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НАУЧНО-ТЕХНИЧЕСКИЙ ВЕСТНИК УНИВЕРСИТЕТ ИТМО ИНФОРМАЦИОННЫХ ТЕХНОЛОГИЙ, МЕХАНИКИ И ОПТИКИ

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Study on received signal strength of femtocell with circular and rectangular microstrip patch antenna designed at 2.55 GHz

Hurissa Dejene ✉

Hawassa University Institute of Technology, Hawassa, Ethiopia

dejcomh11@gmail.com✉, dejeneh@hu.edu.et✉, https://orcid.org/0000-0001-8532-8416

Abstract

In large cities, the coverage and quality of telecommunication services inside buildings is low and needs more effort for its improvement. Signal attenuators like number of walls, number of floors and others affect the quality of received signal. Therefore, femtocells are used for improving the poor performance of network inside buildings and other dead zone areas. The aim of this work is to compare the received signal strength of femtocell with rectangular and circular microstrip patch antenna designed at 2.55 GHz. This work considers the received signal strength of femtocell with the designed rectangular and circular microstrip patch antennas. The performance analysis uses Multi Wall Multi Floor indoor propagation model. The result showed that the total gain of rectangular and circular microstrip patch antenna are 3.6528 dB and 2.924 dB, respectively. The received signal strength of femtocell with rectangular microstrip patch antenna is larger than that of circular microstrip patch antenna designed at the same frequency. The effect of number of walls and floors on the received signal strength of femtocell is also clearly indicated. Generally, it is found that much higher received signal strength is observed in rectangular microstrip patch antenna than in circular one. The outcome of this work shows that femtocells are capable of enhancing signal quality for indoor users.

Keywords

femtocell, gain, microstrip patch antenna, received signal strength

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Исследование уровня принимаемого сигнала фемтосоты с круглой и прямоугольной микрополосковой антенной для частоты 2,55 ГГц

Хурисса Дежен ✉

Университет Хавасса Технологического Института, Хавасса, Эфиопия

dejcomh11@gmail.com✉, dejeneh@hu.edu.et✉, https://orcid.org/0000-0001-8532-8416

Аннотация

В условиях больших городов охват и качество телекоммуникационных услуг внутри зданий низкие, и требуются дополнительные усилия для их улучшения. Аттенюаторы сигнала, такие как стены, межэтажные перекрытия и другие препятствия, влияют на качество принимаемого сигнала. Фемтосоты используются для улучшения низкой производительности сети внутри зданий и в других мертвых зонах. Выполнено сравнение мощности и уровня принятого сигнала фемтосоты с прямоугольной и круглой микрополосковой патч-антенной, рассчитанной на частоту 2,55 ГГц. При анализе производительности применена модель распространения внутри помещений с несколькими стенами и этажами. Результат показал, что суммарное усиление прямоугольной и круглой микрополосковых антенн составляет 3,6528 дБ и 2,924 дБ. Показано влияние количества стен и этажей на уровень принимаемого сигнала фемтосоты. Полученные результаты работы подтвердили, что фемтосоты способны улучшить качество сигнала для пользователей внутри помещений.

Ключевые слова
фемтосота, усиление, микрополосковая патч-антенна, уровень принимаемого сигнала

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Introduction

Femtocell is a low-power cellular base station, typically designed with small size for utilization in a building, home or small business. A general idea which is more universal in the industry is called small cell, with femtocell as one element. It relates up to the facility network via broadband; modern model naturally helps 4 to 8 concurrently active phones in a domestic place based on femtocell hardware, and 8 to 16 mobile phones in enterprise situations [1]. Femtocells give advantage to operators and subscribers. For a mobile operator, the necessity of a femtocell is enhancements to coverage, and capacity for indoor users. Coverage is optimized since femtocells can fill the voids and reduce loss of signal through buildings. Capacity is enhanced by a decrease in the number of phones trying to use the main network cells and by the off-loading of traffic [2]. The performance of femtocell depends on different antenna types. Antenna is one element of communication system that can send or accept information. There are diverse types of antennas needed in numerous scenarios. Some of them are: dipole antenna, yagi uda antenna, array antenna and printed antenna. Among these, printed antennas are fabricated using photolithography technique. The most common form of the printed antenna is microstrip antenna. There are three types of microstrip antennas: Microstrip patch antenna, Microstrip slot/travelling antenna and Printed dipole antenna. Among the above three kinds, microstrip patch antenna can have any shape. Microstrip antenna is regularly rectangular or circular in shape. The greatest significant thing in antenna design is to choose the suitable substrate material [3, 4]. The relative study of rectangular and circular microstrip patch antenna on the received signal strength of femtocell is done in this paper. After that, the performances of these antennas on the received signal strength of femtocell are analyzed.

