GPR Antenna Resolution

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How many antennas should I have?

We have all heard that question, especially coming from the newcomers to the Ground Penetrating Radar (GPR) technology. The people starting to master this technology are amazed that one has to have so many different antennas for what appears to be the same thing, scrutinizing the earth.

What antenna(s) should I choose?

To get a suitable data set is of the paramount importance, so selecting the proper radar antenna in each case is a must. There are countless tables scattered all over the literature and the Internet, putting out controversial information and leaving the unwary in total confusion and with a feeling of despair. To make things worse, manufacturers are not very kind on giving out emission parameters, radiation lobes, transmission loses or any other important data for the antennas they sell. In this paper I'll try to approach one of the many important factors contributing to a successful ground penetrating radar survey, the resolution of the antenna.

A little bit of theory first

What's all this resolution stuff after all? - Bob Pease would say if he dealt with the GPR and I would only say, Amen! In ground penetrating radar there are two types of resolutions: the vertical, which is the one looking straight down into the earth and the horizontal, which is the one parallel to the surface plane of the survey line. In other words, we should be able to calculate, or at least to estimate, the minimum distance the objects we are trying to survey should be apart, vertically and horizontally. So let's get acquainted with each of these terms separately and see if we can make some sense out of it.

The **vertical resolution** is nothing else than the smallest difference in time between two objects the ground penetrating radar can resolve before starting to “see” both as one. A little bit cryptic, right? Well, no, not really. The ground penetrating radar measures time only, the translation into depth comes later from the knowledge of the dielectric constant of the media. But if we consider, for the clarity sake, that the radar measures distance, then we can say that vertical resolution is the smallest distance in the direction perpendicular to the surface that two targets can be apart for us to see them and distinguish them as separate objects. See Figure 1. to get a better idea, it is marked with “Vr” for vertical resolution.

The **horizontal resolution** is a bit more clear because distance is measured in the length units and not in the time units. So, the horizontal resolution is the minimum distance between two objects in the same horizontal plane parallel to the surface that the radar “sees” both object as separate ones. To put it simply, it is the minimum horizontal distance between two targets at the same depth before the radar smears them out into one single event. See Figure 1. to understand a little bit better the concept, it is marked with “Hr” for horizontal resolution.

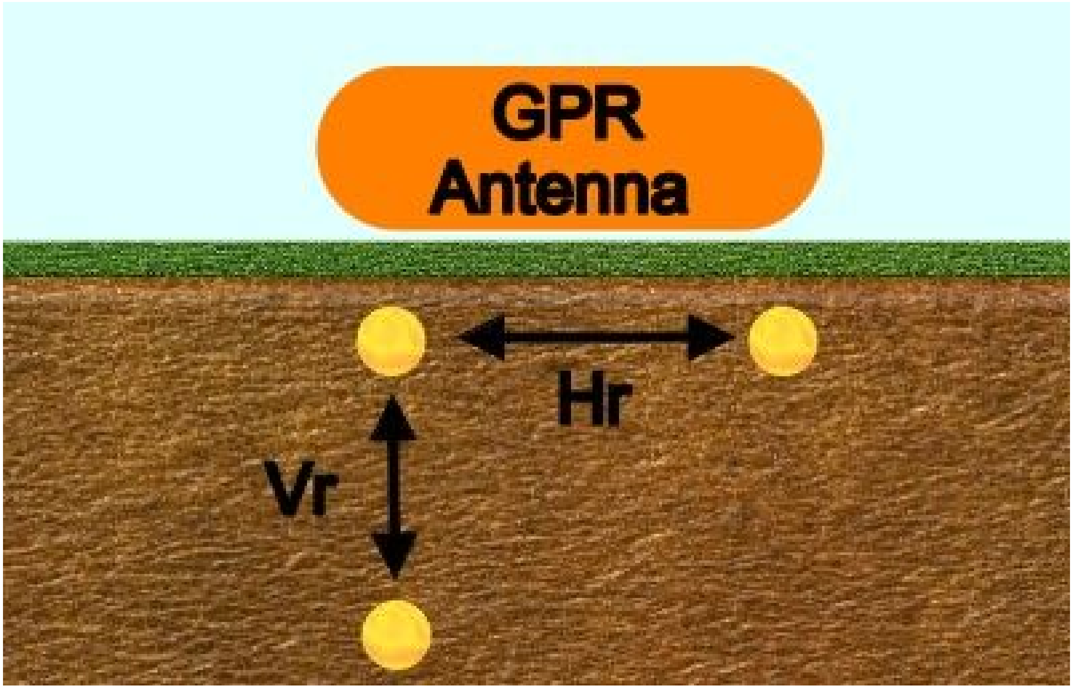

Fig. 1 Vertical and Horizontal resolution diagram, the golden dots are the targets.

