Performance Analysis of Antennas in Structural Health Monitoring

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Abstract. Antennas with good performance are required for advancement in wireless structural health monitoring. Planar inverted-F antenna, dipole and microstrip patch antenna are used to study return loss (S11) at 2.4 GHz when they are embedded inside concrete pier. Antenna performance is studied in air and when it’s placed inside concrete. The return loss and the bandwidth along with other parameters are studied. It is observed concluded that the dipole antenna is more suitable when embedding antenna inside concrete of relative permittivity of 4.45.

1. Introduction
Infrastructure has grown tremendously in last decade or two. Buildings are being built to a height of half a mile in the sky, bridges are getting stretched to ever vast horizons of the sea and the architecture is getting complex every passing minute. With the advancement of tools and machinery we are able to create civil marvels which were not done before. But with increase in complexity of these structures comes with the price of maintaining it. The age old method of visual inspection is outdated. Just imagine inspecting a 50 Km long bridge built on a stretch of water, it’s not impossible to do but it will take months to inspect it added to it the risk involved and the cost. What if we have an earthquake, how will you determine the 50 storey building is safe for its residents to live after the earthquake? So with the advancement in the civil structures we should also advance in the field of maintaining the structures and this is called as Structural Health Monitoring (SHM) [1].Apart from visual inspection there are different ways of determining the integrity of the structure such as ground penetrating radars using BER optics, strain gauges, accelerometers, vibration sensors etc.[2-3] . The wires connect the sensors to a data acquisition center which collects the data received from the sensors and then the data is further processed at base station. At base station the data can be studied and measures can be taken in case of emergency. These sensors require minimal of time and cost and can be done in real time. Recently the focus is shifted on transmitting the data using wireless technology to reduce the cost of maintaining the long stretches of wires which connect the sensors to data acquisition modules [4]. One such way is using transceivers to transmit and receive the data. In wireless SHM the sensor module (pressure sensor) in embedded inside the concrete and connected to one or more transceivers which will have a miniature sized antenna for communication. But to design such a system we should study the performance of antenna we want to design inside the concrete. Studies have been conducted for patch antennas embedded in concrete for 2.45 GHz and beaming powerless antenna embedded inside concrete at 5.7 GHz [5-6]. In this paper, the case study of microstrip antennas is done to show the efficient return loss, gain and bandwidth of antenna. For this study it is used microstrip patch antenna, dipole antenna and planar inverted F antenna (PIFA). It is focus on the return loss of the antenna which will help us determine the operating range and the shift in operating frequency when the antenna is inside the concrete. First it is determine the dielectric constant, bulk conductivity and loss tangent of the concrete which is used for sample. Also the dielectric constant in air. These parameters are used for the simulation to measure the performance of the antennas using HFSS (High frequency structure Simulator).
2. Dielectric Properties of Concrete
Before we start designing the antenna to be embedded inside the concrete pier we should know certain parameters such as relative permittivity (dielectric constant) and conductivity of concrete. These parameters depends on the components used such as sand rubble amount of water etc. while making concrete mix. Propagation of electromagnetic waves is altered in the presence of moisture hence higher the moisture content [7] the stronger will be the effect. The dielectric constant is very sensitive to the moisture content in concrete. Both frequency and the moisture content results in the varied values of the complex permittivity of concrete. Dielectric constant and conductivity increases as the moisture content in concrete increases. The parameters used in the HFSS simulations are listed in table 1.

| Parameters         | Air  | Concrete |
|--------------------|------|----------|
| Dielectric constant, $\varepsilon$ | 1.006 | 4.45     |
| Conductivity, $\sigma$    | 0    | 0.013    |
| Loss tangent, $\tan(\delta)$ | 0    | 0.0212   |

Dimensions for designing the antennas are shown in the figures. Fig 1 is used to design dipole antenna Fig 2 to design planar inverted-F antenna and Fig 3 to design microstrip patch antenna the antennas are designed to have the resonance frequency at 2.4 GHz.
3. Geometry and Computational Details

![Concrete pier](image)

