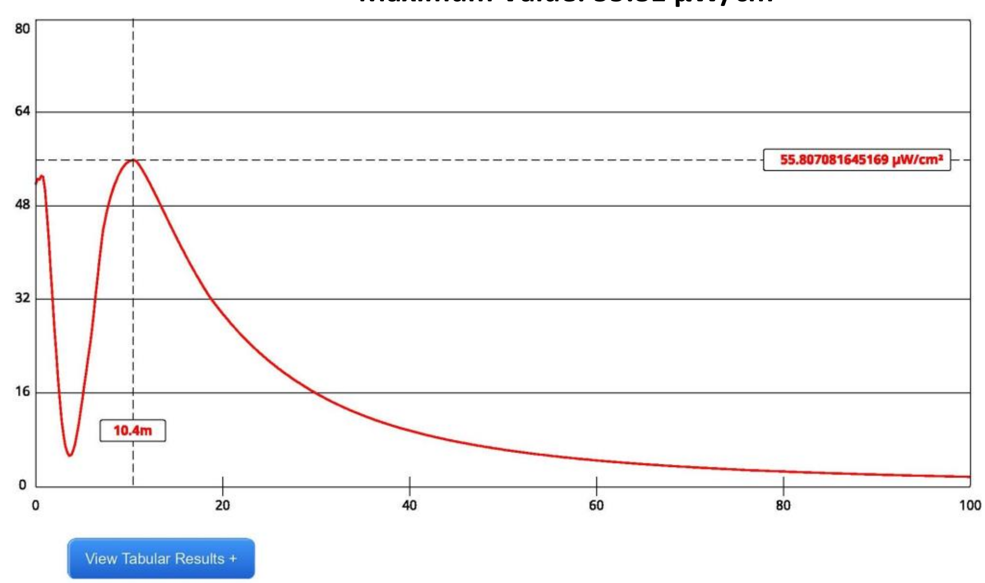
Environmental Protection Statement

An analysis of the proposed W253AF translator site was performed using the Commission's FM Model program and OET Bulletin 65 parameters for FM protection. The proposed antenna for the translator is a two bay Shively 6815 directional antenna with bays spaced at 0.61 wavelength. This antenna has a maximum ERP of 250 watts horizontally polarized and 250 watts vertically polarized. The antenna will be mounted at 92.5 meters above ground level on an existing building Registration Number 1056550. The proposed 2 bay 0.61 wavelength spaced antenna was analyzed using the following parameters.

Horizontally Polarized Radiation	250.0 W
Vertically Polarized Radiation	250.0 W
Distance from Center of Radiation	
Downward to 2 meters above roof,	7 meters
Type of Antenna	Shively 6815
Number of Antenna Elements	2
Antenna Element Spacing	0.61 λ

The following Figure 1 was produced using the FCC FM Model:

Figure 1
FM Model
Maximum Value: 55.81 µW/cm²



Channel Selection	Channel 259 (99.7 MHz)		
Antenna Type +	EPA Type 1: Ring-and-Stub or "Other"		
Height (m)	7	Distance (m)	100
ERP-H (W)	250	ERP-V (W)	250
Num of Elements	2	Element Spacing (λ)	.61
Num of Points	500	Apply	

This system configuration on the tower produces a maximum of 55.81 microwatts per square centimeter at 2 meters above the roof at a distance of 10.4 meters from the tower. This is 27.9% of the 200 microwatts per square centimeter allowed for uncontrolled exposure. There are no buildings within the major lobe of the antenna.

There are two other translators located at this rooftop location. W259BL and W250AB have been previously analyzed by R. M. Smith Associates in a minor modification to license BLFT-20120718ABX. This application has File Number BPFT-20160217ABW and was granted on March 8, 2016. Attached as Exhibit A is the environmental analysis of these facilities. According to this accepted document, W259BL contributes 44% of the maximum allowable field for general public exposure and W250AB contributes 31%. Together with the 27.9% contributed by this proposal gives a maximum percentage of 102.9% of the maximum allowable field for general public exposure at 2 meters above the rooftop. Note that the maximums for each facility do not lie at the same point on the roof. Therefore, it is likely that at no point does the field exceed the maximum of 200 microwatts per square centimeter. Exhibit B, 'Measurement of RF Propagation into Concrete Structures over the Frequency Range 100 MHz to 3 GHz' attached to this document is an analysis of the loss attributable to materials used in building construction. Note that this document gives a figure of 13.9 db for loss in a 2 foot concrete layer. This approximates the loss in the roof structure. Therefore, for all floors below the roof, the maximum power density is 8.4 μW/cm^2 or less. Thus the general public is fully protected from non-ionizing radiation from these rooftop FM translator facilities.

The general public is not allowed near this roof mounted antenna structure. The general public will not be exposed to power density levels exceeding the allowed exposure value from this installation. Maintenance personnel will be fully informed of the antenna and safety precautions will be taken when working near the structure. Danger signs will be posted at the entrance to the roof. The applicant will conduct full measurements of the power density environment at this site should the Commission require.

The applicant certifies that it, in coordination with any other users of the site, will reduce power or cease operation as necessary to protect persons having access to the tower site from radio frequency electromagnetic exposure in excess of FCC guidelines.

No construction, other than the mounting of a light 2 bay FM translator antenna at the 92.5 meter level on the building is required. There is no change to the ground or building structure.

This proposal has no significant environmental impact and complies with 1.1307(b)(3)(i) of the Commission's Rules. Therefore, this proposal is excluded from environmental processing.