How do we calculate them

Now that we know what the vertical and horizontal resolution are, we should be able to get them out from the antenna datasheet the manufacturer supplies, right? Sorry, but no. The antenna manufacturers will be more than happy to give you a lots of commercials, brochures, and almost “out of the geophysics text books” data samples, but nothing else. There is one thing though that we can get from almost every antenna manufacturer on the market, the center frequency of the antenna. Be aware though that different manufacturers specify this parameter differently. A much better approach would be to ask, what is the transmitted pulse width? That would allow you to make your own conclusions on the center frequency in the way you are familiar with.

The reciprocity theorem states that a receiving antenna is as good at receiving as it is at transmitting if all physical and fabrication parameters are kept identical. So, anything that gets transmitted can theoretically get received back by a similar device. Taking into account that the earth works like a low pass filter, then we can surely state that what was not transmitted has absolutely no chance of being received if it has higher frequency than the existing ones in the frequency spectrum of the original signal. The only exception of that rule is if you are using an unshielded antenna and the source of the signal is an external transmitter. This concept is important because I have personally read about antennas marvelously receiving microwaves frequencies with pulse width of 3 to 4 ns. How that happened was unfortunately never explained to me, but I'll publish it out as soon as I know all the facts.

Why is the transmitted pulse or the center frequency so important? It is because the vertical resolution is nothing else than half of the duration of the transmitted pulse in time. If we translate that into depth information then we can say that the vertical resolution is half the width of the transmitted pulse times the velocity in the media:

$$Vr = \frac{Tpulse \cdot c}{2 \cdot \sqrt{RDP}} \quad (1)$$

where:

Vr is the vertical resolution

Tpulse is the transmitted pulse duration, this can be calculated by taking the inversion of the fundamental or center frequency.

c is the speed of light in vacuum

RDP is the relative dielectric permittivity of the media.

Please keep in mind that this is an approximate formula that works most of the time, but not always. The reason for that is that the transmitted pulse will suffer from low pass filtering in the media it is traveling through. Spreading losses of the signal also affect the above explained formula. This means that objects that are far away from the surface will most likely have a different vertical resolution than those closer to the source of the sounding pulse.

Another important factor to consider when trying to estimate the vertical resolution is the type of materials of the two close targets. Materials that produce strong reflections are more likely to mask the objects that are close to them, while materials that produce weak reflections will be easier to detect due to a more local signature. This last conclusion is, of course, true only if the weak reflections are strong enough to be detected reliably otherwise you might loose them entirely.

The bottom line about vertical resolution is that promising too high a resolution is not a good practice. A more conservative approach of taking twice as much as the calculated value will put the survey in a better perspective. The level of expertise of the person interpreting the survey data will also, without any doubt, play an important roll in this matter. GPR surveys, more often that not, don't fail. They just don't live up to the promises made and the expectations from the customer ordering them. Using all the knowledge the theory provides us and exercising common sense is a key to success.

Now, the second type of resolution, the horizontal resolution. This is a topic of much debate and many people have their own opinion on what should be the right way of calculating the horizontal resolution. Basically, one could summarize that the horizontal resolution depends on the following parameters:

1. The amount of traces per unit of distance. If you have 10 traces per meter there is no chance of discriminating objects that are 50 mm apart from one another. Actually I'd be very surprise if you can actually discriminate objects that are 100mm apart from one another.
2. The beam width of your antenna. This parameter is almost never specified in the antennas datasheet and many people use approximations for the real value. It is

obvious that the narrower the beam of the antenna is, the better the horizontal resolution gets.

3. The separation between the transmitting and receiving antenna. This is something that gets overlooked most of the time, but having two antennas closer to one another will most likely increase the probability of both antennas being influenced by external factors identically.
4. The depth at which the objects we need to discriminate are located. Closer to the surface the beam of the antenna is narrower independently on the type of antenna used and therefore by the second parameter mentioned above the resolution is higher.