Materials and Method

Design of Rectangular Microstrip Patch Antenna at 2.55 GHz

The design of this antenna requires substrate material, ground plane, patch, feed line and excitation port. *FR*-4 (flame retardant) — epoxy is the substrate used for this design. It is the most commonly used substrate having considerable mechanical strength and electrical insulating abilities. These properties enable it for wide variety of applications. The other very important material is copper which is used for patch, feeder and ground plane in this design. Dimension of ground plane and substrate is 0.05 m by 0.05 m. Substrate has a thickness of 0.00144 m and thickness of patch and ground plane is 0.00005 m. Once the position in 3D, *x*-size, *y*-size and *z*-size of substrate, ground plane, patch, feedline and port assignment are obtained, rectangular microstrip patch antenna is designed with specified frequency. Finally, radiation boundary is created in order to handle *E*-field and *H*-field of the radiation. In order to determine the width and length of rectangular patch, the following equations are used: for given frequency and dielectric constant, the patch width is given by [5] as

$$W = \frac{C}{2F\sqrt{\frac{E_r + 1}{2}}},$$

where W is patch width, m; C is speed of light, m/s; F is the frequency, GHz; E_r is the dielectric constant. The effective dielectric constant of the microstrip transmission line is also given by [6].

$$E_{eff} = \frac{E_r + 1}{2} + \frac{E_r - 1}{2}\left(\frac{1}{\sqrt{1 + \frac{12L}{W}}}\right).$$

The actual length of the patch is given by [7] as

$$L = \frac{C}{2f_r\sqrt{\varepsilon_e}} - 2\Delta L,$$

where E_{eff} is effective dielectric constant; ΔL is the extension of the patch length given by Hammers tad [8] as

$$\Delta L = 0.412h\,\frac{(\varepsilon_e + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_e - 0.258)\left(\frac{W}{h} + 0.8\right)},$$

where W is patch width, m; ε_e is the dielectric constant and h is the height of the patch. Accordingly, the width and length of the patch is 0.035798 m and 0.027748 m, respectively at 2.55 GHz frequency and 4.4 dielectric constant. The antenna is designed on HFSS software and it looks like as in Fig. 1. The coordinate system is global coordinate and consists of global axes: *XY*: 0 mm 0 mm 1 mm, *XZ*: 0 mm 1 mm 0 mm and *YZ*: 1 mm 0 mm 0 mm.

Design of Circular Microstrip Patch Antenna at 2.55 GHz

For designing this antenna, the same materials and dimensions for rectangular microstrip patch antenna

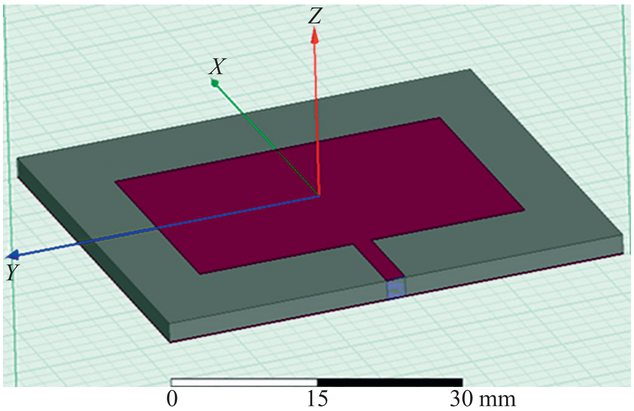

Fig. 1. Rectangular microstrip patch antenna designed at 2.55 GHz

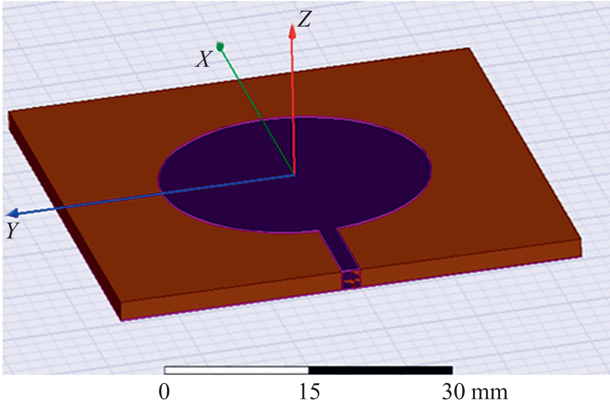

Fig. 2. Circular microstrip patch antenna designed at 2.55 GHz

under Table 1 are used, except the patch shape and its dimension. In order to determine the radius of circular patch, the following equation is used. The radius of circular microstrip patch antenna is given in [9] as

