Microwave Attenuation in Concrete Wall Sections

Dr. Gary L. Johnson

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INTRODUCTION I am investigating the use of a specialized concrete as a construction material for housing for those with Electromagnetic HyperSensitivity (EHS) and/or Multiple Chemical Sensitivity (MCS). An earlier document that I wrote about the first of 2013 was titled "Concrete Construction For EHS and MCS". In it I reported on a study performed by the National Institute of Standards and Technology, NISTIR 6055, *Electromagnetic Signal Attenuation in Construction Materials*, October, 1997. I discussed the theory of electromagnetic losses in water, gravel, and concrete. I gave some preliminary results of crude tests on Quikrete, and my own concrete mixes using gulch sand and road base. I indicated my hope of doing more extensive testing in open air at my gulch when the weather warmed up. The present document contains results since the first of 2013.

The hope is to find a concrete mix that will absorb significantly more cell phone and wireless signals than standard concrete, and build a "Masonry Faraday Enclosure" in a gulch named Bear Gulch, in Rockvale, Colorado using this concrete. The structure will resemble a house or cabin, and will be livable for one or two people for extended periods of time, but will not meet all the requirements of the Uniform Building Code, the National Electrical Code, etc. I believe that some features of the Codes are bad for the health of those with EHS and/or MCS, and that we need research structures, test facilities, etc. to investigate new techniques that can be considered for future Codes.

Many concepts are being explored for the fabrication of this Enclosure. Size would be relatively modest, perhaps 800 to 1000 square feet. As this is written, I am leaning toward putting the Enclosure on a conventional concrete slab. This slab would be made from standard concrete that is available at the local concrete plant. Footings, rebar placement, thicknesses, etc. would be as specified by county documents. Installation would be by an experienced concrete crew.

Next would be to pour walls for the Enclosure with a special concrete mix, with the usual openings for windows, doors, and other necessary penetrations. Wall height would be on the order of nine or ten feet. The inside surface of the wall will be visible to the occupant (and used for thermal mass) so the appearance needs to be relatively good. There are three options (at least) for doing this. One is to put forms in place like might be used for a basement and pour the entire wall at once. A second would be to use a shorter form, pour perhaps two vertical feet, and raise the form before pouring the next layer. A third would be to pour a portion of the wall in a horizontal form, and lift it into place with a crane. The decision about which option to use will be made later.

The outer edge of the concrete wall will be placed perhaps eight inches from the outer edge of the slab. On this strip or apron will be erected a metal skin building, around the concrete wall on the inside. This building will contain the load bearing structure for the ceiling and roof. The concrete wall just has to support itself. The metal skin building might be a Morton building, or at least would use some of the concepts of a Morton building. There would be wood columns made of three 2×6 boards sandwiched together, and spaced about seven or eight feet apart. Morton uses a *large* fiberglass roll that just fits between the columns for wall insulation. On the outside of the columns will be horizontal 2×4 girts about two feet apart. Vertical metal sheets will be nailed (or screwed) to these girts.

The tops of the wood columns would support the roof trusses, which in turn support the metal roof. The trusses span the entire space between the concrete walls, so the Enclosure could be just one big room. Interior partitions can be installed as desired.

Morton built me a research building of dimension 54×90 feet near Manhattan, Kansas in 1996, using the same general type of construction that I am thinking of here. The quality was excellent. If Morton and I decide to work together on this project, we would have an Enclosure with basically no structural issues. We will then be able to focus on the real issues of wiring, lighting, heating, cooling, ventilation, etc.

ABSORBING CONCRETE I have been looking at making concrete with slag from a steel mill in Pueblo. This steel mill (EVRAS) recycles steel scrap in arc furnaces. The mill sells the slag to another company, Harsco, while it is still red hot, even on fire. Harsco checks the slag after it cools and separates out the most strongly magnetic chunks (indicating significant iron content) and sells these chunks back to EVRAS to run through their furnace again. The remaining material is then sold for applications like road base. Their road base will pass through a screen with 0.75 inch openings and sells for $4.65 per ton. It is strongly magnetic and has a higher density than other aggregates, indicating significant remaining iron content.

