**American Journal of Engineering Research (AJER)**
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-11, Issue-02, pp-73-80
www.ajer.org
Research Paper Open Access

# Effects of Building Materials and Structures on Indoor Path Loss of Very High Frequency Radio Wave

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***Abstract*:** *In this paper, the effects of building materials and structures on indoor path loss of Very High Frequency (VHF) radio waves have been presented. The experiment was carried out through illumination of different buildings with VHF radio wave signals from 60W VHF Transmitter at different frequencies of 90MHz, 100MHz, and 105MHz while GSP 730 spectrum analyzer was placed indoor to measure the transmitted signals. The results obtained show that the VHF indoor propagation path loss ranges from 52.14dB to 69.64dB depending on the building materials, structural properties, and transmitted frequency. The estimated reflection loss ranges from 55.67dB to 69.64dB over the frequency range considered and varies from one building to the other. Glass building category shows a little higher reflection loss compared to some of the others because it was fairly coated with metal. The diffraction loss ranges from 14.01dB to 19.28dB and significantly depends on building geometry and transmitted frequency. It was also observed that scattering loss ranges from 40dB to 122.6dB with the glasshouse depicting the highest scattering loss of 122.6dB. Moreover, the deduced attenuation of the VHF signal in each building shows that the signal indoor attenuation depends mainly on the composition of the building materials in terms of their conducting, insulating, and dielectric properties as well as the transmitted frequency. Hence, the results can be taken into consideration by radio engineers and network planners to mitigate the effects of building materials and structures on the indoor propagation of radio waves so as to provide seamless indoor coverage of radio wave signals in buildings.*
***keywords***- *Building, material, structure, radiowave, pathloss*

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Date of Submission: 05-02-2022 Date of acceptance: 18-02-2022

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## I. INTRODUCTION

The desire of every radio communication network user is to see wireless devices of all kinds providing seamless coverage indoors. Meanwhile, this desire places great demands on the infrastructure of any radio network, implying the need for higher powers and more dense networks which invariably results in more interference. The fundamental challenge to free communication indoors is basically due to strong attenuation and fluctuations of signals which are caused by scattering, diffraction, reflection, and absorption of the signals by the building materials. Building entry and indoor losses are increasingly important parameter in link planning; it is poorly characterized due to wide variability within the buildings [1] and [12
The International Telecommunication Union of Radiocommunication (ITU-R) considered that electrical properties of materials and their structures strongly affect radio wave propagation and that it is necessary to understand the losses caused by building materials and structures so as to guide engineers on how to avoid interference in outdoor to indoor propagation [2] and [3].

Rigorous computation of the effects of propagation into buildings, using the method of moments, finite difference time domain (FDTD) methods, or indoor ray-tracing is generally much complex and it presumes the availability of detailed knowledge of the buildings' geometrical and dielectric parameters, both external and internal. In the practice of cell planning, such information is not available. In fact, in order for a building-transmission model to be of practical value, it should be simple and only minimum information about the buildings is required [3], [4], and [11].

The field distribution inside a building is dependent on the specific features of its internal structure, that is, layout and construction materials [1] and [3]. Obviously as in outdoor environments, radio propagation inside buildings is governed by mechanisms such as reflection, diffraction, and scattering from various objects [5] and [10]. Millimeter signals do not penetrate most solid material very well, while signals at lower frequencies can penetrate more easily through buildings [6].

Data relating to domestic building materials and structures commonly found in underdeveloped countries like Nigeria are scarce in literature and poorly represented compared to that of developed countries. Hence, this paper is focused on the effects of building materials and structural properties on the indoor propagation of VHF radio waves.

## II. EXISTING INDOOR PROPAGATION MODELS

Indoor radio propagation is dominated by the same mechanisms as outdoor namely reflection, diffraction, and scattering. However, conditions are much more variable. For instance, signal levels vary greatly depending on whether interior doors are open or closed inside a building where antennas are mounted. Antenna mounted at deck level in a partitioned office receives vastly different signals than those mounted on the ceiling. Also, the smaller propagation distances make it more difficult to ensure far-field radiation for all receiver locations and types of antennas [6] and [7]. Some of the key models which have recently emerged are:

### *A. Partition Losses Model*

The losses between floors of a building are determined by the external dimensions and materials of the building, as well as the type of construction used to create the floors and external surroundings. Buildings have a wide variety of partitions and obstacles which form the internal and external structure. Partitions vary widely in their physical and electrical characteristics, making it difficult to apply general models to specific indoor installations [6] and [7].