Charles F. Ellis PE
Ellis Engineering
July 27, 2016

R. M. SMITH ASSOCIATES
BROADCAST TECHNICAL CONSULTANTS
P.O. BOX 345 – JENSEN BEACH, FL 34958
Tel: (772)-335-0688 Fax: (772)-672-3448
E-MAIL bob@rmsmith.com

W295BL – MINOR MODIFICATION OF LICENSE
EXHIBIT 17

The application of which this Exhibit is a part requests a minor modification of the license (F.C.C. File No. BLFT-20120718ABX) for FM translator W259BL in Concord, NH. This application requests a change in the directional antenna system by rotating the currently authorized Kathrein-Scala CA5-FM/CP/RM antenna from an azimuth of 0 degrees True to an azimuth of 270 degrees True. No other changes are proposed. The antenna will remain at 7 meters above the roof of the building on which it is mounted.

The attached Table 1 shows the RF field density that will be generated, by the proposed operation, at two meters above the roof in the azimuth of the main beam of the antenna. As seen in the table, the maximum field density to be generated is 87.3 uW/cm^2 at a distance of 8 meters from the base of the mounting pole. This level is less than 44% of the maximum allowable field for general public exposure.

The licensed antenna for W250AB is located at a distance of 9 meters from the proposed antenna at a height of 6.8 meters above the roof. The operating parameters for W250AB were entered into the F.C.C. FMMODEL computer modeling program and the highest field density from the W250AB antenna was found to be 61 uW/cm^2 at a distance of 8.8 meters from the base of the antenna. This level is less than 31% of the maximum allowable field for general public exposure.

Even if the W295BL and W250AB maxima were coincident in location, which they are not, the combined field would be less than 75% of the maximum permissible for general public exposure.

The roof is not normally occupied and the access door is locked to prevent unauthorized access.

W295BL
MINOR MODIFICATION OF LICENSE
EXHIBIT 17 - TABLE 1

Antenna Make	Scala	
Antenna Model	CA5-FM/CP/RM	
ERP (W)	500	250 Horiz + 250 Vert
Antenna C/R AGL (m)	7	
Height over Head (m)	5	

Horizontal Distance from Antenna (m)	**Downward Angle (o)**	**Distance from C/R (m)**	**Field**	**Power Density uW/cm2**
0	90.0	5.0	0.157	16.5
1	78.7	5.1	0.140	12.6
2	68.2	5.4	0.137	10.8
3	59.0	5.8	0.201	19.8
4	51.3	6.4	0.313	39.9
5	45.0	7.1	0.423	59.8
6	39.8	7.8	0.528	76.3
7	35.5	8.6	0.618	86.2
8	32.0	9.4	0.682	87.3
9	29.1	10.3	0.732	84.4
10	26.6	11.2	0.772	79.6
11	24.4	12.1	0.799	73.0
12	22.6	13.0	0.832	68.4
13	21.0	13.9	0.852	62.5
14	19.7	14.9	0.863	56.3
15	18.4	15.8	0.881	51.8
16	17.4	16.8	0.891	47.2
17	16.4	17.7	0.901	43.2
18	15.5	18.7	0.910	39.6
19	14.7	19.6	0.918	36.5
20	14.0	20.6	0.922	33.4
25	11.3	25.5	0.942	22.8

Measurement of RF Propagation into Concrete Structures over the Frequency Range 100 MHZ to 3 GHz

by

Clayborne D. Taylor
Samuel J. Gutierrez
Steven L. Langdon
Kenneth L. Murphy
William A. Walton, III

Phillips Laboratory/WSM
3550 Aberdeen Ave. SE
Kirtland AFB, NM 87117-5776

ABSTRACT

A concrete structure with few ports of entry for RF was illuminated over the frequency range of 100 MHz to 3 Ghz to characterize the propagation of RF signals into the interior region of the structure. The construction of the building tested is standard for a blast hardened facility. Outside walls of the structure are two-feet thick concrete with horizontal and vertical rebar separated by only eight inches. And the flat roof/ceiling is three-feet thick concrete with a two-inch steel plate base. With only one door located at the rear of the building and one set of windows across the front of the building, RF penetration through windows, doors and walls can be isolated and characterized separately.

Illumination of the concrete structure is provided by using two log-periodic antennas driven from two wideband linear amplifiers for the frequency range 100 MHz to 1 Ghz. Above 1 Ghz two traveling-wave tube amplifiers were used to reach 3 Ghz. Swept frequency measurements of the RF attenuation into the building were performed by using automatic network analyzers with the amplifier/antenna configurations. Logarithmic spacing of the frequency samples was used in the frequency sweep process. In all cases the antennas were oriented to produce a vertically polarized electric field with a horizontally polarized magnetic field.

The RF penetration is characterized by transfer functions that are ratios of the penetrant field to the incident field. In order to remove the antenna-to-measurement point distance variable, both the penetrant field and the incident field were recorded at the same distance from the antenna. The incident field is measured by directing the antenna toward an open region and measuring the horizontal magnetic field component at the surface of a large metal plate resting on the ground. Considering radiation conditions obtain, the incident electric field is computed from the magnetic field measurement.

Measured data for the penetrant field are compared with theoretical predictions to verify the results. Interior measurements indicate that the rebar attenuation of the electric field was not significant above 120 MHz while the rebar attenuation of the magnetic field was not important above 200 MHz. Near the window there is little attenuation at all frequencies. However, there is significant attenuation, more than 50 dB, through the concrete roof/ceiling for all frequencies.

1. INTRODUCTION

The electromagnetic coupling through structures from the exterior to the interior depends upon a number of factors [1]. Radio frequency signals in and around structures may vary considerably from point to point, since the energy may arrive from different directions at different times due to multiple propagation paths. The vector addition of signals from multiple paths may add together to produce a deep null at one point or a sharp peak at another. A complete deterministic theoretical analysis of the RF penetration through structures is not tractable, which suggests the use of a geometric/statistical model that accounts for both specular reflections from the walls and ceilings, and random scattering from equipment and various objects within the environment [1]. One such model that is being used by many investigators is called SIRCIM (Simulation of Indoor Radio-Channel Impulse-response Models) [2].