**Figure. 4.** Concrete pier used for embedding antenna

The concrete pier used has a radius of 125mm and height of 120mm. The antenna to be examined is placed at the origin and is surrounded by an air box of dimensions as shown in the Table 1. Where, “a” is the length of the air box, “b” is the width and “c” is the height of the box. The air box is used to place antenna inside the concrete pier. The concrete pier is designed in shape of a cylinder with specific dimensions and parameters of concrete. The height and radius of the pier can be varied with respect to the antenna design. A radiation box can be considered at a distance of 31.25mm from the design. This is obtained by using Radiation Box=$\lambda/4$(λ=c=f; f = 2.4GHz):

| Dimensions of box | Dipole | Microstrip | PIFA |
|-------------------|--------|------------|------|
| a                 | 80     | 86         | 46   |
| b                 | 5      | 86         | 66   |
| c                 | 5      | 6          | 14   |

4. Results and Analysis

4.1 Antenna in air

Simulated return loss ($S_{11}$) plots for all antennas in air as shown in Fig 5. From the Fig. 5 it is observed that PIFA, dipole and microstrip have their resonances at 2.38GHz, 2.34GHz, and 2.2GHz respectively. The corresponding bandwidth are 17.91, 11.66, none within -10dB return loss. The microstrip antenna exhibits additional resonance which is not shown here.
Figure 5: Return loss ($S_{11}$) in air for (a) Dipole antenna (b) Microstrip patch antenna (c) PIFA

Table 3: simulated parameters in air

| Parameters | PIFA | Dipole | Microstrip |
|------------|------|--------|------------|
| $S_{11}$ 2.5GHz | 2.34GHz | 2.2GHz |
| Bandwidth 17.916 | 11.66 | None |
| Gain 3.762264 | 2.196746 | -4.45465 |

4.2. Antenna in concrete
The concrete loading effects on the antenna working was observed. Fig. 5 shows the simulated results of the dipole, microstrip and PIFA when embedded in concrete. When embedded in concrete the resonant frequencies of the PIFA and the dipole decreased from their values in air of 2.38GHz and 2.5GHz to 1.9GHz and 2.0GHz respectively. The dielectric loading presented by the concrete is responsible for this. Since the air box (a, b) containing the dipole is small it allows smaller gaps between the sides of the dipole and the nearby concrete. This is why the PIFA and dipole suffered a larger reduction in its resonant frequency. Whereas the resonance of the microstrip increased from value in air of 2.2GHz to 2.21GHz or remained almost constant as shown in Fig. 6 this is due to the fact that patch radiates primarily through the fringing electric fields between the patch and the ground plane. Since there are no fields on top of the patch is sufficient to keep it immune from any change in its resonant frequency. The bandwidth of the dipole antenna got affected the most due to loading effect it increased from 11.66 in air to 15.53 (as return loss goes below 10dB) in concrete. The bandwidth of PIFA decreased to none (as return loss goes below 10dB) in concrete from 17.16 in air.
Table 4 Simulated data for antennas in concrete is shown in table.

| Parameters          | PIFA   | Dipole | Microstrip |
|---------------------|--------|--------|------------|
| Return loss (S11)   | 1.9GHz | 2.0GHz | 2.2GHz     |
| Bandwidth           | None   | 15.53  | 2.104      |
| Peak realized Gain  | 0.737479 | 3.3569 | 1.4395     |

Figure 6: Return loss (S11) in concrete (a) Dipole (b) Microstrip patch (c) PIFA
5. Conclusion
The prospects of wireless communication using antennas embedded in concrete are studied. The study of a planar inverted-F antenna, a dipole, and a microstrip patch antenna embedded in concrete show guidelines for future use. Comparing the performance of the antenna in air and embedded inside concrete it realize that the dipole antenna is the suitable antenna and PIFA is the best characteristic when it is used in air.

The future scope of this paper is the performance can be analyzed with taking different materials for the concrete with different parameters and calculating the return and transmission losses. The Steel bars can be also embedded inside concrete and simulated in HFSS. The performance of antenna may vary as antenna performance degrades in the presence of metal surfaces. If the antennas are miniaturized, it can be used can be used with RFIDs or individual distributed sensor nodes.

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