### *B. Long-distance Path Loss Model*

Both theoretical and measurement-based propagation models indicate that average received signal power decreases logarithmically with distance, whether in outdoor or indoor radio channels. The average large-scale path loss for an arbitrary Transmission-Reflection (T-R) separation is expressed as a function of distance by using path loss exponent. Indoor path loss has been shown by many researchers to obey the distance power law as given by [6] and [7] as;

$$PL(dB) = PL(d_o) + 10nlog\left(\frac{d}{d_o}\right) + X_o \qquad 1.0$$

where the value of n depends on the surroundings and building, and $X_o$ represents a normal random variable in dB having a standard deviation of $\sigma$ dB.

### *C. Ericsson Multiple Breakpoint Model*

The Ericsson radio system model was obtained by measurements on multiple floors of an office building. The model has four breakpoints and considers both an upper and lower bound on the path loss. Rather than assuming a log-normal shadowing component, the Ericsson model provides a deterministic limit on the range of path loss at a particular distance. The model assumes that there is 30dB attenuation at 1m which can be shown to be accurate at a frequency of 900MHz and unity gain antenna.

### *D. Attenuation Factor Model*

An in-building propagation model that includes the effect of building types, as well as the variations caused by obstacles, was described by Seidel. This model provides flexibility and was shown to reduce the standard deviation between measured and predicted path loss to around 4dB as compared to 13dB when only a log-distance model was used in two different buildings. The attenuation factor model is given by [6] as;

$$PL\,(d)[dB] = PL(d_0)[dB] + 10n_{SF}log\left(\frac{d}{d_o}\right)FAF(dB)$$

2.0

where $n_{sf}$ represents the exponent value for the same floor measurement. If a good estimate for n exists on the same floor, then the path loss can be predicted by adding appropriate value of FAF [6].

### *E. Log-normal Shadowing*

The model in equation (1) does not consider the fact that the surrounding environmental clutter may be vastly different at two different locations having the same T-R separation. This leads to measured signals which are vastly different than the average value predicted by equation (1). Measurements have shown that at any value of d, the path loss PL(d) at a particular location is random and distributed log-normally about the mean distance-dependent value. That is;

$PL(d)[dB] = PL(d) + X_O = PL(d_o) + 10nlog\left(\frac{d}{d_O}\right) + X_O$

3.0a

and

$P_r(d)[dBm] = P_t[dBm] - PL(d)[dB]$

3.0b

where $X_O$ is a zero-mean Gaussian distributed random variable in (dB) with a random variable $\sigma$. The log-normal distribution describes the random shadowing effects which occur over a large number of measurement locations which have the same (T-R) separation but have different levels of clutter on the propagation path. This phenomenon is referred to as log-normal shadowing.

## III. EXPERIMENTAL SET-UP AND MEASUREMENT CAMPAIGN

Figure (1) represents the building geometry and the instrumentation configuration. The indoor propagation measurement of the VHF radio wave was carried out using a 60W VHF transmitter that operates at the FM frequency range of 88.0 MHz to 108.0 MHz. The transmitter gain ranges from -6dB to +6dB. A Rabbit ear vertical polarized omnidirectional antenna was connected to the transmitter at a height of 0.79m for signal transmission. The spectrum analyzer of frequency range 150KHz to 3GHz was used to receive the indoor signal strength, its gain is in the range of -3dB to +3dB with a vertically polarized antenna connected to it. Measuring Tape was used to measure the building distances, height, width, and length and a 1.5kva generator was used for a power source in a remote area void of power supply.

The categories of buildings (figure 2) used in this work are classified as shown in Table 1. These buildings are peculiar to Nigeria sub-Urban, towns, and villages. The External–Internal properties of all buildings used in this work consist of different sections with different lengths, widths, and heights as given in Table 1. The transmitter was placed at a height of 0.79m above the ground and at 4m away from each building to ensure maximum illumination of the building with the transmitted VHF radio wave at 90MHz, 100MHz, and 105MHz respectively, while the transmitted waves were received with the receiver at a height of 4m at some strategic locations indoor.