There are a variety of approaches to the study of RF penetration of structures. For some applications a theoretical approach may be the best. This permits the penetration evaluation of structures that are not accessible for measurement. And a theoretical analysis is expected to be far less expensive than direct measurement. On the other hand, the results from the theoretical approach will have some associated uncertainty and may be highly inaccurate under certain conditions. Critical parameters may not be known and may not be attainable for some structures. Probably the greatest weakness of relying on theoretical analysis is that often erroneous calculations are not readily apparent.

Another approach to determining the RF penetration of structures would be one that relies primarily on a data base of measurements. For some applications this approach would be best. It would provide confidence in the accuracy of the penetration data for those structures tested. And there would be little need to determine the electromagnetic characteristics of the structure which may be inaccessible. However, there are some significant disadvantages to this approach. First, the data base that is accumulated may not be sufficiently complete to include all the structures of interest. Second, data collection is generally far more expensive than performing calculations.

It is expected that a combination of theoretical modeling and measurement is the best approach for the structures and frequencies of interest in wireless communication. For simple structures, the approach of relying primarily on theoretical analysis would be adequate where there is little risk in being able to develop an analysis with acceptable accuracy. For more complex structures it is recommended that the RF penetration be obtained from a few well-understood site-specific models that are verified and supplemented by measured data.

Two of the goals of the presented study are the quantitations of RF penetration through windows and concrete walls over the frequency range 100 MHz to 3 GHz. Personal-Comunication System (PCS) frequency bands extend from 800 MHz to 2.2 Ghz. In most structures there are a number of propagation paths between the source and the receiver operating in the PCS frequency regime. Consequently a structure was selected that essentially isolates propagation paths and provides direct quantitation of the attenuation for specific propagation paths. This can be achieved by illuminating a structure with only a few ports of entry for RF and with significant wall attenuation.

Building 12500 located on the A-15A site at Eglin AFB, FL was selected for this study. The walls of the building are 2-feet thick poured-in-place concrete and the ceiling is 3-feet thick concrete with a one quarter-inch steel plate spot-welded to parallel 6" X 12" steel I-beam reinforcement. As a result of its construction, the flat roof/ceiling configuration should provide good, if inadvertent, electromagnetic shielding. The construction of the building tested is standard for a blast hardened facility. Outside walls of the structure are reinforced with horizontal and vertical rebar with 8-inch spacing both horizontally and vertically. There is only one exterior door located at the rear of the building and one set of windows located across the front of the building. Consequently, RF penetration through windows, doors and walls can be isolated and characterized separately.

The RF penetration is characterized by transfer functions that are ratios of the penetrant field to the incident field. In order to remove the antenna-to-measurement-point distance variable, both the penetrant field and the incident field were recorded at the same distance from the antenna. The incident magnetic field is measured by directing the antenna toward an open region to a magnetic field sensor that is attached to a large metal plate resting on the ground. Accordingly the measured magnetic field component is 2 X the incident field component. Assuming radiation conditions obtain, the incident electric field is 120π Ohms X the incident magnetic field.

2. ANALYSIS

2.1 Analysis of RF Penetration through a slab of material

The analysis of the RF transmission through a slab of building material, as illustrated in Figure 1, may be accomplished by using transmission line theory. Considering plane wave propagation the line voltage represents the electric field, the line current represents the magnetic field, and the characteristic impedance of the transmission line represents the intrinsic wave impedance of the medium supporting the plane wave. In

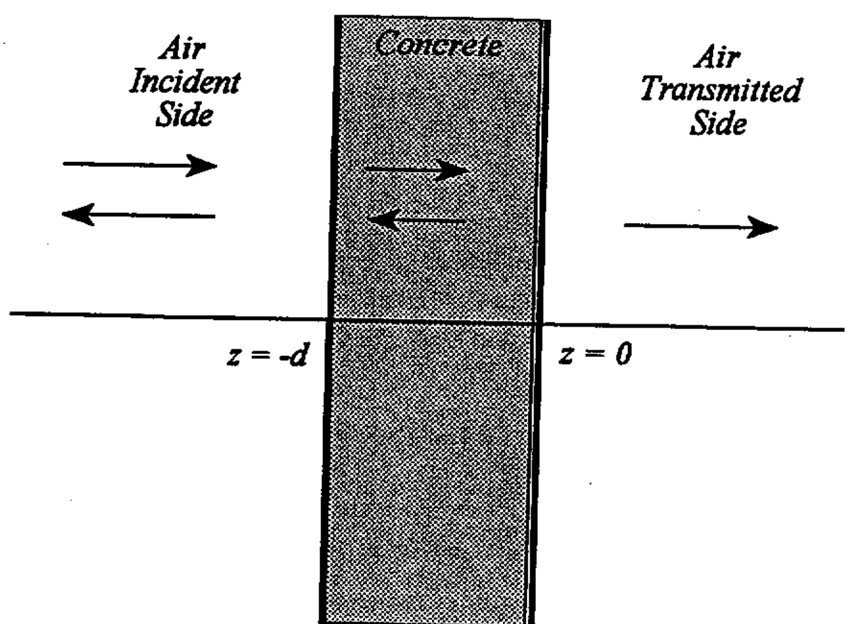


Figure 1. Illustration of the transmission of RF through a slab of concrete

determining the transmission through a slab of lossy material with thickness "d" the analogous transmission line problem is the determination of transmission through a section of lossy transmission line, length "d", inserted in a lossless transmission line. The voltage $V_o(z)$ and current $I_o(z)$ on the incident side of the section, for $z \leq d$, may be expressed,

$$V_o(z)=V_o(e^{-j\beta_o z}+\Gamma_o e^{+j\beta_o z})$$

and

$$I_o(z)=\frac{V_o}{Z_o}(e^{-j\beta_o z}-\Gamma_o e^{+j\beta_o z})$$

Here Z_o is the characteristic impedance of the transmission line and β_o is the propagation constant. For the plane wave propagation problem being considered one would use

$$Z_o=\sqrt{\frac{\mu_o}{\epsilon_o}}$$

and

$$\beta_o=\omega\sqrt{\mu_o\epsilon_o}$$

The reflection coefficient Γ_o is determined by the application of appropriate boundary conditions. Note that $\omega = 2\pi f$ is the radian frequency.

