Concrete Construction For EHS and MCS

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INTRODUCTION I recently purchased 59 acres in Rockvale, Colorado that includes a gulch which has relatively low cell phone and power line fields. I am exploring the concept of building 25 to 50 housing units (probably individual cabins) in the gulch for those of us who have Electromagnetic HyperSensitivity (EHS) and/or Multiple Chemical Sensitivity (MCS). I am told that many modern building materials (plywood, drywall, paint, etc.) contain chemicals that can take years or decades to outgas to the level where they can be tolerated by the chemically sensitive. Concrete seems to be more acceptable than most other building materials. Its basic formula (without admixtures) is water, cement, sand, and gravel. The only volatile in the formula is water. Therefore, the use of concrete for floor and walls in these cabins is certainly worthy of consideration.

Concrete is somewhat electrically conductive. There is a grounding technique called the Ufer ground (named after the inventor), consisting of a ring or loop of concrete in the earth that forms a better electrical ground than the usual practice of one or two copper clad ground rods driven 8 or 10 feet into the earth. Electromagnetic waves (cell phones, WiFi) will pass through a concrete wall but the losses in the concrete will cause the signal to be attenuated. This attenuation will be advantageous to those with EHS. So we have two distinct reasons to explore the use of concrete in the walls of housing units for those with EHS and/or MCS. This document examines the attenuation of electromagnetic signals in the GHz frequency range as the signals pass through concrete.

NIST The National Institute of Standards and Technology (NIST) performed an early study on this topic, published as: NISTIR 6055, *Electromagnetic Signal Attenuation in Construction Materials*, October, 1997. They were interested in developing a real-time, non-line-of-sight surveying system that can "see through walls". They took radar horn antennas, placed them 2 m apart and pointed at each other, then placed sections of walls between the antennas and measured the attenuation. The frequency range studied was 0.5 to 18 GHz. Wall materials included brick, masonry block, plain concrete, reinforced concrete, glass, lumber, plywood, and drywall.

Better studies have been done since 1997, but this one illustrates the challenges of making such measurements, so I will use it as a bad example.

Many different formulas are used in making concrete, depending on the strength required, so NIST actually tested eight different formulas. Concrete for each formula or mix was tested in three different thickness, 4, 8, and 12 inches. A summary of their results, total attenuation in dB for 8 inches of concrete, is given in the following table.

Freq. GHz	Ave dB	Min dB	Max dB
0.5	22	18	25
1	25	22	28
1.5	29	26	32
2	31	29	35
3	48	40	52
4	50	42	53
5	52	45	55
6	56	49	69

We see that the attenuation in 8 inches of concrete increases from about 22 dB at 0.5 GHz to about 56 dB at 6 GHz.

NIST used radar technology for this study. That is, a short pulse was transmitted into the building material and was detected on the other side by a radar pulse receiver. The receiver was modified from the normal situation of receiving a reflected pulse to that of receiving a transmitted pulse. The procedure is quite sophisticated. There are several situations that could cause results to not be correct.

The equations for electromagnetic wave propagation through lossy media might be shown to students in the first EM Theory course, typically taught to electrical engineering students in their junior year. But the math is daunting enough that a detailed discussion does not occur until some more advanced EM Theory course in graduate school. It appears that the NIST engineer writing this report did *not* have this advanced course. The report mentions getting help from the MIT Radiation Lab, where it can be safely assumed that people had struggled through a good many advanced EM Theory courses. The content of the report is similar to that of a Master's thesis. It would take more math to make it into a Ph.D dissertation. If a Master's level student of mine had given me this document for a thesis, I would have sent him back to fix it, to discuss in detail why the plots of attenuation versus frequency do not pass the 'smell' test. The NIST engineer did not have the equivalent of a grumpy old professor demanding a better product. The MIT engineers were not hired for that function, so the report has several weak spots.

One obvious one is the jump in attenuation between 2 and 3 GHz. From 1.5 to 2 GHz attenuation increases by 2 dB, from 2 to 3 GHz by 17 dB, and from 3 to 4 GHz by 2 dB. The big change between 2 and 3 GHz definitely looks strange. They used two different equipment and antenna packages, one for 0.5 to 2 GHz and another for 3 to 8 GHz. I would think that if both sets of equipment were used properly, the change in attenuation per increment in frequency would be much more uniform. At the least, this issue needs to be noted and explained. I could not find a word of discussion.