Measurements were carried out in different buildings of different materials and structural properties and categorized into five categories based on similarities as shown in table 1, and the effects of different materials and structural properties on VHF radio waves were established. Path losses were estimated in each measurement scenario using the equation given by [8] as;

Path loss (dB) = $Tx_{power} - Rx_{signal\ strength}$

4.0

where Tx is the transmitter and Rx is the receiver. However, to deduce the indoor propagation loss accurately, free space loss was initially deduced due to the fact that the transmitter was located 4m outside each building using the equation given by [7] as;

$FSPL(dB) = 32.44 + 20\log(f) + 20\log(d)$

5.0

where d is the distance from the transmitter to the receiver and f is the signal frequency in MHz.

The 2-ray propagation model technique was adopted to determine the reflection loss based on geometrical optics by considering both the direct path and ground reflected path between transmitter and receiver. Hence the reflection loss $R_L$ (dB) was estimated using equation (6.0a) given by [6] and [9] as

$R_L = \Gamma(\theta_\Delta - P_L)$

6.0a

where $P_L$ is the indoor path loss for the 2-ray reflection model and is given by [6] as;

$P_L = 40\log d - (10\log G_t + 10\log G_r + 20\log h_t + 20\log h_r)$

6.0b

where, $G_t$ is the gain of the transmitter, $G_r$ is the gain of the receiver, $h_t$ is the height of the transmitter, $h_r$ is the height of the receiver, and d is the distance from the transmitter to the receiver.

The phase difference $(\theta_\Delta)$ is expressed by [6] as;

$\theta_\Delta = \frac{2\pi f\cdot\Delta}{c}$

6.0c where f is the frequency, c is the speed of light and $(\Delta)$ is the path difference between the line-of-sight and the ground reflected paths expressed by [6] as;

$\Delta = \sqrt{(h_t + h_r) + d^2} - \sqrt{(h_t - h_r) + d^2}$

6.0d

and $\Gamma$ is the reflection coefficient.
The diffraction loss in each building at the VHF frequencies under consideration was estimated using equation (7.0a) given by [3] and [6] as;

Diffraction Loss = $Gd(dB) \times \Gamma$

7.0a

where,

$$Gd(dB) = 20\log\left(0.4 - \sqrt{0.1184 - (0.38 - 0.1v)^2}\right) \qquad 1 \le v \le 2.4$$

7.0b

and $V$ is the Fresnel Kirchhoff diffraction parameter given by [3] and [6] as;

$$V = h\sqrt{\frac{2(d_1+d_2)}{\lambda d_1 d_2}}$$

7.0c

The scattering loss factor($P_s$) of each selected building material and structure at the frequencies under consideration was estimated using equation given by [6] as;

$$P_s = exp\left[-8\left(\frac{\pi\sigma_h sin\theta_i}{\lambda}\right)^2\right] I_o\left[8\left(\frac{\pi\sigma_h sin\theta_i}{\lambda}\right)^2\right]$$

8.0

where $\sigma_h$ is the standard deviation of the surface height about the mean surface height, $\lambda$ is the wavelength and $\theta_i$ is the transmitting antenna tilted angle. In this case, the transmitting antenna tilted angle is $45^o$.