Slag is commonly added to concrete as a part of the aggregate in other parts of the world. The woman doing the weighing of trucks and collection of costs had heard that Harsco slag had too much lime to make really strong concrete. I suspect that it will be strong enough for a non-load bearing wall of a single-story Enclosure, but that remains to be tested.

WALL SECTIONS To test the microwave absorption of different concrete recipes, I built several wall sections. I built a form of 0.75 inch plywood and 2×4 inch lumber that would sit vertically on bare earth, with both top and bottom open. The resulting concrete wall section is 45 inches wide, 3.5 inches thick, and up to 36 inches tall. I used a small auger to make two vertical holes under the wall section, about 3 inches diameter by 12 inches deep. With a monolithic pour, these holes fill with concrete that is integral with the wall section and will provide some resistance to overturning. No rebar was used.

The first section built about 5/28/13 was one of Quikrete, six bags or 480 pounds dry weight. The material was mixed in a wheelbarrow with a hoe, one bag at a time. No record was kept of the amount of water used, but I considered the material to be relatively dry for hand-mixed concrete. The hoe would scour to the bottom of the wheelbarrow, leaving a wall of wet concrete on each side, with no liquid visible on the steel bottom.

An internal concrete vibrator (made by DeWalt and battery powered) was inserted into the concrete after the first five bags were shoveled into the form. It was operated a few seconds and then moved a few inches along the form (up and out, then in and down, but not sideways). The form was essentially full of concrete before vibrating, but was at least six inches below the top after vibrating. There was plenty of room for the sixth bag in the form after vibrating. Actually the final level was about an inch below the top of the form. I did not use the vibrator again when I shoveled the sixth bag into the form, assuming I could easily work and compact the top few inches of concrete in the form. I was wrong. There is a marked change in the surface texture of the wall section at the boundary between the fifth and sixth bags. My guess is that this will not make a significant difference in attenuation measurements.

The second section was built about 6/3/13 using 90% gulch sand and 10% Portland cement, by weight. The relatively flat bottom of the gulch has a very sandy soil. But the very bottom, the waterway where water has flowed exactly once during my ownership of over one year, consists of sand that would not look out of place in a child's sandbox. I used a quarter-inch screen to remove the small fraction of larger rocks. I then used a digital scale and measured 36 pounds of sand into a five gallon bucket for transport to the location of the wall section. Two of these buckets were dumped into a small electric concrete mixer, along with eight pounds of Portland cement. This step was just for blending the cement into the sand, so no water was added. The blended material was dumped into the wheelbarrow, where the water was added. The density of sand is lower than the density of the aggregate in Quikrete, so only 400 pounds (dry weight) of this mix was needed to fill the form to within about two inches of the top. The surface appearance of this concrete is good. One might consider using it for the final surface of an interior wall in a house, perhaps just covered with a coat of paint.

The third section was built about 6/7/13 using 80% slag, 10% gulch sand, and 10% Portland cement, using a total of 480 pounds dry weight. The density was about 148 pounds/ft^3. The slag has some fine material in it, but not sufficient to fill the voids between the larger chunks, resulting in a very rough surface texture. As it turned out, 10% gulch sand was not enough to yield a smooth surface texture. The upper half of the section was fairly smooth, but the lower half had more of the texture of a popcorn ball.