For the region of the lossy line, $-d \leq z \leq 0$, the voltage and current may be expressed,

$$V_1(z)=V_1(e^{-\gamma z}+\Gamma_1 e^{+\gamma z})$$

and

$$I_1(z)=\frac{V_1}{Z_1}(e^{-\gamma z}-\Gamma_1 e^{+\gamma z})$$

In the foregoing the complex propagation constant γ and complex characteristic transmission line impedance for a lossy transmission line may be expressed in terms of the distributed series impedance and shunt admittance. However, for the plane wave propagation problem,

$$\gamma = j\omega\sqrt{\mu(\epsilon - j\frac{\sigma}{\omega})} = \alpha + j\beta$$

and

$$Z_1 = \frac{j\omega\mu}{\gamma}$$

The complex amplitude V_1 and reflection coefficient Γ_1 may be determined by the application of appropriate boundary conditions.

For the exit medium, $z \geq 0$, the voltage and current take on relatively simple forms.

$$V_2(z) = V_2 e^{-j\beta_o z}$$

and

$$I_2(z) = \frac{V_2}{Z_o} e^{-j\beta_o z}$$

Note that the exit medium and the incident medium are considered to have the same properties.

Requiring that $V_1(0) = Z_o I_1(0)$ yields

$$\Gamma_1 = \frac{1-(Z_1/Z_o)}{1+(Z_1/Z_o)}$$

and

$$\Gamma_o = \frac{-\Gamma_1 + \Gamma_1 e^{-2\gamma d}}{1 - \Gamma_1 \Gamma_1 e^{-2\gamma d}} e^{+j2\beta_o d}$$

Defining the transmission coefficient for the slab to be $T = V_2 / V_o$, while using $V_1(0) = V_2(0)$ and $V_o(-d) = V_1(-d)$, yields the expression for the transmission coefficient

$$T = \frac{V_2}{V_o} = \frac{(1+\Gamma_1)(1+\Gamma_o e^{-j2\beta_o d})}{1+\Gamma_1 e^{-2\gamma d}} e^{-\gamma d + j\beta_o d}$$

Note that there are two mechanisms for reducing the transmission coefficient, power reflection and power absorption through conduction and/or hysteresis.

2.2 Constitutive Electrical Properties of Building Materials

In order to evaluate the transmission coefficient, which quantitates the RF transmission loss, the constitutive electrical properties of the material must be known. Although some data exists, the constitutive electrical parameters are not well documented for building materials. Castillo and Singaraju [3] provide data recorded at Malmstrom AFB, MT for the frequency range 100 kHz to 100 MHz for concrete and soil. More recently Sou, Landron and Feuerstein [4] provide data over the range 1700 MHz to 18000 MHz for concrete, brick and limestone.

In Table 1. the effective permittivity and conductivity of a few building materials are provided for a range of frequencies from data collected by Sou et al. [4]. For their study samples of stone and brick were cut to waveguide dimensions using different kinds of band saws with some sanding to reduce air gaps as much as possible. However, the concrete samples were prepared by solidifying liquid concrete inside a waveguide for the measurements. The limestone came from Virginia Tech's physical plant, the brick samples were cut from a standard common face solid brick, and the concrete material was Bondex's concrete patch (item #39005).

In a recent study of the constitutive electrical properties of concrete, Halabe et al. [5] developed a predictive model for the complex dielectric permittivity which considers frequency, temperature, moisture content, chlorine content and the concrete mix constituents. Parameters considered appropriate for the A-15A building used in this study of RF penetration are 10% porosity, aggregate dielectric constant of 5, temperature of 25 °C, and salinity = 50 ppt. An important factor is the moisture saturation level, i.e., the extent to which the air voids are filled with water. For horizontal bridge decks it has been reported that the moisture saturation level during the summer months varies from 40 to 50 percent [6]. Consequently, the moisture saturation level of the concrete in the A-15A building is assumed to be 40% since the RF penetration measurements were made during the summer months. And for the analysis the models developed by Halabe et al. [5] are used to compute the complex dielectric constant for concrete as a function of frequency.

Table 1. The Effective Permittivity and Conductivity of Building Materials [4]

FREQ.	CONCRETE		BRICK		LIMESTONE	
MHz	ϵ_R	σ(S/m)	ϵ_R	σ(S/m)	ϵ_R	σ(S/m)
1723	6.11	0.133	4.62	0.0174	7.36	0.0235
2000	5.64	0.153	4.50	0.0173	7.25	0.0213
2600	5.10	0.146	4.26	0.0197	7.06	0.0179
3230			4.40	0.00324	7.13	0.0232
8200			4.45	0.0225	6.73	-0.0259
12000			4.40	0.0502	29.6	0.434
18000			4.11	0.0364	6.83	0.183

Combining the data from the Halabe model with the results from Castillo and Singaraju [3] and with the results from Sou et al. [4] provides the constitutive electrical parameters that are shown in Table 2.