$$a = \frac{F}{\sqrt{\left(1 + \frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right)}},$$

where F is calculated by the equation $\frac{8.791\cdot 10^9}{f_r\sqrt{\varepsilon_r}}$ and ε_e is the dielectric constant of a substrate; h is the substrate thickness, m; a is the radius of the patch, m; and f_r is the resonant frequency, GHz. Accordingly, the radius of this patch is 0.01444 m at 2.55 GHz, and 4.4 is taken for dielectric constant. The antenna is designed using HFSS software and it looks like as in Fig. 2. The coordinate system is global coordinate and consists of global axes: *XY*: 0 mm 0 mm 1 mm, *XZ*: 0 mm 1 mm 0 mm, and *YZ*: 1 mm 0 mm 0 mm.

Received Signal Strength of Femtocell

Once the design of rectangular and circular microstrip patch antennas at 2.55 GHz are done, then the calculation involving received signal strength of femtocell follows it. The total gains obtained from rectangular and circular microstrip patch antenna at 2.55 GHz are used for manipulation of femtocell received signal power. The path loss of femtocell is expressed in dB and depends on distance, the line of sight clearance between the receiving and transmitting antenna and antenna height. Simulation is done to identify the best indoor path loss model. According to the results from the simulation, MWMF (Multi Wall Multi Floor) has low path loss as compared to other models. As a result, it is selected for femtocell indoor propagation analysis. The MWMF path loss is expressed in [10] as

$$L_{MWMF} = L_O + 10n\log(d) + \sum_{i=1}^{I}\sum_{k=1}^{k_{wi}} L_{wik} + \sum_{j=1}^{J}\sum_{k=1}^{k_{fi}} L_{fik},$$

where L_O is calculated by $L_O = 20\log\left(\frac{4\pi}{\lambda}\right)$; n is the power decay index; d is the distance, m; I is the number of wall categories; J is the number of floor categories; k_{wi} is the number of traversed walls; k_{fi} is the number of traversed floors; L_{wik} is the loss of k^{th} wall traversed, dB; and L_{fik} is the loss of k^{th} floor traversed, dB. Many performance parameters related to femtocell are measured in decibels; for instance, signal strength is often specified in decibels. For determining received signal strength of femtocell gain, frequency and distance of transmitting and receiving antenna are considered. The mathematical equation used

Table 1. Parameters of circular and rectangular microstrip patch antenna

Parameters	Circular Microstrip Patch Antenna	Rectangular Microstrip Patch Antenna
Frequency, GHz	2.55	2.55
Radius of the patch, m	0.0014444	—
Length of the patch, m	—	0.027748
Width of the patch, m	—	0.035798
Substrate type	FR4-epoxy (ε_r 4·4)	FR4-epoxy (ε_r 4·4)
Substrate thickness, m	0.0014	0.0014
Feeder type	Microstrip line	Microstrip line
Ground plane, m	0.05 × 0.05	0.05 × 0.05
Exitation	Lumped port	Lumped port
Radiation boundary, m	0.1 × 0.1	0.1 × 0.1

to determine the received signal strength of femtocell is given in [11] as

$$P_r = \frac{P_t G_t G_r}{\text{path loss}},$$

where P_r is the received power, dB; P_t is the transmitted power, dB; G_t is the gain of transmitting antenna, dB; and G_r is the gain of receiving antenna, dB. The study identifies the best antenna type for femtocell based on the received signal strength.