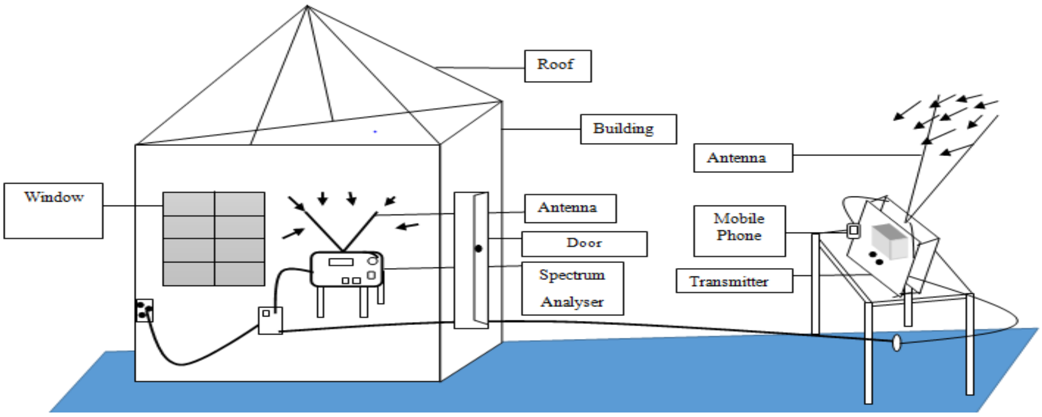



Figure 1: Building geometry and instrumentation configuration

**Building (D) Outdoor**

**Building(D) Indoor**

**Building (E) Outdoor**

**Building (E) Indoor**

**Figure 2: Outdoor and indoor structures of two of the buildings selected for measurement campaign**

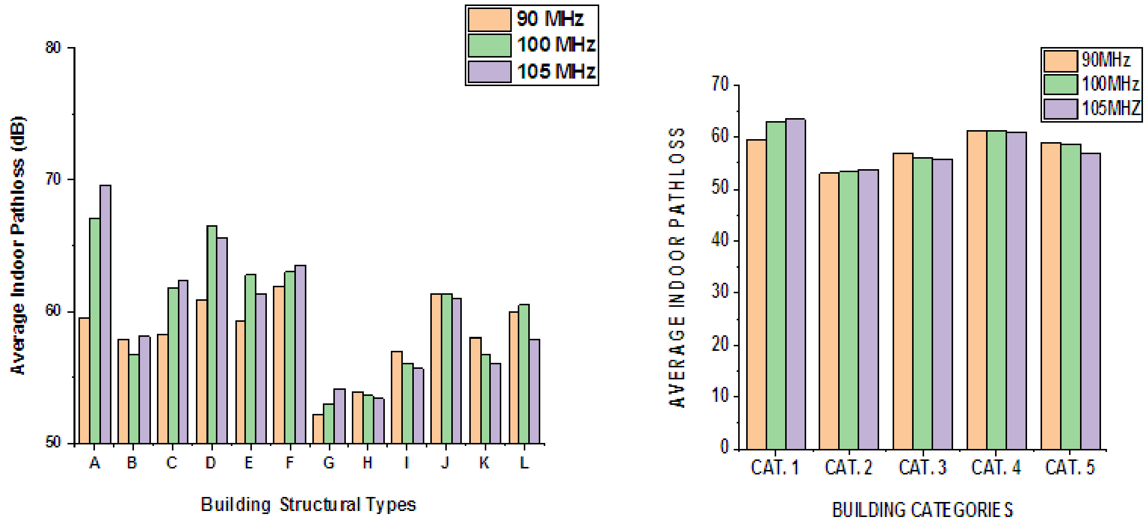
***Table 1: Materials, Categories and structural properties of the selected buildings***

| Building | Cat. | Structural Building Properties | W (m) | L (m) | H (m) |
|---|---|---|---|---|---|
| A | 1 | *Brick / Plastered / Glass Window / Inside Painted / Concrete floor.* | 3.0 | 3.0 | 2.6 |
| B | 1 | *Brick / Plastered / Glass Window / Concrete floor.* | 3.0 | 3.0 | 2.6 |
| C | 1 | *Brick / Plastered / glass Window / Fully Painted / wood door/ Concrete Rugged floor.* | 3.7 | 3.7 | 2.5 |
| D | 1 | *Brick / Plastered / glass Window / Fully Painted / Concrete Tiled floor.* | 3.5 | 7.1 | 2.6 |
| E | 1 | *Brick / Plastered / glass Window / Fully Painted / wood door/ Concrete floor.* | 3.6 | 3.7 | 2.6 |
| F | 1 | *Brick / Plastered /Full Glass door/ Concrete floor/ Concrete roof.* | 7.4 | 1.9 | 2.8 |
| G | 2 | *½ Brick / Net Full Window / Fully Painted / Wood door / Concrete Floor.* | 3.7 | 6.2 | 2.9 |
| H | 2 | *½ Brick / Net Full Window / Fully Painted / Wood door / Concrete Floor.* | 3.9 | 5.6 | 2.9 |
| I | 3 | *Brick / ½ Wood Door / Concrete Floor.* | 7.4 | 8.7 | 2.9 |
| J | 4 | *Full Glass Built / Concrete Tiled Floor* | 8.7 | 12.4 | 3.1 |
| K | 5 | *Mud / Wood Window / Wood Door* | 3.6 | 3.7 | 2.6 |
| L | 5 | *Mud / Plastered / Wood Window / Wood Door* | 4.9 | 5.6 | 2.4 |

