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Microwave Coupler Feeds Outdoor Antenna Through Walls

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FDTD modeling was used to develop this coupler, which can be used to send signals from an outdoor WLAN antenna through a wall to indoor equipment

Microwave wall couplers were originally developed for room-to-room LAN connections, where inexpensive 2.4 GHz access points, operating as bridges, are connected on each side of a transmission blocking wall by microwave wall couplers (Fig. 1).

Now, with citywide WiFi becoming available in many cities and towns, a new application for the couplers can simplify and improve wireless installation for many houses. Figure 2 shows a passive antenna feed, with a panel antenna directly connected to a coupler. Inside the house an identical coupler receives the WiFi signal through the wall (or roof), which is then retransmitted by a wireless access point to computers and wireless devices inside.

In order to keep coupling losses as low as possible, a good design for the coupler had to be found. Since magnetic and acoustic techniques do not provide sufficient bandwidth and reach, a coupling microwave patch antenna system was designed using common design equation [1] and refined by Finite Difference Time Domain (FDTD) simulation [2].

Over the years FDTD became a main choice for electromagnetic simulations due to its good accuracy, aided by the rapid increase of computational speed and RAM capacity of PCs. With the simulations that follow, about 5 to 12 hours are needed for one computer run with 6 cuts through the object's dimension using a 1.4 GHz computer with a 512 MB RAM. The program really does not care in what area you want your simulation done. It is important to include enough cells to cover plenty of free space around the objects for fields you may need later. For the couplers a block of cells, called grid or mesh, with $x = 200$, $y = 200$ and height $z = 300$ cells, a total of 12 million cells are needed for computation and high-resolution display without need for a finer subgrid, which is optional for fine tuning of the geometry at a later time.

In real dimensions, the grid is 400 × 400 × 600 mm in size. The 2 mm cell size gives good resolution of the electromagnetic field for all data. The accuracy, however, is dependent upon a number of time steps of the input source. The shortest calculation time is reached with transient and sinusoidal excitation, when near-zone field points data do not change significantly with an increase in the

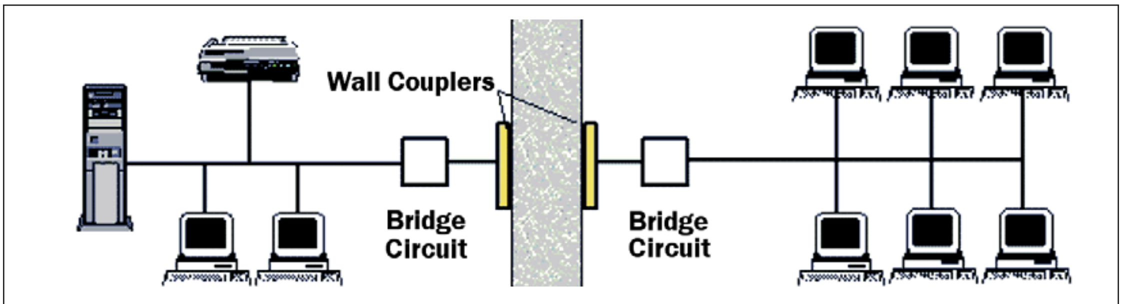

Figure 1 · Through-wall couplers eliminate the need for repeaters or wired connections.

Figure 2 · A wall coupler with WLAN antenna, installed on a brick wall.

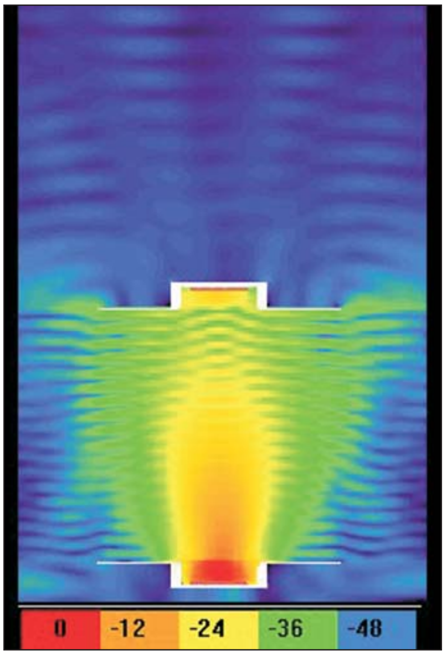

Figure 3 · Electromagnetic field of a vertical cut for 5.3 GHz couplers on a 25 cm concrete wall.