A fourth section was built on 6/17/13 using 75% slag, 15% gulch sand, and 10% Portland cement. A total of seven wheelbarrow loads were mixed. I would dump a bucket containing 30 pounds of slag into the mixer, then a bucket with 12 pounds of gulch sand and 8 pounds of Portland cement, then a second bucket with 30 pounds of slag, for a total dry weight of 80 pounds (the same as a sack of Quikrete). I would blend the material with the mixer for perhaps half a minute, dump into the wheelbarrow, then add water and stir with a hoe until it 'looked' like wet concrete. The material would then be carefully shoveled into the form. When the form was almost full, I would start using the vibrator. As the concrete settled, I added more concrete, while continuing to use the vibrator. A total of 560 pounds dry weight filled the form to about the same height as the 480 pounds of the third section. The density of this concrete is about 172 pounds(dry weight)/ft^3. This suggests that the additional sand in the mix was able to better fill the voids between slag pieces, resulting in a significantly higher density product.

A fifth section was built about 6/25/13 using 70% slag, 21% gulch sand, and 9% Portland cement. Again, seven wheelbarrow loads were mixed, but each load contained 84 rather than 80 pounds dry weight. The total dry weight of the section was then 588 pounds. The density was about the same as Slag #2, or 172 pounds/ft^3. The appearance of the concrete surface was almost acceptable. We might decide to use this recipe for the first Enclosure, and patch any areas of roughness. If we are mixing concrete on site, and pouring it into slip forms, we might adjust the recipe between layers. The appearance of the concrete will be important to those using this research, but is not high on the priority list for the first Enclosure. We must have an Enclosure that is structurally safe, electrically safe, and chemically safe. After that, physically attractive would be nice but not essential.

MEASUREMENT PROTOCOL We start with a signal source of adjustable frequency and amplitude, in this case the HP8620C. We use the portion of its frequency range between 1.6 and 2.4 GHz. The amplitude can be varied between 0 and 13 dBm (dB above one milliwatt; 0 dBm = 1 mW, 13 dBm = 20 mW), according to the dial of a single-turn potentiometer. The precision of a given reading could vary by as much as half a dB, between the reading of the dial and the internal construction of the potentiometer. For some comparison readings, I use output with the potentiometer turned all the way counterclockwise (minimum) and all the way clockwise (maximum) to eliminate dial reading error.

The HP8620C is connected to an ETS-LINDGREN Model 3115 Double-Ridged Guide Antenna with a coaxial cable about 50 feet long. (I sit at a small table at a right angle to the maximum power radiation direction of the antenna to collect data. The antenna radiates some power in all directions, but using a relatively long coaxial cable reduces the signal strength at the table). The guide antenna has a gain of about 14 dB over the frequency range of 1.6–2.4 GHz. The half-power beamwidth is about 60^o at 1.6 GHz, dropping to about 40^o at 2.4 GHz. The antenna width, height, and length are 24.4, 15.9, and 27.9 cm, respectively.

The antenna nose (the rectangular opening where the field exits the antenna) is placed 20 cm away from the concrete section. This is 1.067 wavelengths at 1.6 GHz increasing to 1.6 wavelengths at 2.4 GHz. This distance (20 cm) is somewhat arbitrary. We would like to have a true plane wave incident on the section, which would require the antenna to be located an infinite distance away. We would also like to have a section of infinite extent, so there are no issues of reflection and diffraction from the edges. These desires are obviously impossible to fulfill, so compromises must be made. I looked at results with the antenna 20, 30, 40, 50, and 70 cm from the section, and it appears that the 20 cm separation gives meaningful results with minimal effects from the edges of the section.

The signal detector is a GigaHertz Solutions HF38B. This is a hand held instrument with a detachable log periodic antenna. I mounted the detector on a block of wood with the antenna pointed at the center of the concrete section and the LCD display facing the instrumentation table. I would read the display with a telescope, since it was located up to 50 feet away. The HF38B has three scales: 19.99 μW/m^2, 199.9 μW/m^2, and 19.99 mW/m^2. The nose of the antenna is located 121 cm from the concrete section. The total nose-to-nose separation of the transmitting and receiving antennas is then $121 + 20 + 9 = 150$ cm. (The 9 cm is the thickness of the concrete section.)