## IV. RESULTS AND DISCUSSIONS

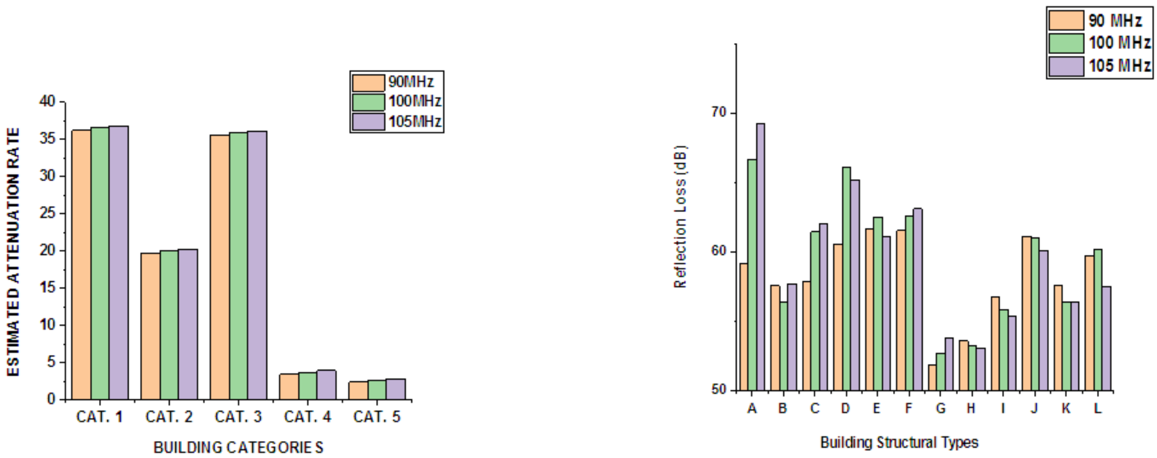
Figure 3a shows the variations in average indoor path loss at the transmitted frequency of 90 MHz, 100 MHz, and 105 MHz for the twelve buildings considered in this experiment. It is obvious from the graph that the indoor propagation path loss depends on the building structural materials and the frequency of transmission. The result shows that indoor propagation path loss estimated from the measured indoor signal strength ranges from 52.14dB to 69.64dB, with buildings A and B having the highest losses while buildings G and H have the least path losses The result in figure 3b shows that buildings with similar properties as categorized in table 1 gave almost the same or closely related values of indoor propagation path loss at the frequency of transmission considered. These two results revealed clearly that building materials and structures have significant effects on the indoor propagation of VHF radio waves.

Figure 3c shows the variations in VHF signal attenuation against building categories. It was observed that attenuation by building material and structure increases with an increase in frequency in all the building categories. Building category 1 has the highest attenuation in the range 36.24dB to 36.88dB because of their material compositions. It has been established in the literature that brick walls and concrete walls have the tendency of impeding radio wave transmission into buildings by absorption or reflection. Buildings in category 4 and category 5 have the least VHF attenuations in the range of 3.45dB to 3.98dB for category 4 and 2.44dB to 2.88dB for category 5 respectively. The results obtained in categories 4 and category 5 are due to the compositions of the dielectric materials of these two categories which allow signals to pass through them more easily with little absorption than other building categories. These results make it obvious that VHF signal attenuation in buildings depends on the material composition and the frequency of transmission.




(a) (b)

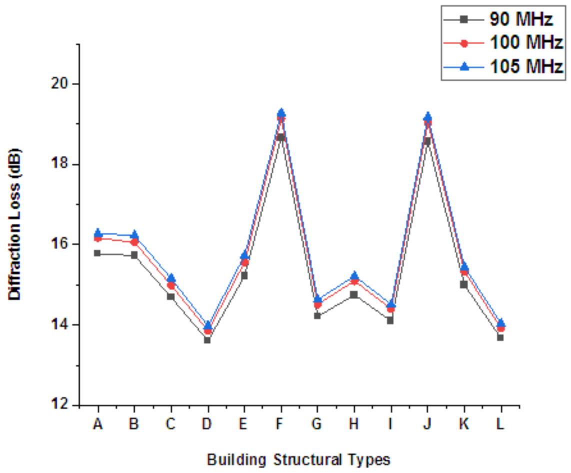
Figure 3: (a) Average Indoor Path loss of the selected buildings structures at (90, 100 and 105) MHz (b) Average Indoor Path loss against building categories at (90, 100 and 105) MHz