Results and Discussions

Basic Antenna Parameters of the Design

This work compares the received signal strength of femtocell with rectangular and circular microstrip patch antenna designed at 2.55 GHz. The design of both antennas is done with HFSS simulator. Basically, ANSYS HFSS software is used to design Rectangular and Triangular Microstrip Patch Antennas. The gains of the designed antennas are used in calculating the received signal strength of femtocell. For calculating (plotting) the received signal strength of femtocell, MATLAB is used in this work. The proposed rectangular and circular microstrip patch antenna is designed according to the dimensions detailed in Table 1. To study their effect on received femtocell strength, the performances of these antennas at 2.55 GHz are plotted. The dimensions of substrates, ground planes, patches, and feeders and excitation ports are obtained from empirical equations; they are put in Table 1. The performance analysis of these antennas is done with basic parameters. The most significant parameters of an antenna structure are reflection coefficient ($S11$), Radiation pattern, gain, and others. The reflection coefficient, total gain and radiation pattern of rectangular microstrip patch antenna are plotted and shown in Fig. 3, respectively. For this antenna, the value of $S11$ is found about –8.354 dB at the resonant frequency of 2.55 GHz. The gain of the proposed rectangular patch antenna is found to be around 3.6528 dB for the far field pattern. For circular microstrip patch antenna, the reflection coefficient, total gain and radiation pattern are plotted and shown in Fig. 4, respectively. For this antenna, the value of $S11$ is found to be about –0.994 dB at the resonant frequency of 2.55 GHz. The gain of the proposed circular patch antenna is found to be around 2.924 dB for the far field pattern. Generally, from the simulation results, it is found that the characteristics of rectangular microstrip patch antenna are better than that of circular microstrip patch antenna. Specifically, it is shown that much higher gain is observed in the rectangular microstrip patch antenna for the specified frequency.

Radio Link Operation between Macrocell and Femtocell Base station

The radio link operation between the macrocell and femtocell base station are dependent on channel allocation, interference management, handover, femtocell deployment