A second soft spot is the lack of mention of reflection of signal at the concrete surface. When an electromagnetic wave goes from one medium to another (air to concrete) a fraction is reflected and a fraction propagates into the second medium, decreasing in magnitude if the medium is lossy. When the wave hits the concrete-to-air surface the fractions of reflection and transmission are the same. This topic is emphasized in the first EM Theory course (for lossless media). For concrete, the fractions transmitted and reflected are about the same for both the lossless and the lossy cases. If we assume the lossless case and nonmagnetic sand and gravel, the fractions are a simple function of the relative permittivity ϵ_r. NIST did not mention what ϵ_r might be for concrete. I found one more recent paper that stated $\epsilon_r = 6$. This can vary significantly with water content, and less so with the particular aggregate, but I am confident that ϵ_r will not be less than 4 nor greater than 9. If $\epsilon_r = 4$, then the transmitted electric field is 2/3 of the incident electric field. Expressed in dB, the transmitted field will be

$$20 \log(2/3) = -3.522 \text{ dB}$$

below the incident field. If $\epsilon_r = 9$ the transmitted field will be at -6.021 dB with respect to the incident field. The same set of numbers apply when the wave exits the concrete, so the signal strength drops by 7 dB upon passing through a wall with $\epsilon_r = 4$ and by 12 dB for a wall with $\epsilon_r = 9$. There are some interesting aspects to the portions of the wave that are reflected internally, that bounce back and forth, losing a portion of their strength at each bounce. They can either increase or decrease the original signal depending on their relative phase angle. The details involve something called a *bounce diagram*. In our case, where it appears that our signal loses at least 10 dB upon passage through 4 inches of concrete (20 db through 8 inches, 30 dB through 12 inches, etc.) the first bounced signal will be at least 20 dB down from the original signal (two trips through at least 4 inches of concrete) so we can safely ignore the effect.

The point of this discussion is that this loss of 7 to 12 dB is *independent* of the wall thickness or losses. If the wave propagating through 4 inches of concrete with $\epsilon_r = 4$ lost 10 dB due to internal losses, the wave on the exit side of the concrete should be $10 + 7 = 17$ dB down from the incident wave. An 8 inch thick wall should see 27 dB, a 12 inch thick wall should see a 37 dB decrease, etc. The NIST curves given for three thicknesses of concrete do not show this offset, and there is no attempt at an explanation.

A third soft spot in the NIST report is the non-uniformity in plots of attenuation versus frequency for the different thicknesses. Whatever happens in 4 inches of concrete should happen twice in 8 inches and three times in 12 inches. The three plots of attenuation versus frequency should be equally spaced. If the 4 inch plot is flat, the other two should be flat also. The following table gives the attenuation in dB for the 4 inch concrete from 3 to 8 GHz.

Mix	3GHz	4GHz	5GHz	6GHz	7GHz	8GHz
1	23	23	23	25	27	28
2	25	25	25	26	28	30
3	22	22	22	24	25	27
4	24	24	24	26	28	30
5	24	24	24	25	26	27
6	25	25	25	26	27	29
7	17	17	17	18	20	22
8	25	25	26	28	30	33

For every mix the attenuation is essentially flat (to within a dB or so) from 3 to 5 GHz and then shows a relatively slow monotonic decline of perhaps 5 dB as the frequency increases to 8 GHz. For Mix 1, the attenuation in 8 inches varied from 46 dB at 3 GHz to 62 dB at 8 GHz. The attenuation values and the shape of the curve 'look' and 'feel' right. The attenuation in 12 inches varied from 73 dB at 3 GHz to 90 dB at 8 GHz. One might expect $3(23) = 69$ dB instead of the 73 dB actually observed, but 4 dB is a relatively small difference in this context, and smaller signals are more difficult to measure accurately, so the 12 inch curve also 'feels' right.