Table 2. Constitutive Electrical Parameters Measured for Concrete

Frequency in MHz	Dielectric Constant	Conductivity in S/m
10	(18.6*)	(0.0102*)
50	(13.0*)	(0.0215*)
100	7.93 (11.1*)	0.0337 (0.0347*)
1000	6.07	0.0684
2000	5.87 (5.66**)	0.083 (0.142**)
3000	5.80	0.095

* This result is taken from Castillo and Singaraju [3].
** This result is obtained by averaging the parameters measured by Sou et al. [4] over the range 1800 MHz to 2100 MHz.

The results shown in Table 2. exhibit sufficient consistency considering that different concrete samples are used in the measurements. However the measured conductivity from Sou et al. [4] depart somewhat from the other data. Perhaps the Bondex Concrete Patch material that is used by Sou et al. contained an additive which altered the electrical conductivity. It is a common practice to add an epoxy resin to concrete patch material to improve its adhesion property.

2.3 Computed Transmission Losses for Building Materials

Using the constitutive electrical properties in Table 1, results are computed for the transmission loss through 4" and 8" walls and shown in Table 3. These results generally indicate that the attenuation losses are not very significant for the frequency ranges and the wall thicknesses considered. Since reflection losses are included along with the material attenuation versus frequency, some oscillations in the transmission losses are expected when the ohmic losses are low.

Table 3. RF Attenuation through Building Materials

FREQ.	CONCRETE PATCH		BRICK		LIMESTONE	
MHz	4 inches	8 inches	4 inches	8 inches	4 inches	8 inches
1723	10.4dB	19.5dB	3.4dB	3.3dB	3.0dB	5.5dB
2000	12.3dB	22.9dB	1.9dB	3.9dB	4.2dB	5.1dB
2600	12.0dB	22.8dB	3.2dB	4.4dB	3.7dB	5.0dB
3230			2.2dB	1.3dB	2.8dB	5.3dB
8200			3.1dB	5.2dB	2.2dB	-----
12000			4.7dB	9.0dB	18.9dB	32.1dB
18000			4.1dB	7.3dB	13.5dB	25.2dB

For the measurements that are presented in a subsequent section, the structure had concrete walls that were two feet in thickness with steel reinforcement rods forming a mesh inside the concrete. Since the electrical and magnetic connectivity of the rods is not known, the initial consideration of RF attenuation will focus only on the power loss associated with the concrete material. Using the constitutive electrical parameters shown in Table 2, computations are made for the attenuation expected for the concrete walls and ceiling of Building 12500 at the A-15A site. Of course the total attenuation for the ceiling including the I-beams and the steel plate should exceed the concrete losses by a significant amount and the total attenuation through the 2-foot walls containing the steel reinforcement rods may exceed the concrete losses by a significant amount at the lower frequencies near 100 MHz. Estimates of the attenuation from rebar are provided by Rohrbaugh for a variety of parameters [6]. Results for the concrete attenuation without rebar are provided in Table 4.

Table 4. RF Attenuation through Concrete Walls

Frequency in MHz	2-Foot Wall Thickness	3-Foot Wall Thickness
100	13.9dB	19.4dB
200	16.7dB	23.9dB
400	21.0dB	30.5dB
600	24.2dB	35.3dB
1000	28.7dB	42.2dB
1400	31.9dB	47.0dB
1800	34.5dB	50.9dB
2000	35.6dB	52.6dB
2400	37.8dB	55.9dB
3000	41.1dB	60.8dB

MEASUREMENTS

The building selected for studying RF penetration into buildings is a blast-hardened structure at the Eglin Air Force Base A-15A site on Santa Rosa Island, FL. Low-level continuous-wave illumination was used for the frequency band 100 MHz to 3 Ghz with the illumination and interior measurement points illustrated in Figure 2. Two antennas and four amplifiers were required to cover the frequency band. The

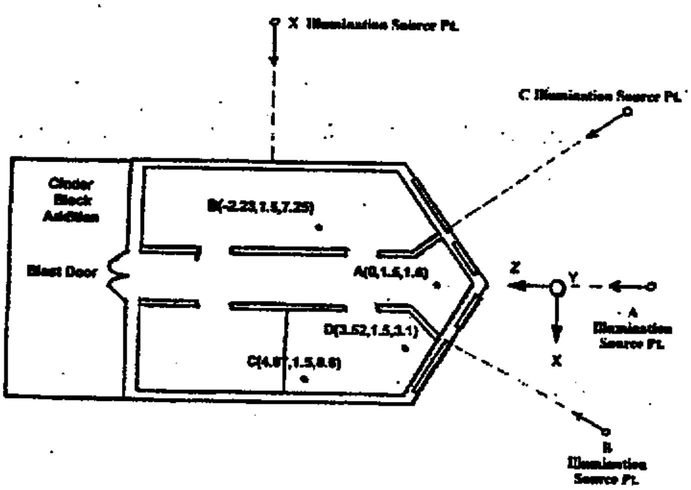


Figure 2. Diagram of Building 12500 at the A-15A Site on Elgin Air Force Base, FL

antennas, log-periodic linear arrays, were positioned as close to the building as possible yet keeping the structure within the main lobes of the antenna patterns. Both antennas were oriented so that the illuminating electric field was vertical and the illuminating magnetic field was horizontal.

In order to quantitate the attenuation the illumination field was measured by directing the antennas toward an open region and measuring the magnetic field at points corresponding in distances and orientations to the internal measurement points of the illuminated building. The incident field is measured by placing a 4' X 8' aluminum sheet on the ground and locating a magnetic field sensor near the center of the sheet. The magnetic field sensor responds to the induced surface current on the plate that is simply 2 X the incident magnetic field strength. Only the incident magnetic field is recorded. The incident electric field strength is obtained by using the properties of the far zone radiation fields, i.e. the ratio of the electric field strength to the magnetic field strength is 120π Ohms.