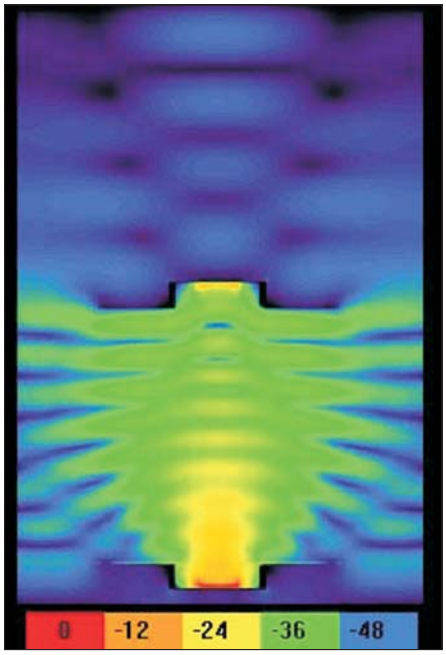

Figure 4 · Electromagnetic field of a vertical cut for 2.4 GHz couplers on a 25 cm concrete wall.

number of time steps.

Experimenting with FDTD is not unlike testing a two-port device. S-parameters can be measured and input and output impedances are directly shown. An external shunt component may be added to the 50-ohm input and output terminals for the device under test. Here, the devices are a wall coupler pair, with patch antennas inside of metal housings, placed on opposite sides of a building wall [3].

It took numerous configurations to create a radiation focus into solid walls of typical construction thicknesses. We targeted concrete as one of the more lossy materials which also has a high dielectric constant (due to its high sand and gravel content).

Figure 3 shows an *xz*-cut through near-center of both couplers with patches in each housing and a 25 cm (~10 inches) concrete wall between them. The bottom coupler is transmitting 5.3 GHz (0 dB, relative) to the upper coupler. The concrete wall location is easily recognized by the high wave periodicity of its field in contrast to the free space pattern above the signal receiving coupler. A color scale represents the field magnitudes and provides a rough estimate of what can be expected as coupling loss from input port to output port. The actual numerical result for the magnitude of S_{21} shows a loss of 23 dB.

In Figure 4, the couplers are operating at 2.4 GHz, also through a concrete wall of 25 cm thickness. Noticeable by a blue and purple colored field surrounding the couplers is the remaining stray radiation, which is 48 dB down from the transmission power at the lower port. In these couplers, the metal plating of the substrate has been enlarged to resonate at 2.4 GHz. All electric parts are removed from the display, including the brown color of the substrates in order to show the fields inside. Here, the numerical readout for magnitude of S_{21} shows a signal loss of 15 dB from port to port.

The 8 dB higher loss at 5.3 GHz is not a surprise. The higher frequency causes a loss penalty of 20 log (5.3/2.4) = 6.9 dB. This relationship can be found by using equation (3-54) of Kraus [4], solved for equal apertures (coupler openings). The result points to the fact that the 5.3 GHz coupler is more efficient than the 2.4 GHz coupler. Material losses are higher at 5.3 GHz, so the 5.3 GHz coupler losses are not equal to the 2.4 GHz couplers when the material independent losses due to the higher frequency are deducted.

The coupler system gain is computed from the field data by the FDTD software into normalized power gain. Figure 5 shows this gain as 0.03, equal to a loss of 15 dB. For a secure wired LAN environment, such power losses are unimportant and may actually need to be further increased by an attenuator in order to make unwanted transmissions undetectable to the outside [3].

For an application like that shown in Figure 2, the losses are overcome by using a panel antenna with a gain of 18 dBi, therefore, retaining a 3 dB signal gain for the inside access point. Operating an inside antenna is often not possible because the outside signal's angle of incidence for concrete and brick reaches additional losses of 6 dB at an angle of 40° to 50° from the vertical (normal) of the out-