The curves for each of the other 7 mixes have some anomaly, significant enough that I would send my graduate student back to the lab to either repeat the measurement or figure out why the anomaly occurred. For example, the 12 inch plot for Mix 3 shows an attenuation of 93 dB at 8 GHz, somewhat greater than the expected $3(27) = 81$ dB but still in the plausible range. However, the plot dips to 108 dB at 7.3 GHz. My first guess is that this sharp dip is due to an unusual distribution of gravel in that particular block of concrete that was scattering the signal in directions different from the receiving antenna. This guess could be checked by moving the block horizontally or vertically, or reversing it, to have the signal pass through a different portion of block. Again, there was apparently no recognition that anything might be wrong and no attempt to explain the anomaly.

USEFULNESS OF NIST REPORT In spite of what I consider shortcomings of the NIST report, it still has some value to us. Cell phone frequencies for 3G and 4G, according to Wikipedia, are in several bands between 698 and 894 MHz, between 1710 and 2155 MHz, and from 2496 to 2690 MHz. NIST shows an attenuation of between 20 and 30 dB in 8 inches of concrete for these frequencies, maybe more for the top band. The top band is in the middle of the 2 to 3 GHz gap for which no data is available, and the attenuation in 8 inches of concrete at 3 GHz is more like 40 to 50 dB.

We would like more attenuation than 20 to 30 dB, but in my gulch, where my old cell phone cannot make a call, this might be enough. We start running into 'weak link' items like windows and doors, which require some effort to get more than 20 dB attenuation. The signal tends to leak or 'bleed' through the joints, cracks, seams, and other openings. It takes significant effort to keep this from happening. But dealing with openings is a topic for another time. The present task is to explore how far we can go with concrete, attenuation wise. Is there a cost-effective method of getting at least 50 or 60 dB attenuation in a concrete wall, at cell phone frequencies? How might this be studied?

ATTENUATION FORMULA Attenuation of electromagnetic signals in concrete is a complicated matter. It seems appropriate to develop a formula that will allow us to isolate different loss mechanisms and discuss them somewhat intelligently. Those who have had the junior level EM Theory course should recognize the symbols and perhaps be able to go back to their textbooks to fill in some of the gaps. Others can just sit back and enjoy.

Maxwell's two curl equations in a source-free, linear, homogeneous, and isotropic medium can be written as

$$\bigtriangledown \times E = -\hat{z}H \tag{1}$$

$$\bigtriangledown \times H = \hat{y}E \tag{2}$$

We define the *wave number* of the medium as

$$k = \sqrt{-\hat{z}\hat{y}} \tag{3}$$

The wave number is, in general, complex, and may be written as

$$k = k' - jk'' \tag{4}$$

The magnitude of an electric field traveling in the x direction is given by

$$E = E_o e^{-k''x} \tag{5}$$

The attenuation of the electric field after traveling a distance x is

$$20 \log e^{-k''x} \text{ dB} \tag{6}$$

The quantities $\hat{y}$ and $\hat{z}$ are given by

$$\hat{y} = \sigma + \omega\epsilon'' + j\omega\epsilon' \tag{7}$$

$$\hat{z} = \omega\mu'' + j\omega\mu' \tag{8}$$

where σ is the conductivity, $\omega = 2\pi f$, f is the frequency in Hz, and $j = \sqrt{-1}$. In the lossless case, the permittivity is

$$\epsilon = \epsilon' = \epsilon_r \epsilon_o \quad (9)$$

where ϵ_r is the relative permittivity and $\epsilon_o = 8.854 \times 10^{-12}$.

The permeability in the lossless case is

$$\mu = \mu' = \mu_r \mu_o \quad (10)$$

where μ_r is the relative permeability and $\mu_o = 4\pi \times 10^{-7}$. As a professor of mine made the habit of saying at the most obscure places: Obviously, all we have to do is plug in the values for σ, f, etc. of the above expressions into a calculator that knows how to take the square root of a complex number, and we have our attenuation. Unfortunately, we do not know the values of σ, μ'', and ϵ'' well enough to do this with any confidence in our numbers. But we can start talking about the various types of losses and perhaps get to the point where we can made an educated guess about what to try next to get a concrete that is more absorbing.