The measurements of the "illuminating" field are shown in figure 3. These measurements were performed to establish the uniformity of the field within the main lobe and the reproducibilty of the measurements. At low frequency there is good uniformity but above 1 GHz the uniformity degrades. These do not represent the field developed by the antenna only, since reflections from the ground are included in the measurements.

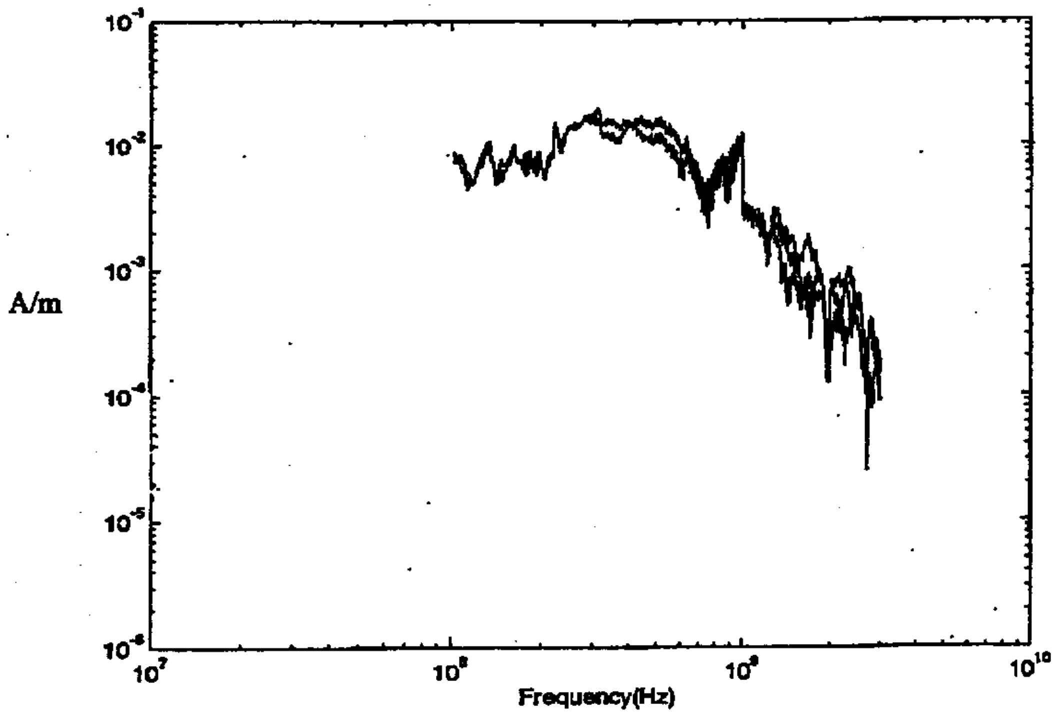


Figure 3. Incident magnetic field measured at the surface of a 4' X 8' aluminum sheet placed on the ground surface.

For the propagation loss in a two-feet thick concrete wall, figure 4 shows the ratio of the principal component of the internal magnetic field (H_z) to the incident field for the measurement point B and the source point X. Minimum attenuation seems to occur in the frequency range 120 MHz to 205 MHz. In this range the

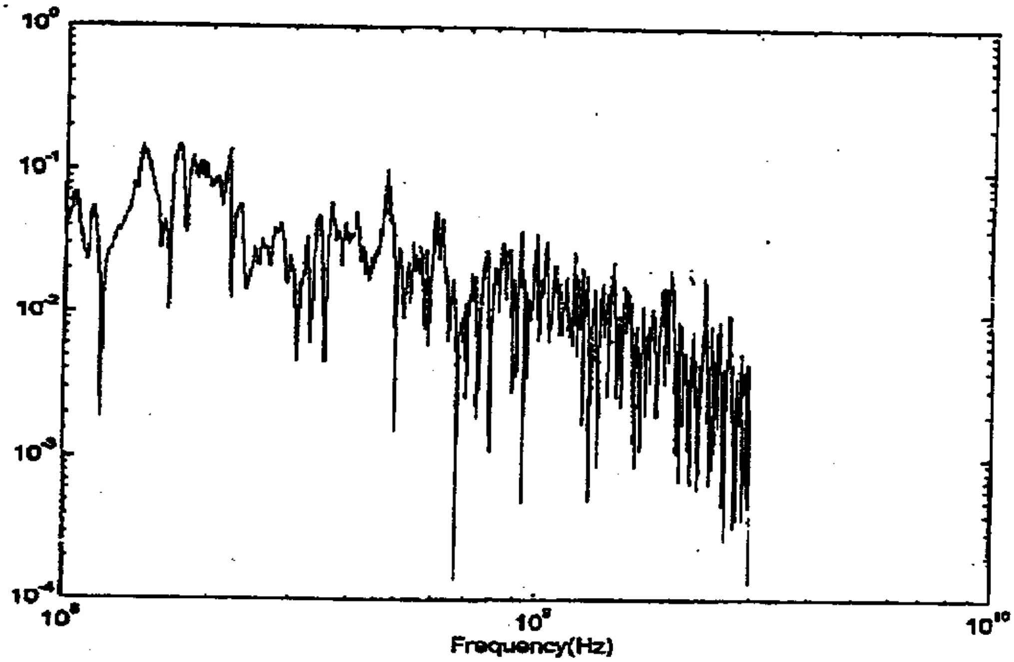


Figure 4. The internal magnetic field (H_z) at measurement point B relative to the incident magnetic field for illumination source point X.