As stated earlier, there are many different criteria for the horizontal resolution and while it is a much more understandable concept, there are many factors influencing it and giving ground for so much controversy. I personally however, have found that the following formula fits best the results in real conditions:

$$Hr = \frac{c}{4 \cdot f \cdot \sqrt{RDP}} + \frac{D}{\sqrt{RDP+1}} \quad (2)$$

where:

Hr is the horizontal resolution

c is the speed of light in vacuum

f is the center frequency of the antenna

RDP is the relative dielectric permittivity

D is the depth to the plane where the two objects are located.

As with the case of the vertical resolution, this formula is by no means exact all the time and due to all the factors influencing the horizontal resolution it will only give a good idea on what to expect. When planning a survey it is a good idea to take the results produced by this formula with great reservations. For instance the focusing that occurs in the different layers in the media will create different “illuminated” zones that we can not predict and therefore the results will be less accurate.

Some examples

It would be silly to put all of these formulas together and not make a single experiment to prove them right, or at least acceptable. The experiments are simple and if you have a ground penetrating radar control unit and a microwave antenna you should be able to repeat them without any trouble at all.

For the vertical resolution I decided to make two different experiments. The first one using two plane reflectors and the second one using two cylindrical reflectors to get some hyperbolas.

For the horizontal resolution the two plane reflectors I used were a 1.6mm thick metal plate and a 10mm thick Plexiglas plate. Both planes were at least twice the larger size of the antenna in all directions. I used Styrofoam blocks of 50mm to create the separations between the two layers. This gave me a really easy setup and allowed me to change conditions quickly and efficiently. A diagram of the setup is presented in figure 2.

Fig. 2 Setup of the experiment for the vertical resolution in layers.

I collected a series of data files, the first one with only the metal plate 150mm from the antenna. The second file was recorded with the Plexiglas 100mm from the metal plate and the last one with the Plexiglas separated only 50mm from the metal plate. I used an antenna with a center frequency of 1300MHz that would theoretically give a resolution of 116mm in this particular setup. As you can see in Figure 3. the results are somewhat better than the calculated resolution for this antenna. The two plates are still visible when separated only 50mm from each other. Of course, one can argue that in real life data it would be very easy to miss it and I would certainly agree with that. That's the reason why expecting a 100mm resolution is a better approach.

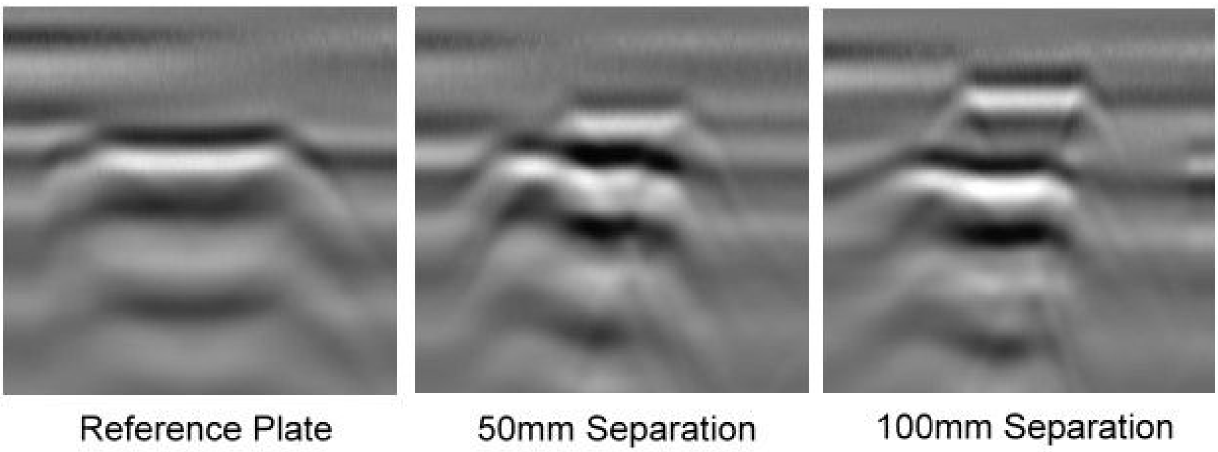

Fig. 3 Experiments results for the layers setup.

Would it be the same if the two reflectors were cylindrical shaped and metallic like the re-bars in concrete slabs? Most probably the interpretation difficulty would increase, compared to the previous example.

The setup for the pipes is almost identical to the setup for the layers except now I used 10mm steel pipes instead of the plates. A diagram presenting the setup is shown in Figure 4.