LOSSES IN WATER Water has two types of loss, conduction and dielectric. Conduction loss is due to the motion of electrons and ions through the water. The conductivity of distilled water at 25^oC is $\sigma = 1.7 \times 10^{-4}$ mho/m. By way of comparison, the conductivity of copper is about 5.8×10^7 mho/m, more than 11 orders of magnitude greater. Adding salt to water greatly increases the conductivity. Seawater, for example, has a conductivity of about 4 mho/m, still much below the conductivity of metals. Concrete contains less than perhaps 15% water, which is chemically bound to the constituents of the cement, so the notion of current flow in liquid water no longer applies. We know that salt is not a good additive to concrete, because of corrosion. My initial assessment is that adding water soluble chemicals to concrete to increase losses by increasing conductivity is *not* the way to proceed.

Dielectric loss in water is due to the character of the water molecule. The molecule tends to align itself with the electric field, and tends to rotate as the electric field reverses, bumping into adjacent molecules which are doing likewise. It is thus independent of the availability of free electrons or ions. If the heat energy produced per molecule rotation is a constant, then if we double the frequency, the amount of heating should double. This indeed seems to be the case for GHz frequencies. According to a table in the back of Harrington (an old EM Theory textbook I once studied from) at 25^oC, $\epsilon_r'' = 1.25$ at 0.3 GHz and 12.00 at 3 GHz, almost exactly the factor of ten predicted for a factor of ten increase in frequency.

A factor of ten in the losses is equivalent to 20 dB difference in attenuation. If this dielectric loss (proportional to frequency) were the only loss in concrete, then we would expect 20 dB greater attenuation at 5 GHz than at 0.5 GHz. We go back to the NIST data and see an average attenuation of 22 dB at 0.5 GHz and an average attenuation of 52 dB at 5 GHz, a difference of 30 dB rather than 20. I would have asked my graduate student to check the experimental technique at this point. If the number really is 30 dB, I would have asked the student to speculate about other possible loss effects. Discrepancies like this are a great opportunity to fix poor experimental technique (most likely) or to make a discovery of new phenomena (rare but important). I should reiterate that this is experimentally challenging and it is easy to miss a few dB. If my student had been within 5 dB or so of the predicted 20 dB, I probably would not have said a word, or maybe even 'well done'. But a difference of 10 dB pushes my tolerance a bit.

At this point we might ask the attenuation in water alone, just in case we wanted to build our house under water, or perhaps use a thin fish tank for the walls. We can ignore the conductivity and magnetic losses, in which case Equations 3, 7, and 8 become

$$k = \sqrt{-j\omega\mu(\omega\epsilon' + j\omega\epsilon''} = \omega\sqrt{\mu}\sqrt{\epsilon' - j\epsilon''} \tag{11}$$

Shen and Kong (another EM Theory book) give a measured value for the complex permittivity for distilled water at 25^oC and 3 GHz as

$$\epsilon = 76.7\epsilon_o(1 - j0.157) \tag{12}$$

My HP calculator shows

$$\sqrt{1 - j0.157} = 1.003 - j0.0783 \tag{13}$$

We are only interested in the -j0.0783 portion to get the k'' term, which is

$$k'' = 2\pi(3 \times 10^9)\sqrt{4\pi \times 10^{-7}}\sqrt{76.7(8.854 \times 10^{-12}}(0.0783) = 43.1 \tag{14}$$

The attenuation per meter is then

$$20 \log e^{-43.1(1)} = -374 \text{ dB/m} \tag{15}$$

The attenuation in 4 inches would be

$$-374\frac{\text{dB}}{\text{m}}\left[\frac{4\text{inches}}{39.37\text{inches/m}}\right] = -38 \text{ dB} \tag{16}$$

and -76 dB for 8 inches, etc.

Water has a higher dielectric loss at 3 GHz than any other material that would make sense for building construction. This suggests that very high attenuations (90 dB or more) with walls no more than 8 inches thick may not be technically possible if we use only dielectric loss to attenuate the signal. We may have to add a metal skin to the outside of the house, for example, or add some material with magnetic losses to the concrete.