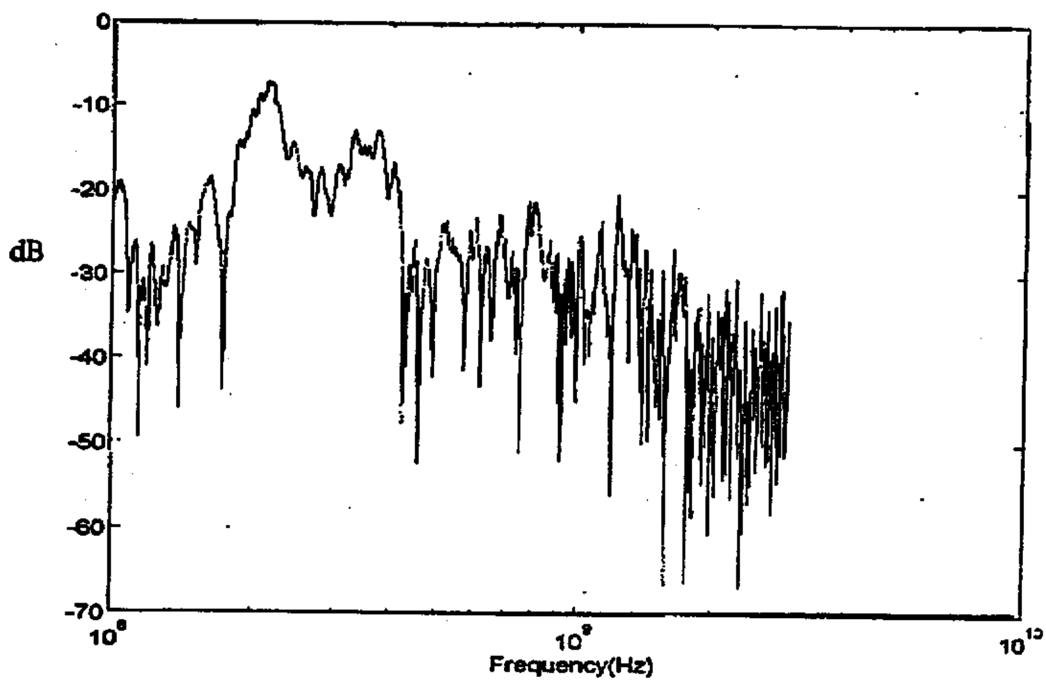


Figure 5. The internal electric field (E_y) at measurement point B relative to the incident electric field for illuminating source point X.

attenuation is less than 20 dB, which is consistent with the calculations shown in Table 4. Apparently below 120 MHz rebar attenuation is significant. Note that the maxima and minima in the data of figure 4 are consistent with internal standing wave patterns and external resonances. Corresponding results for the electric field are shown in figure 5. Both figures are consistent with one another and with calculations. Because of the locations of the source and the measurement points for figures 4 and 5, multipath contributions are expected to be negligible.

Propagation through the windows of Building 12500 is shown in figure 6. Here the ratio of the principle component of the internal electric field (E_y) to the incident electric field is shown for measurement point A and source point A. These data show little attenuation of the field propagating into the interior of the

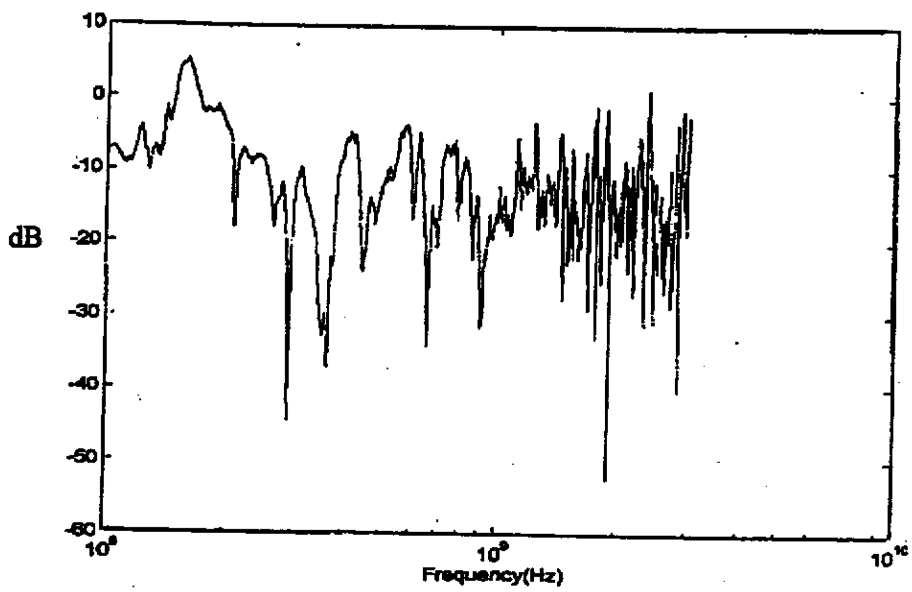


Figure 6. The internal electric field (E_y) at measurement point A relative to the incident electric field for illumination source point A.

building. Correponding results for the principle component of the magnetic field (H_x) are shown in figure 7. For the same illumination, a second measurement point is considered, where the internal measurement is located some distance from the window. In figure 8 the ratio of the principle component of the internal electric field to the incident field is provided for measurement point B and source point A. At low frequency significant attenuation is seen that appears to decrease with increases in frequency, which is consistent with propagation through apertures.

Although the data are not shown, Building 12500 was illuminated from directly overhead and internal field measurements were performed. In all cases the field attenuation exceeded 50 dB.