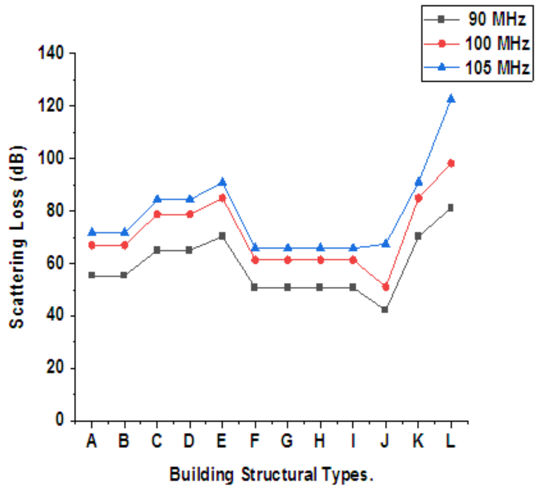

(c) (d)

(c) Estimated Attenuation rate (dB) against building categories (d) Estimated reflection loss against building materials and structural types

Figures 3d, 3e, and 3f show the estimated reflection loss, diffraction loss, and scattering loss against building materials and structural types. Figure 3d shows the result of indoor path loss due to the reflection of the radio wave from the surface of each building. It was observed using a two-ray propagation model that the reflection losses vary from building to building and are frequency dependent. The estimated reflection loss ranges from 55.67dB to 69.64dB over the frequency range considered. Buildings A, C, D, E, and F have higher reflection losses compared to other buildings. This is due to the fact that the walls are fully plastered, painted, and are made of concrete floors and metal doors in some cases with some of the windows coated with silver for quality light reflectivity. Building J made of Glass wall show a little high reflection loss because it was fairly coated with metal. Building G and H have the least reflection loss because of half-height brick walls and the empty upper layer which enhanced free propagation of the VHF radio wave.




(e)




(f)

(e) Estimated diffraction loss against building materials and structural types (f) Estimated scattering loss against building materials and structural types

The result in figure 3e shows that diffraction loss differs from building to building based on the geometry of the building and the transmitted frequency. The graph depicted that buildings F and J have the highest diffraction losses in the range of 18.57dB to 19.28dB respectively. Building F is made with a glass door while the whole building J is made up of glasses and has the highest height. The highest diffraction losses in these two buildings (F and J ) can be traced to their glass components and geometry. Other buildings show relatively low diffraction losses in the range of 13dB to 16dB.

Figure 3f depicted the estimated scattering loss due to each building material and structural properties. It was observed that scattering losses vary from about 40dB to 122.6dB. It is clearly obvious that as the frequency increases, the scattering losses increases. Building J (Glasshouse) has the highest scattering loss of 122.6dB which is in agreement with the literature and the losses also increase with the increase in transmitting frequencies. Building K and L have the least scattering losses in the range of 40dB to 60dB respectively. The results show that the scattering loss is material, structure, and frequency-dependent as well. The results of the three propagation mechanisms show that diffraction loss is smaller compared to reflection and scattering losses which may be due to the proximity of the transmitter to each building and the dependence of the diffraction parameters on building geometry.

## V. CONCLUSION

This paper has presented the results of the effects of different building materials and structures on indoor propagation of VHF radio waves at the transmitting frequencies of 90MHz, 100MHz, and 105MHz respectively. The aim of the study was to evaluate the indoor propagation loss of VHF radio waves due to variations in building materials and structures and to quantify losses due to reflection, diffraction, scattering, and absorption or attenuation relative to the building's materials and structures. The results obtained in this paper showed clearly that the VHF indoor propagation losses vary from building to building and depend on the building materials, structural properties, and frequency of transmission. Further estimation of VHF indoor propagation losses revealed that the indoor propagation path losses are also due to reflection loss, diffraction loss, and scattering loss by the building materials and structures. Moreover, estimated attenuation of the VHF signal in each building shows that the VHF signal attenuation depends on the compositions of the building materials in terms of their conducting, insulating, and dielectric properties as well as the frequency of transmission of the radio wave. Hence, these results can be used by building engineers, radio engineers, and network planners to mitigate the effects of building materials and structural properties on the indoor propagation of radio waves so as to provide seamless indoor coverage.

**ACKNOWLEDGMENT**

We acknowledge one of our technical staff and two of our undergraduate students for their support during the measurement campaign

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