations and in part because the GPR antenna predominantly emitted interference only at certain frequencies.

The tests with the GSSI Model 3102 500-MHz antenna were conducted behind the Mines Building on the University of Arizona campus. The Model 3102 is well shielded above the antenna in contrast to the low-frequency Model 3200 antenna. The tests were conducted on April 22, 1999. The electrical properties of the soil at this location are very similar to the Avra Valley Test Site soils. The survey was run over concrete and asphalt overlying the soil as well as bare soil. Again the GSSI control console and the GRORADAR software were used with the antenna. This equipment was remote from the antenna and did not contribute interference. The equipment was working very well and successfully imaged a pipe beneath the asphalt at a depth of approximately 0.5 meter.

The same types of tests were run with the 500 MHz antenna as had been run at Avra Valley. The receiver frequency, the receiving antenna orientation, and the receiver mode that led to the strongest interference changed along the profile lines as we passed from concrete cover to asphalt cover to soil only and as we passed different features along the building. From these measurements, interference was noted on some radio stations at distances up to 5 m. I would suggest that this test is similar to the type of GPR survey we are seeing run in urban areas to map utilities. Although 5 meters is not a large distance, it is certainly possible to encounter other radio receivers in a crowded urban environment at these distances.

In summary, it is a challenge to make meaningful quantitative interference measurements with a GPR antenna. A GPR interference test will depend greatly on the near-surface soil electrical properties since the GPR antenna is closely coupled to the ground, unlike typical communication antennas. For example, when our 500 MHz nominal center-frequency antenna is used in areas that have low-conductivity soils, the dominant radiated energy is close to 500 MHz. When this same antenna is in used in areas that have high-conductivity soils, the dominant radiated frequency may be less than 250 MHz. Furthermore, the subsurface layering may have a significant effect on potential interference. For example a subsurface layer with a large contrast in electrical properties can reflect energy back to the surface. Particularly if the top layer has very low loss, this could lead to increased interference from the GPR unit.

The intent of these preliminary tests was simply to see if there was any detectable interference on a portable radio. One must not extrapolate these tests to other soil conditions. I believe this has been a worthwhile exercise - - small interfering signals were detected at short distances from the GPR unit in these tests. My intention in making this test was simply to see if there was any potential for interference. The objectives of this simple test were apparently the same as the Olhoeft et al. cell phone test, i.e. is there an issue and if there is, then we should look into it more. I would suggest that much more extensive tests, under a wide variety of soil conditions, are needed to begin to quantify the potential for interference from GPR units. It would also be valuable to use many different GPR units and antennas, including a variety of low-frequency unshielded antennas and high-frequency shielded antennas.

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