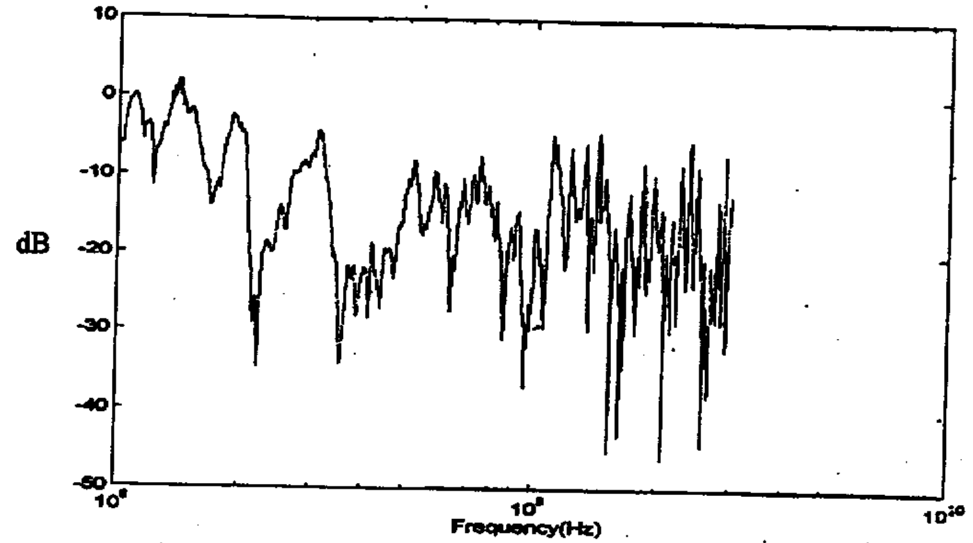


Figure 7. The internal magnetic field (H_x) at measurement point A relative to the incident magnetic field for illumination source point A.

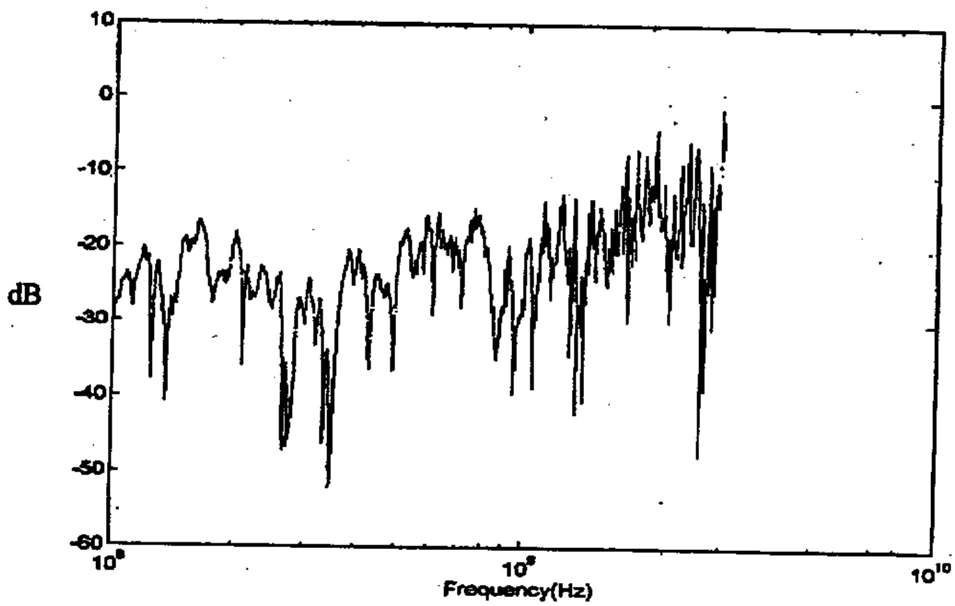


Figure 8. The internal electric field (E_y) at measurement point B relative to the incident electric field for illumination source point A.

CONCLUSIONS

By illuminating a blast hardened concrete structure with only one door and one set of windows it is possible to isolate and study the modes of RF penetration from the exterior to the interior of concrete structures. For two-feet thick concrete walls, the measured attenuation above 200 MHz appears to increase with an increase in frequency. And for frequencies near and below 100 MHz, rebar attenuation becomes significant and seems to affect the magnetic field more than the electric field penetration. In the frequency range between 120 and 205 MHz the attenuation is often less than 20 dB. For four-inch and eight-inch thick walls the attenuation is much less (see Table 3).

Propagation through the windows seems to be primarily line-of-sight propagation with very little attenuation seen near the window. At distant points from the window the attenuation is about 20 dB in the lower frequencies and the attenuation appears to decrease with increase in frequency. Inside the structure standing wave conditions occur that result in substantial oscillations in the variation of the penetrant field with frequency.

For propagation through the structure concrete roof/ceiling significant attenuation occurs.

REFERENCES

1. T.S. Rappaport and S. Sandhu, "Radio-Wave Propagation for Emerging Wireless Personal-Communication Systems," *IEEE Antennas and Propagation Magazine,* Vol. 36, No. 5, pp. 14-23, October 1994.

2. T.S. Rappaport, S. Seidel and K. Takamizawa, "Statistical Channel Impulse Models for Factory and Open Plant Buildings Radio Communication System Design," *IEEE Transactions on Communications,* May 1991.

3. J.P. Castillo and B.K. Singaaju, "Effects of Wave Reflection on Objects Near a Plane Ground," ATHAMAS Memo 8, Phillips Laboratory, Kirtland AFB, NM 8717, 1 May 1975.

4. C.K. Sou, O. Landron, and M.J. Feuerstein, "Characterization of Electromagnetic Properties of Building Materials for use in Site-Specific Propagation Prediction," MPRG Technical Report #92-12, VPI&SU, Blacksburg, VA, 27 June 1992.

5. U.B. Halabe, A. Sotoodehnia, K.R. Maser, and E.A. Kausel, "Modeling the Electrromagnetic properties of Concrete," *ACI Materials Journal*, Vol. 90, No. 6, pp 552-563, November-December 1993.

6. J. Rohrbaugh, "Shielding Effewctiveness of Concrete Literature Search Results," Internal report, Philliups Laboratory, PL/WST, Kirtland AFB, NM, October 1995.