The basic concept is to take open air measurements away from any concrete section, with the antenna nose-to-nose distance held at 150 cm, and record the power density P_1 as shown on the screen of the HF38B, at nine different frequencies, 1.6, 1.7, . . ., 2.4 GHz. The antennas are then moved to opposite sides of a concrete section, and the power density readings for P_2 are recorded for the same frequencies. The attenuation in dB is then given by

$$A = 10 \log(P_2/P_1) \qquad \text{dB} \tag{1}$$

There are several factors that could conceivably have an effect on attenuation values, such as air temperature, relative humidity, relative tightness of the coaxial cable connectors, state of charge for the 9 V battery in the HF38B and the deep cycle batteries driving the inverter for the HP8620C, etc. On a measurement day, readings were taken for all five concrete sections and for no section as quickly as possible (about 2-3 hours). Attenuation calculations were made using the data from only that day.

THEORY AND MEASUREMENT CHALLENGES Concrete contains both chemically bound water and free water. During the curing process, which lasts for months or years, some free water in converted into chemically bound water. Free water can enter the concrete to some saturation condition, and can be driven off by a drying process. Free water molecules are dipolar and will vibrate at the frequency of an applied electromagnetic field. This vibration converts electromagnetic energy into thermal energy. A higher frequency produces a more rapid vibration and a greater conversion of energy. Microwave ovens, mostly operating at 2.45 GHz, use this principal to heat food by heating the moisture within the food. Operating a microwave oven empty or with totally dry food is an invitation for trouble.

We therefore expect the attenuation of microwave signals within concrete to vary widely with the free water content. Since we are doing open air measurements, we would expect the results to be different after a long dry spell as compared with immediately after a rain. We will definitely see this effect in our data. Even for a concrete wall enclosed in some protective structure, we would expect the free water content to vary with the internal and external relative humidities and the temperature gradient across the wall. This means that we will never to able to say that the attenuation of wireless signals through a concrete wall of a given composition and thickness is some precise number.

An important feature of all concretes made with both sand and aggregate is that it is heterogenous. The exact arrangement of lumps is random. Most of the incident signal propagates through the sand and Portland cement rather than directly through the lumps. The lumps tend to change the direction of the signal propagation (diffraction). For one specific location and orientation of the antennas, the net effect of diffraction around thousands of lumps might be a focus or concentration of signal, a ‘hot’ spot. Move the transmitting antenna a few centimeters parallel to the concrete section and the transmitted signal sees an entirely different distribution of lumps, which might result in a lower power level. This is also a frequency dependent phenomenon. A hot spot at one frequency might be a dead spot at another frequency.

In addition to this heterogenous feature, the method I used to vibrate the concrete probably added a structured inhomogeneity to the section. The vibrator is basically a cylinder about an inch in diameter that is inserted vertically into the wet concrete. On the way in, the cylinder would push all the concrete out of the way. Vibration would then cause all the concrete outside the cylinder to assume a maximum density, minimum void configuration. Then, as the vibrating cylinder is removed, some portion of the wet concrete will flow back into the empty space. My guess is that this vertical cylinder will have a different structure/composition from the surrounding material. My first assumption would be more fines and fewer big chunks. These columns might well act like a diffraction grating.

If we take the average of the attenuation values obtained by pointing the transmitting antenna at different spots on the wall section, we should arrive at a representative or meaningful value. Obviously, the more spots we look at, the more meaningful the average will be. My measurement system is manual (not automated), so looking at an excessive number of spots becomes too labor intensive. I arbitrarily selected five spots to measure. One spot was with both antennas pointed directly at each other, but with the center of the wall section between antennas. I would then move the transmitting antenna parallel to the wall section a distance of 10 cm, then another 10 cm, then 10 cm the other side of center, then 20 cm the other side of center. The receiving antenna remains fixed, pointing at the section center in all cases. Rather than the center of the antenna beam, we are looking at 3.8^o and 7.6^o off center, respectively, for the ± 10 and ± 20 cm cases. The signal decrease for these small angles should be small, and should average out in any case.