LOSSES IN CEMENT, SAND, AND GRAVEL Other constituents of concrete will have some dielectric losses, not as much as water per unit mass but still important to our goal of high attenuation. There may be sands and gravels that would have magnetic losses or conduction losses. There may be a trade-off between high loss and high strength which would need to be considered. We are not building a nuclear power plant or a skyscraper, so really high strength is probably not necessary. We need to test each of the readily available sands and gravels to find the one with the greatest losses.

DIRECT MEASUREMENT OF CONCRETE ATTENUATION Direct measurement of attenuation requires a signal generator, a transmitting antenna, a receiving antenna, and a detector. I have a HF35C detector with a log periodic antenna that is built to measure electromagnetic field power density over the frequency range of 800–2500 MHz. It is an inexpensive consumer product with little documentation on accuracy or how the display varies with frequency, but should be useful in comparing one concrete mix with another. If it proves to be inadequate for the detailed tests that I hope to do, then a professional grade field strength meter will need to be purchased.

I bought a sweep frequency oscillator, the HP 8620A with a HP 86222B RF plug-in, rated at 13 dBm power output from 0.01 to 2.4 GHz, and a horn antenna, the Electro-Mechanics Co. Double Ridge Guide Horn Antenna Model 3115, rated from 1 to 18 GHz. The oscillator will operate at a single frequency or will sweep over a range. It would be possible to sweep over the 800 to 2400 MHz range in 0.1 or 0.01 second to give an integrated average over the range of the HF35C, if that seemed to yield consistent results.

The basic idea of testing is rather simple. Point the two antennas at each other with open space between, apply a known power to the transmitting antenna, and record the received power density at the HF35C. Then place a vertical wall of concrete (or a patio block on its edge) between the antennas and record the received power density again. The difference should be the amount absorbed by the patio block. The difference is then used to calculate the attenuation in dB/inch of concrete. In practice, things are never that easy, as we shall see.

I poured four different patio blocks to test my concept. I used 35 pounds of dry material plus 4 to 6 pounds of water to get something that looked like wet concrete. I took out 2.5 pounds of mixed concrete for a separate test to be described later, then dumped the mixed concrete into a form that was 14 inches on a side. The resulting patio block is 2 to 3 inches thick.

The control or reference block was made from Quikrete, a commercial product available in 80 pound bags, that just needs water to form concrete. A second block was made from Quikrete Masonry Cement, intended for use as mortar between bricks. A third block was made from 8% Portland cement and 92% sand from the flood plain in the gulch. This sand would be a nice material for a child's sandbox. The fourth block was made from 8% Portland cement and 92% road base from the new driveway into the gulch (actually the portion of road base that passed through a 1/8th inch screen). If concrete made from readily available (and reasonably priced) materials turned out to have adequate attenuation and strength, we could at least consider making concrete on site.

The experiment was set up in my lab in Cañon City, Colorado. The building was built in 1945. The floor is concrete, and the outside walls are plate glass windows and cinder block. There is steel furniture and a large copper screen room in the space. No material specifically built to absorb RF was used. I set the gain control of the oscillator such that the largest amplitude displayed by the HF35C was in range. I then measured the HF35C received signal, in μW/m^2. I did this twice, for two slightly different configurations, one with the antennas farther apart and closer to the floor and the second with the antennas 1.3 m apart and 0.66 m above the floor. The HF35C signal was recorded every 0.02 GHz from 1.0 to 2.3 GHz. Results were *not* believable! Typical were the numbers for 1.42 GHz (1716 and 1350 μW/m^2) and 1.44 GHz (1410 and 1600 μW/m^2). The field strength dropped for one configuration and increased for the other as frequency increased by a relatively small amount. This suggests that the signal from the transmitting antenna that had gone past the receiving antenna had reflected off the far wall, and was bouncing off the ceiling, walls, and floor, setting up a three-dimensional standing wave pattern in the room. Waves were coming to the HF35C from all sides, sometimes in phase (hot spot) and sometimes out of phase (dead spot). Changing frequency changes wavelength, which changes the standing wave pattern. Hot spots and dead spots move with respect to the HF35C so that its displayed reading changes drastically. The readings are useless.