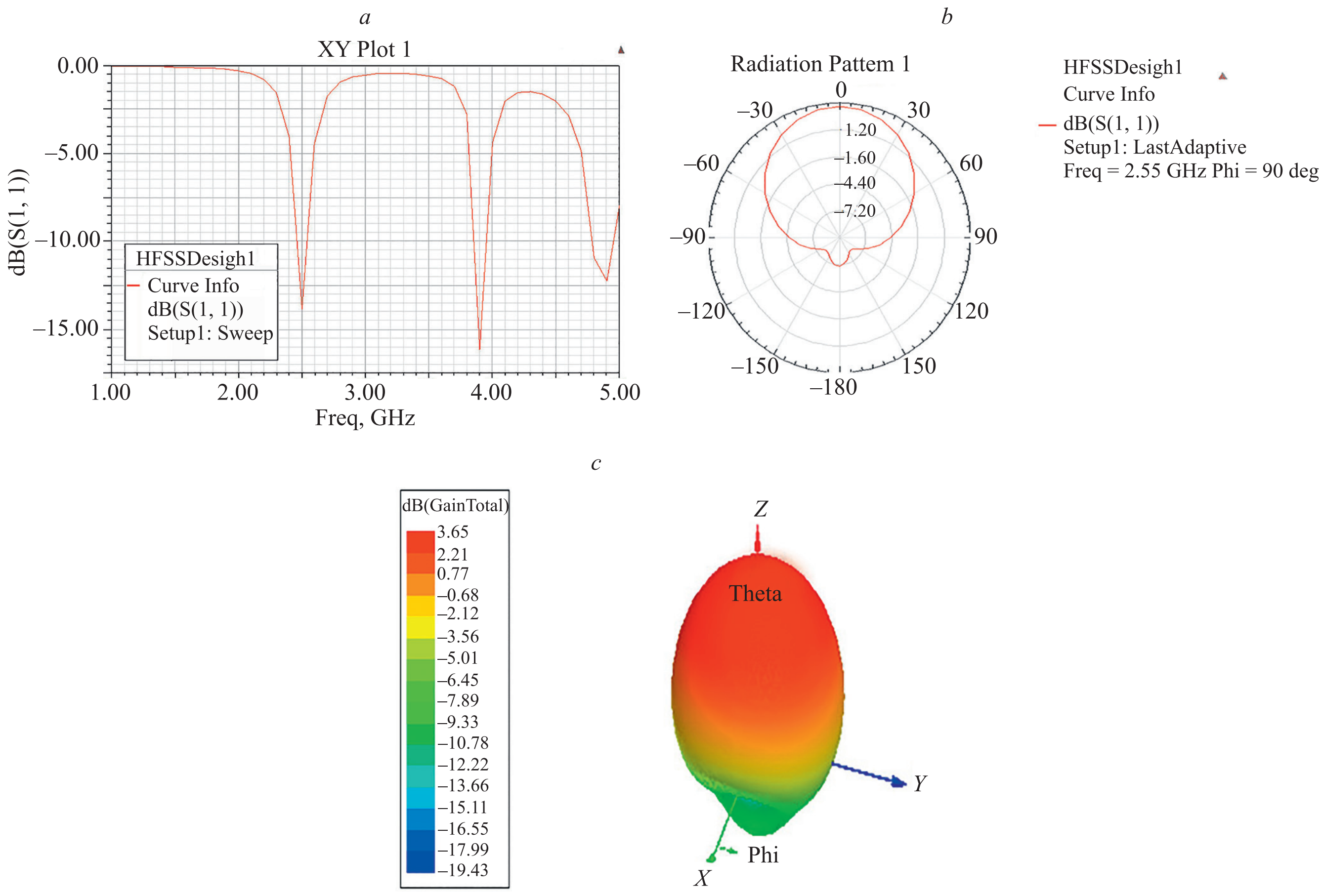

Fig. 3. Reflection coefficient $S11$ (*a*), radiation pattern (*b*) and total gain (*c*) of rectangular microstrip patch antenna

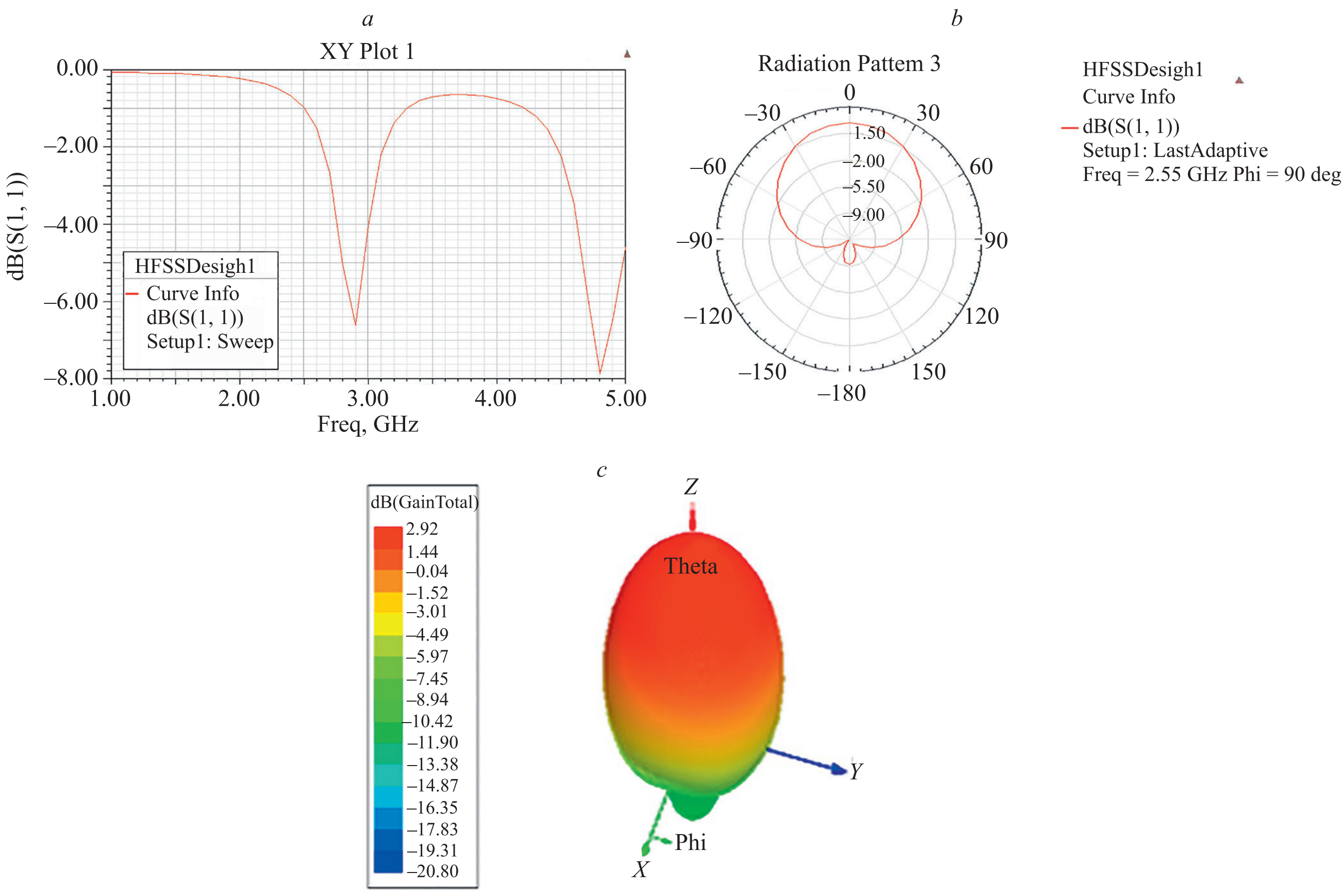

Fig. 4. Reflection coefficient *S*11 (*a*), radiation pattern (*b*) and total gain (*c*) of circular microstrip patch antenna