The attenuation tables that will be presented shortly have the average and the standard deviation of each data set of five numbers. A small standard deviation suggests that the concrete section is relatively uniform. A large standard deviation suggests that the section is relatively non uniform (or that the measurement technic is flawed).

ATTENUATION DUE TO REFLECTION When an electromagnetic wave is incident upon a boundary between two different materials, such as air to concrete, a fraction of the wave is reflected. For a concrete wall, the transmitted portion travels through the wall, losing amplitude because of the concrete losses. When the surviving portion of the original wave hits the inside wall, the same fraction of power is reflected, but with different phase shifts in the electric and magnetic fields than when the wave hit the first boundary. The lossless case is treated in an early course in electromagnetic theory. Calculations get to be challenging in the lossy case, so this is usually treated in a later course.

If we know the permittivity and magnetic permeability of the concrete, then we can calculate the apparent attenuation due to reflection. The permittivity is a complex number due to the losses in water. Both the real and imaginary parts change widely as the amount of free

Table 1: Attenuation by Lossless Reflection

ϵ_r	P_T	$10 \log P_T$
4	0.889	-0.51 dB
9	0.75	-1.25 dB
16	0.64	-1.94 dB

water changes. The permeability will be essentially the same as free space for concretes made with Quikrete and gulch sand, but will be a complex number when slag is used in the concrete, due to the iron in the slag. Since none of these numbers are known with any precision, there seems to be little point in doing extensive calculations. I will just look at the simplest case.

The impedance seen by a plane wave traveling in free space (the ratio of electric field to magnetic field) is

$$\eta_o = \sqrt{\frac{\mu_o}{\epsilon_o}} = 377 \qquad \Omega \tag{2}$$

The impedance of a lossless, non magnetic medium with relative permittivity ϵ_r is

$$\eta_1 = \frac{377}{\sqrt{\epsilon_r}} \qquad \Omega \tag{3}$$

The reflection coefficient for a plane wave vertically incident from free space to the medium with $\epsilon = \epsilon_r$ is

$$\Gamma = \frac{\eta_o - \eta_1}{\eta_o + \eta_1} = \frac{\frac{1}{\sqrt{\epsilon_r}} - 1}{\frac{1}{\sqrt{\epsilon_r}} + 1} \tag{4}$$

The fraction of power density that is reflected is

$$P_R = \Gamma^2 \tag{5}$$

By the Law of Conservation of Energy, the fraction of power density that is transmitted through the interface is

$$P_T = 1 - \Gamma^2 \tag{6}$$

P_T and $10 \log P_T$ are given in Table 1 for three values of ϵ_r, 4, 9, and 16.

Completely dry sand and many aggregates will typically have relative permittivities in the range of 3 or 4. Water has a much higher relative permittivity, up to about 80 depending on the temperature. The bound and free water in concrete will raise the relative permittivity substantially. I have seen hints that some (dry) concretes will have an ϵ_r of about 9. Saturated concretes will have a larger ϵ_r, perhaps as high as 16 or even more. Let us consider the middle row of Table 1, for $\epsilon_r = 9$. A plane wave vertically incident on a lossless dielectric with $\epsilon_r = 9$ will have 25% of the incident power density reflected back toward the source, and 75% into the dielectric. None of this 75% is lost inside the *lossless* dielectric. When the wave hits the second surface of the dielectric, going from the dielectric back into air, the same percentages appear again, 75% of the 75% continuing on, and 25% of the 75% reflected back into the dielectric. The wave continues to bounce back and forth between the two surfaces of the dielectric, losing the same fraction at each bounce. The 25% of the 75% eventually leaves the dielectric, part in the forward direction and part back toward the source. How much goes which direction depends on the thickness in wavelengths of the dielectric. At one frequency, all the 25% of the 75% continues on. At another frequency, all of the 25% of the 75% is reflected back toward the source.