Microwave ovens have the same problem of hot spots and dead spots. This is why the better ovens will have a rotating platform so a given parcel of food will rotate through both the hot spots and dead spots, and the entire container of food will be more-or-less uniformly heated.

There are two options by which I might get useful data. I can buy absorbing material and set up a proper test chamber in my lab, or I can wait until spring and do open air testing at the gulch, where there are no walls and ceilings to reflect signals back to the HF35C. The open air testing will be much cheaper, so that is what I will try next.

INDIRECT MEASUREMENT OF CONCRETE ATTENUATION I am trying another scheme that appears able to qualitatively rank various candidate materials. I use a microwave oven operating at the frequency of 2.45 GHz. In one series of tests, I put one pound of tap water in a 20 oz Styrofoam cup and measure the temperature. I do likewise with a second cup that contains just over a pound of the candidate material, perhaps 20 ounces. The two cups are placed symmetrically on the turntable and the microwave operated for one minute. The cups are removed and the temperatures measured again. The following table contains some early results for concrete made from various materials.

Test	$\triangle$T water	$\triangle$T for:	Material
1	19^{o}F	84^{o}F	magnetic soil, 10% cement
2	18^{o}F	84^{o}F	magnetic soil, 15% cement
3	24^{o}F	72^{o}F	sand from gulch
4	19^{o}F	95^{o}F	road base
5	19^{o}F	84^{o}F	Quikrete
6	18^{o}F	87^{o}F	Quikrete Mason mix Type S
7	45^{o}F	10^{o}F	Portland cement (no water)
8	24^{o}F	24^{o}F	Water in second cup

Tests 1 and 2 use the magnetic portion of a local iron-bearing soil. The iron-bearing fraction will jump vertically from the finely powdered soil to a strong magnet. About 20% of this particular soil has this property. It was a little tedious, but 5 or 6 pounds of this magnetic soil were extracted from about 30 pounds of soil.

This particular soil was found in my daughter's yard, located on a bluff overlooking the Arkansas River valley to the north, in Cañon City, Colorado. My yard, located a mile away, does not have this type of soil. I assume this magnetic soil was hauled in from elsewhere, perhaps in some iron bearing gravel.

Test 3 uses sand from my gulch. The rocks on my land appear to be a type of sandstone, a relatively soft stone that breaks easily and flakes off during freeze-thaw cycles. The hillside and valley bottom contain a large fraction of sand. There are places with the same appearance as a nice beach. It would not be difficult to extract enough sand from the property to build 25 to 50 concrete cabins. If the sand happened to be a better RF absorber than the sand and gravel used by the local concrete supplier, then we would want to pursue the issue further. Unfortunately, this seems to be one of those good ideas that did not pan out. The microwave oven absorption was even less than standard Quikrete (Test 5). I will test the patio block made with this material when I do open air testing, but do not expect different results.

Test 4 uses the fines from the road base recently installed on my driveway, that portion that passes through a 1/8th inch screen. The color is that of rust, suggesting some iron content. There has been a steel mill in Pueblo for many years, where the tailings are made into road base, so it is possible this is the same material. In any event, it appears that iron bearing materials are available in quantity, at a reasonable price. One issue would be whether concrete made from this material is of adequate strength. The only way to be positive about the answer is to make several batches of concrete with this material and different fractions of cement, and test for strength. But this test for absorbing microwave fields is certainly encouraging that a concrete more lossy than standard can be produced.

Test 5 uses Quikrete as a standard or control case. Test 6 uses a mortar mix which costs two or three times as much as Quikrete. It would only be of interest if it was substantially more absorbing than Quikrete, which it is not.

Test 7 uses just Portland cement in powder form (no water or aggregate). It is almost completely nonabsorbing. We get attenuation from the water and aggregate in the concrete rather than the cement component. For some concrete recipes, strength increases with a larger amount of cement in the mix. I would not expect greater attenuation with more cement. Cement is a major component of the cost of concrete, so we are inclined to put in just enough to get the necessary strength but not more.