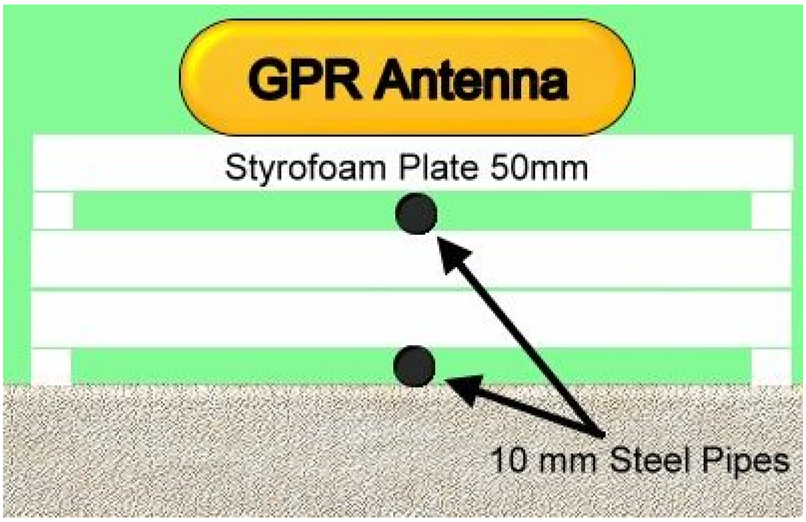

Fig. 4 Setup for the experiment using vertically spaced pipes

The results are much more difficult to interpret and at 50mm separation it is almost impossible to identify the second target if you do not have previous knowledge of what's “buried” under. Figure 5. shows that even at 100mm distance the strong reflection caused by the first pipe makes it very difficult to detect the second one. Many experienced GPR practitioners may argue with me that they would spot the second pipe at 50mm without any trouble at all. That's because the two strong positive, black in this case, hyperbolas would nicely collapse into dots when migration is applied to them. That might or might not be the case, I personally would prefer to use a higher frequency antenna and have them separated nicely.

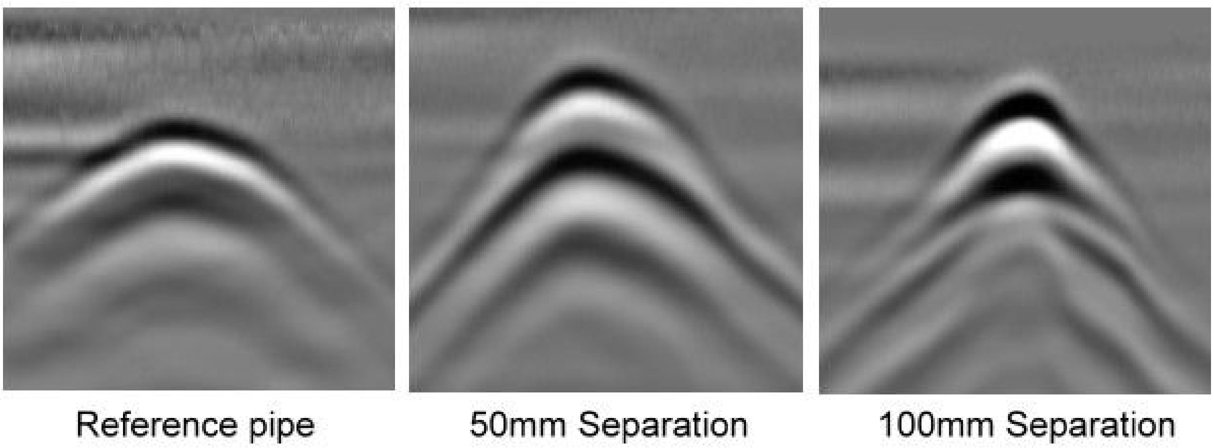

Fig. 5 Experiment results for the two pipes vertical resolution.

For the horizontal resolution experiments I used some 20mm pipes, but I placed them in the same plane, parallel to the surface. The distance from the antenna to the pipes was reduced to 85mm and the horizontal distance between the pipes was changed from 250mm to 100mm and 50mm for the closest separation.