The case where all the power entering the dielectric eventually exits the other side would result in a 'minimum' attenuation, as shown in Table 1. The attenuation for this case would be -1.25 dB. The 'maximum' attenuation would be another -1.25 dB or a total of -2.5 dB. For $\epsilon_r = 16$ the attenuation would range from -1.94 to -3.88 dB, depending on the thickness of the wall section. We will explore the meaning of these numbers in the following material about concrete made with gulch sand.

GULCH SAND DATA Attenuation values for the concrete section made with gulch sand are given in Table 2. The 7/12/13 data were collected after a long period of hot, dry weather. All sections should have a minimum content of free water and minimum attenuation. The 7/16/13 data were collected the morning after a slow one inch of rainfall the previous day. The free water and attenuation should be maximum. The 7/24/13 data were collected after a few days of hot, dry weather, but not as long as the hot, dry period before 7/12/13.

The first thing we notice is that the received signal is *larger* with the concrete section in place than the open air value for six frequencies on 7/12/13 and two frequencies on 7/26/13. I think this effect is due to the front and rear surfaces of the section not being perfectly flat and parallel to each other. The ends of my form were bolted through a standard 2×4 so the section was a nominal 3.5 inches thick at the ends. In the center, however, the pressure of the concrete caused the form to bulge out, to perhaps 4 inches thick. The section therefore has the shape of a convex lens, which would focus or concentrate the signal passing through. The effect is not great, no more than 1.5 dB at 1.6 GHz, and mostly well under 1 dB.

The portion of attenuation due to reflection tends to mask this lensing effect. If we see a measured increase in signal of 1.5 dB, and reflection caused a loss of say 1 dB, then the true lensing effect would be $1.5 + 1 = 2.5$ dB.

Table 2: Attenuation in Gulch Sand Wall Section

	7/12/13		7/16/13		7/24/13	
Freq	Mean	S.D.	Mean	S.D.	Mean	S.D.
1.6	+1.50	0.20	-2.42	0.34	+0.62	0.56
1.7	+1.13	0.14	-3.10	0.56	+0.80	0.29
1.8	+0.20	0.24	-6.31	1.06	-0.46	0.33
1.9	+0.39	0.28	-5.24	0.71	-1.13	0.73
2.0	+0.56	0.15	-4.89	0.28	-0.31	0.10
2.1	-0.02	0.24	-4.37	0.59	-1.03	0.50
2.2	-0.12	0.35	-4.16	0.51	-1.30	0.38
2.3	+0.34	0.11	-4.78	0.41	-0.27	0.18
2.4	-0.10	0.27	-4.28	0.50	-0.71	0.25
Mean	+0.43		-4.40		-0.42	

The effect of rain was to increase attenuation by 4 or 5 dB. Water is *very* lossy, so this suggests that the concrete section did not absorb very much free water. We will see similar increases in attenuation for the other types of concrete after rain, suggesting that the quantity of free water absorbed is similar in every case. The concrete walls in the Masonry Faraday Enclosure will not be exposed to rain, so we should view the 'dry' condition as most representative of the final structure.

The main conclusion from this particular test is that the attenuation of concrete made from local sand, Portland cement, and bound water, is *really* poor! It is about as transparent to microwaves as window glass. If we want significantly lower signals inside an enclosure, we will need to replace much of the sand with an aggregate that has absorbing characteristics.

QUIKRETE DATA Now we look at data (Table 3) for the concrete section made from Quikrete, purchased from the local Ace Hardware in 80 pound bags. I assume that these data are only valid for Quikrete made at one particular plant, using one particular aggregate. It would made sense to manufacture a product like this at many different plants across the nation, to minimize shipping costs. The aggregate and sand would have to pass mechanical and chemical tests to ensure the resulting concrete had adequate strength. But no microwave signal absorption tests would be performed. The aggregate at one quarry might be as lossless as our gulch sand, while aggregate from another quarry might be highly absorbing.