Test 8 indicates that the temperature of two pounds of water increased by 24^{o}F after one minute in the microwave oven. Another test showed that 3 pounds of water increased in temperature by 16^{o}F when microwaved for one minute. Since it takes one BTU to heat one pound of water by one degree F, 2 pounds and 24^{o}F or 3 pounds and 16^{o}F means that 48 BTUs were absorbed by the water in one minute. It would be nice if the total energy absorbed by the oven contents were always 48 BTU, but such is not the case. My limited testing suggests a total energy absorbed in the range of 40 to 60 BTU.

I will need to measure the heat capacity of the various concretes. I suspect it is on the order of 0.25. That is, a given number of BTUs absorbed into a pound of concrete with heat capacity of 0.25 will raise the temperature 4 times as much as the same number of BTUs in a pound of water. If the temperature of a pound of water in a microwave oven increased by 20^{o}F, then the increase in a pound of Quikrete with heat capacity of 0.25 would be 80^{o}F, similar to the numbers in the above table.

One thing that I have learned is that chemistry is a *very* important factor. One might think that one could measure the losses in aggregate, cement, and water separately, and just combine them in the proper proportion to get the losses in the resulting concrete, but this is *not* the case. The chemistry of concrete changes as it hardens, and concrete continues to get harder over periods of months and years, so the chemistry is continuing to change during that period. To compare two different formulas for concrete, one makes a batch of each formula and pours the concrete into cylindrical forms, typically 6 inches diameter and 12 inches in length, then lets it cure for 28 days under controlled conditions. The cylinders of concrete are then broken by a special machine to determine the strength. A cylinder tested after 6 months will show a greater strength than the 28 day test, but most of the strength has been reached after 28 days, so this has been defined as the day of testing.

My concrete made from Quikrete and from road base seems to have fairly constant losses with time. However, the concrete made from the magnetic soil is getting *more* lossy with time. The 84^{o}F average in the above table is obtained from 64^{o}F at the start and 104^{o}F at the end. The concrete made from gulch sand is getting *less* lossy with time. This is fascinating (at least to me) and will need considerable testing to quantify and validate.

BUILDING TECHNIQUES How do we build a cabin with concrete in the exterior wall? One method that has been fairly well developed is the insulation concrete form (ICF). A company makes modules that can be stacked together like Lego blocks. A module for one company is 44 inches long, 16 inches tall, and 13 inches thick. There is 2.5 inches of Styrofoam on the outside, an 8 inch gap where the concrete will be poured, and another 2.5 inches of Styrofoam on the inside. The two portions of Styrofoam are held 8 inches apart by a framework of hard black plastic that was embedded in the Styrofoam when it was foamed.

There are strips of the black plastic just under the Styrofoam, both inside and outside, that will accept screws that will hold on a wall covering (metal, Masonite, drywall, etc.). Electric wiring is installed in channels cut into the inside portion of Styrofoam.

One advantage of ICF is the soundproofing. Interior space will be *much* quieter with the ICF wall as compared with say a 2 by 6 wall with fiberglass insulation. Also a 2 by 6 wall with fiberglass has very little RF attenuation as compared with concrete. The 2 by 6 wall would be covered with metal on the outside to block RF, but the same metal could be put over the ICF wall, to get even greater attenuation.

ICF looks promising enough that I am tempted to build the first cabin with this technique. Make the concrete as lossy as possible, then cover the exterior with a metal shell, with careful attention to bonding of the joints and seams. We would use double pane windows with low-E glass, a somewhat common aluminum screen (not fiberglass), and a second screen, probably made of stainless steel. The screens also have to be carefully bonded to the exterior metal and to the concrete.

The disadvantage of ICF is that we must cover the interior Styrofoam (it is fragile) with something that is probably MCS unfriendly. Drywall and commercial paints will outgas for years. Drywall covered with ceramic tile and a low volatile grout might work.

Another version of a concrete and insulation wall is to put the foam in the middle and pour concrete against the foam both outside and inside. The challenge here is to form it so the concrete surface is flat, smooth, and straight. If the surface was good enough, it could be the final surface on the inside (and also on the outside if the attenuation was adequate). This certainly has the potential of lowering the overall cost, and is therefore worthy of continued thought.