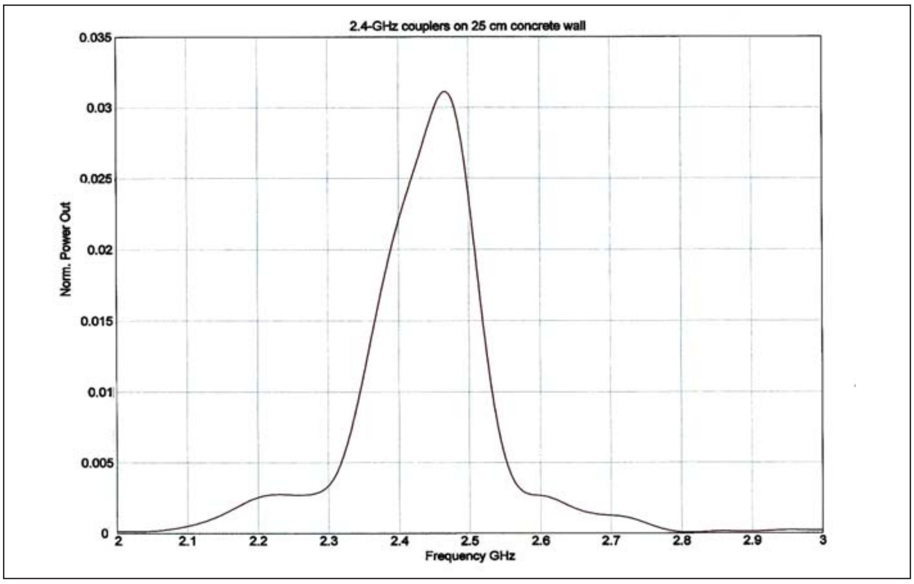

Figure 5 · Normalized output power of the receiving 2.4 GHz coupler communicating through a 25 cm concrete wall.

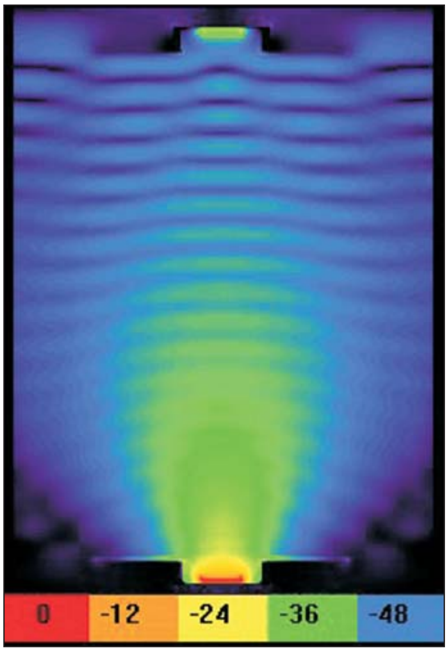

Figure 6 · Electromagnetic fields of a vertical cut near center; 2.4 GHz couplers on a 51 cm concrete wall.

side wall. In this system, the panel antenna attached to the outside coupler (Fig. 2) can be turned as far as ±90º off the normal, directing it into the strongest transmission. In other installations, there may be cable losses and other unpredictable losses. For example, at 2.4 GHz a 10-inch wall of moist concrete has a loss of 24 dB, increasing to 50 dB when wet. In contrast, a dry concrete wall of 20 inches (51 cm) shows a loss of 24.5 dB (Fig. 6). The ground plane of the coupler helps keep the concrete underneath dry, in addition to aiding the microwave beam concentration.

The bandwidth of the coupler is material and frequency dependent. A single patch antenna (without a housing [3]) has a 3% bandwidth, which increases for concrete to 7% at 2.4 GHz (Fig. 5) and increases to 11% at 5.3 GHz when operating as a coupler pair.

At this time no attempt was made to increase the bandwidth further. There are many solutions available in the literature for wide bandwidth microstrip patches suitable as coupler parts. Reduction of coupler losses is the subject of ongoing R&D.

Finally, readers should note that the FDTD algorithm is not without errors. Warnik [5] gives an approximation of error accumulation with time step size and time. Guidelines for FDTD simulation setup can be found in this other references, or provided by FDTD software vendors.

Conclusion

These couplers provide quick, flexible, cable-free installation of WiFi house antennas, avoiding building restrictions and lightning arrestors.

The wall coupler is a new device that could not have been built without an electromagnetic simulation program such as the FDTD algorithm, because of the difficulty in achieving confinement and concentration of RF with sub-wavelength reflector dimensions, and a path through materials with frequency dependent dielectrics and losses.

Field confinement is important for secure LANs, both wired or infrared (IR). The wall coupler's stray radiation becomes unreadable outside an office area when used with approximately –60 dBm or less power (power level adjustment to a minimum for a given wall).

References

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