We see that Quikrete is more absorbing than concrete made from gulch sand. The 7/12/13 data had a mean attenuation for all frequencies of -4.55 dB. The attenuation gets better/greater with increasing frequency, as it should. But we would like an even greater attenuation, which we will be able to get by using slag for aggregate.

ATTENUATION FOR SLAG BASED CONCRETE Tables 4, 5, and 6 show attenuation for concrete made with 80%, 75%, and 70% slag, respectively. We note immediately

Table 3: Attenuation in Quikrete Wall Section

	7/12/13		7/16/13		7/24/13	
Freq	Mean	S.D.	Mean	S.D.	Mean	S.D.
1.6	-2.38	0.55	-6.06	0.38	-4.29	0.48
1.7	-3.48	0.64	-6.88	1.16	-5.00	0.66
1.8	-3.89	0.24	-8.20	0.38	-5.99	0.38
1.9	-4.32	0.74	-8.45	1.05	-6.34	0.44
2.0	-4.38	0.81	-9.17	0.90	-6.01	0.27
2.1	-4.74	0.56	-9.73	0.74	-7.02	0.66
2.2	-5.07	0.83	-9.08	0.50	-8.00	0.68
2.3	-5.65	1.14	-9.93	0.87	-7.49	0.69
2.4	-7.01	0.90	-10.48	1.12	-8.27	0.71
Mean	-4.55		-8.66		-6.49	

that the attenuation is much higher than for the first two concrete sections. The 7/12/13 data shows mean attenuations over 9 frequencies of about -13.5 dB for Slag #1, and about -17 dB for Slags #2 and #3. As mentioned earlier, the density (dry weight equivalent) for Slags #2 and #3 is about 172 pounds/ft^3 as compared with 148 pounds/ft^3 for Slag #1. This means that the amount of slag per unit volume is about $148(0.8) = 118.4$ pounds/ft^3 for Slag #1 and about $172(0.75) = 129$ pounds/ft^3 for Slag #2. It seems reasonable that more slag per unit volume would result in greater attenuation, as we see.

Table 4: Attenuation in Slag #1 Wall Section

	7/12/13		7/16/13		7/24/13	
Freq	Mean	S.D.	Mean	S.D.	Mean	S.D.
1.6	-11.78	0.73	-13.05	0.63	-12.36	0.52
1.7	-11.81	0.69	-13.76	1.15	-12.64	0.53
1.8	-11.48	1.46	-15.73	1.45	-14.14	1.43
1.9	-12.50	0.85	-16.55	0.96	-14.69	0.90
2.0	-12.16	0.79	-16.76	1.23	-14.84	0.88
2.1	-13.24	1.17	-18.76	1.12	-16.35	1.19
2.2	-14.53	1.60	-20.97	2.52	-17.77	1.44
2.3	-15.76	1.12	-24.30	3.34	-20.31	1.46
2.4	-18.04	1.24	-28.80	3.77	-24.78	4.06
Mean	-13.48		-18.72		-16.43	

The higher density concretes would probably be less permeable to air and water vapor, hence may hold more free water. This might explain an increase in attenuation greater than the proportional increase of slag per unit volume.

We note that the standard deviations are getting larger for the slag based concretes as opposed to the sand and Quikrete concretes. The inhomogeneousness is getting greater, so minor changes in antenna position result in larger changes in received signals. Other effects are probably becoming more significant as well. There will be diffraction of the transmitted signal off the top and sides of the concrete section into the shadow region occupied by the receiving antenna. This will be small but not zero. A signal strength in the range of -20 dB would not surprise me. The diffracted signal will combine with the 'straight through' signal with different phase shifts to produce greater variability in measurements than would be otherwise expected.

Reflections from the sides of the gulch and from metal objects like my camper and pickup may also start appearing for these low signal level measurements. The attenuation measurements that we are attempting to make are extremely difficult to do, either open air or in an absorbing chamber. We could spend more time and money to refine these measurements, but I believe I have shown that slag from the steel mill in Pueblo will make concrete that will absorb microwave signals reasonably well. It is time to develop a plan for larger scale testing.