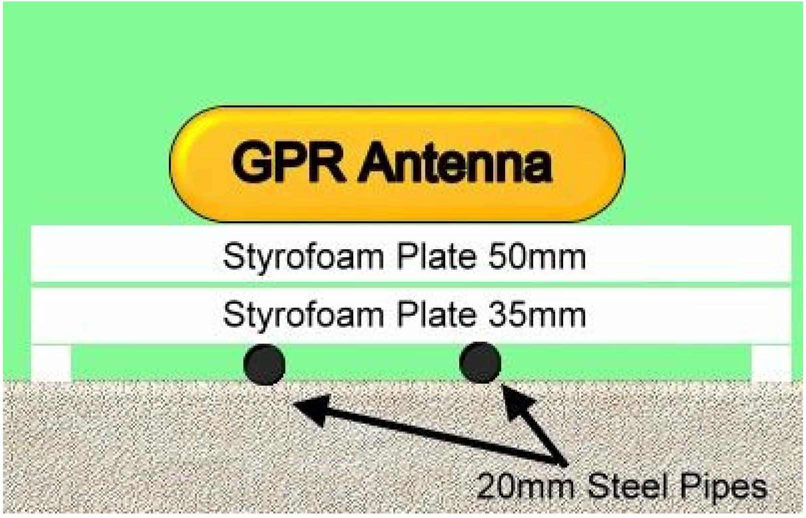

Fig. 6 Setup for the horizontal resolution experiment.

The simple formula explained above for the horizontal resolution gives an estimate for the horizontal resolution of 117mm. This estimate seems to be a little too high if you consider Figure 7. where the results of the experiment are shown.

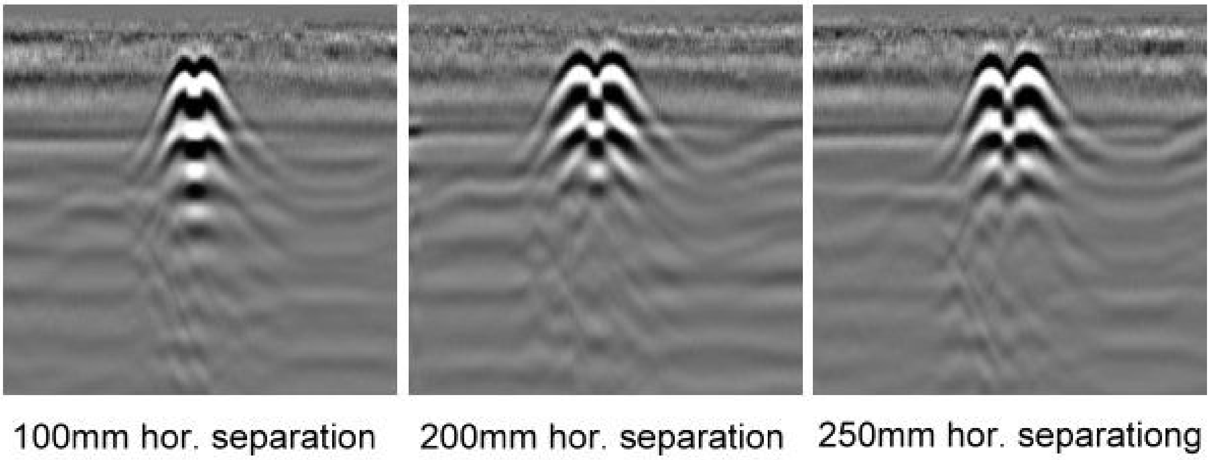

Fig. 7 Experiments results for the horizontal resolution separation

It appears that the resolution is quite higher, in fact, one could easily say that 100mm separation is quite OK. That is approximately 15% better than the estimate, but one must consider all the factors affecting the outcome of the experiment.. In real survey conditions the relative dielectric permittivity won't be even close to being a constant, neither is the radiated frequency a single spectral line. Hence the fact that the estimated horizontal resolution shown in formula number two is only a very good starting point to estimate the viability of the survey.

Conclusions

Coming back to the question that started this discussion: *how many antennas should I have?* The answer would be very simple, *as many as the amount of radically different survey jobs you need to undertake*.

It is not my intention to further confuse anyone with the presented material. This conclusions are based on what I have read in the literature listed in the reference section and on my personal experiences. I believe it is a good practice to analyze all the factors affecting the outcome of a ground penetrating radar survey before rising too high hopes in the people that have placed their trust in this technology. Sometimes it can be too much trust and not enough facts that will ruin a survey result.

I leave you at the starting point for you to draw your own conclusions and do a little bit of experimentation to find out what works best for your particular line of surveys.

All the data used in this article was collected using a SIR-3000 control unit from GSSI USA and our own antenna GCB-1500. The data was processed with our own software GPRSoft PRO and the document was prepared using the OpenOffice writer.

If you have any questions or suggestions please send an email to mail@geoscanners.com and the words “GPR antenna resolution” in the subject. I'll answer to all emails according to time availability.

References

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