Table 5: Attenuation in Slag #2 Wall Section

	7/12/13		7/16/13		7/24/13	
Freq	Mean	S.D.	Mean	S.D.	Mean	S.D.
1.6	-11.75	0.28	-12.87	0.44	-11.07	0.25
1.7	-12.53	0.34	-14.43	1.13	-12.32	0.32
1.8	-12.80	0.07	-15.24	0.49	-13.74	0.19
1.9	-14.34	0.44	-19.25	0.56	-15.17	0.41
2.0	-15.60	0.44	-21.07	0.97	-16.69	0.54
2.1	-16.90	0.44	-23.83	1.70	-18.40	0.83
2.2	-19.20	0.60	-27.87	3.10	-21.72	1.83
2.3	-21.67	1.23	-34.48	2.80	-26.93	2.25
2.4	-26.76	1.91	-34.30	4.86	-32.08	4.03
Mean	-16.84		-22.59		-18.68	

A TEST STRUCTURE At the beginning of this document I outlined a possible plan for Masonry Faraday Enclosures. These would consist of a conventional slab on grade, four (non load bearing) walls made from slag based concrete recessed in from the edge of the slab, which are enclosed by a metal building. A logical next step would be to build a small shed (less than 200 square feet) to make sure that we know what we are doing. There would be one door and one window, to allow us to practice pouring a slag based concrete around openings, and also to polish our techniques for installing metal screens and electrically bonding screens to concrete so the Faraday cage concept is not compromised. I am leaning toward a wall 9 or 10 feet tall (rather than 7 or 8 feet) and perhaps 8 inches thick.

Extensive attenuation tests would be performed on the concrete walls before the window, door, or metal building are installed. The transmitting antenna would be located a greater distance from the shed than was practicable with the small wall sections, at least several meters. Height above grade would be an important variable. We would examine at least three cases: midway up the wall, level with the top of the wall, and above the top of the wall (looking down into the interior). The receiving antenna would be placed at different locations (floor, chest height, ceiling, near wall, far wall, central, etc.).

Table 6: Attenuation in Slag #3 Wall Section

	7/12/13		7/16/13		7/24/13	
Freq	Mean	S.D.	Mean	S.D.	Mean	S.D.
1.6	-14.64	1.10	-15.06	1.07	-14.14	0.51
1.7	-14.79	0.48	-15.14	0.93	-14.10	0.53
1.8	-15.45	0.53	-17.10	0.66	-15.73	0.88
1.9	-15.72	0.69	-18.09	1.79	-15.84	0.54
2.0	-16.26	0.51	-17.96	1.03	-15.75	0.78
2.1	-17.52	0.42	-19.64	1.33	-16.90	0.82
2.2	-18.07	0.20	-20.47	1.28	-18.22	0.74
2.3	-19.45	0.68	-23.69	1.57	-19.51	1.02
2.4	-22.50	0.54	-25.83	1.72	-20.94	0.90
Mean	-17.16		-19.22		-16.79	

Then the metal building would be installed, and finished out at what might be reasonable for a larger Enclosure. Interior walls would be plastered and/or painted. Insulation would be placed in the gap between the concrete walls and the metals walls, and also in the attic. Then the same attenuation tests as performed earlier would be performed again. We would now have some information on the (additional) attenuation provided by a metal building, especially on the signals coming in from above.

A last step would be to wire the shed for 24 VDC LED lighting and perhaps a 24 VDC receptacle. Power would come from my existing solar panels and 24 V battery bank. The wiring provides a path for microwave signals to travel from outside to inside without passing through concrete or metal siding. We will look at how much gets through, and whether it is possible to shunt these signals to earth.

When the shed has been fully tested, we can start thinking about building one or more Masonry Faraday Enclosures. This will obviously be a major step.