and more. Channel allocation is very important and there are two kinds that can be used in heterogeneous networks. These are co-channel and adjacent channel allocation. In co-channel allocation, the channels are shared among the macro and femtocell's users. The channels to the femtocell and macro users are allocated based on the channel states experienced by each user for each channel. These pre-computations of channel states are done in radio resource management. These computations are sent to all femtocells. For the user whose channel state is more, the channel is allocated to it. It promotes frequency reuse principle however interference is high, but can be controlled with power management. In adjacent channel allocation, the channels are not shared among the femto and macro cells as well as among the femto and macro users. Co-channel allocation mechanism is used for this work. The other important parameter is interference management and it is a fundamental interference scenario between macro and femto cells as well as between femtocells might be because of channel allocation, power difference and femtocell access methods. But there are a number of interference mitigation methods that can provide good performances. Power control mechanism is one of the best solutions for managing interferences. The self-optimizing of femtocell manages these problems.

The other parameter is handover and it is a technique to ensure that seamless coverage is perceived by the user when moving from place to place. It is more challenging than normal macro cell cellular handover technique. This is because of the backhaul network is different and little possibility of direct communication between the femtocells and the macro cell. The base station with the highest signal to interference plus noise ratio will be chosen. The threshold time interval (T) for handover is set 0 when the registered users move from macro cell to the femtocells. If it is not registered users, the threshold stay time may be 10 s or 20 s depending on the speed. The velocity of the user equipment can be set as low speed between 0–15 km/h, medium speed between 15–30 km/h, or high speed above 30 km/h. In addition to the mentioned parameters, femtocell deployment is also vital. Based on different needs, different amounts of resources may be required on different time scales. To feel these needs, femtocells are developed for residential, enterprise and outdoor use for public access deployment. The intended deployment area for this work is enterprise and residential. *Access Control Modes*: a basic choice in femtocell deployments is the set of users which are allowed to access each femtocell. Closed access restricts the set to specifically registered users, while open access allows any mobile subscriber. There are a lot of performance metrices to study the radio link between macrocell and femtocell.

Received Signal Strength of Femtocell

The based on the path losses have been calculated, the corresponding received strength of femtocell for rectangular and circular microstrip patch antenna are indicated on Fig. 5. As the path loss increases, the received signal strength decreases. This is due to multiple reflection of signal with structures of the building. It is indicated on the graph that femtocell users have good received signal level in the part of building near around the femtocells. The results show that it is necessary to install femtocells in buildings under long term evolution. Fig. 5, *a* shows the received signal strength of femtocell using rectangular and circular microstrip patch antenna for one number of wall and one number of floor. Fig. 5, *b* indicates received signal strength of femtocell using rectangular and circular microstrip patch antenna for one number of wall and five numbers of floors. Fig. 5, *c* indicates received signal strength of femtocell using rectangular and circular microstrip patch antenna for five numbers of walls and one number of floor. Generally, it is possible to determine the received signal strength for arbitrary number of walls and floors. The graphs show that as the number of walls and floors increase, the loss increases too. The increases in loss leads to decrease in received signal strength of femtocell. The Received Signal Strength Indicator (RSSI) of mobile network shows the signal quality of received signal. It is a negative value and the closer it to 0, the stronger the signal. The result from Fig. 5 shows that the calculated RSSI values of femtocell are within the allowable range of communication. The recommended mobile signal strength for LTE (Long-Term Evolution) is shown in the Table 2. If the RSSI of femtocell is larger than that of LTE (–65 dBm), the handoff will occur to femtocell. The result obtained are within the allowable date rate of femtocells according to the data from mobile signal strength recommendation.

Table 2. Mobile signal strength recommendation [12]

RSSI	Signal Strength	Description
Greater than –65 dBm	Excellent	Strong signal with minimum data speeds
Between –65 dBm and –75 dBm	Good	Strong signal with good minimum data speeds
Between –75 dBm and –85 dBm	Fair	Fair but useful fast and reliable data speeds may be attained but marginal data with drop-outs is possible
–85 dBm and –95 dBm	Poor	Performance will drop drastically
Less than or equal to –95 dBm	No Signal	disconnection

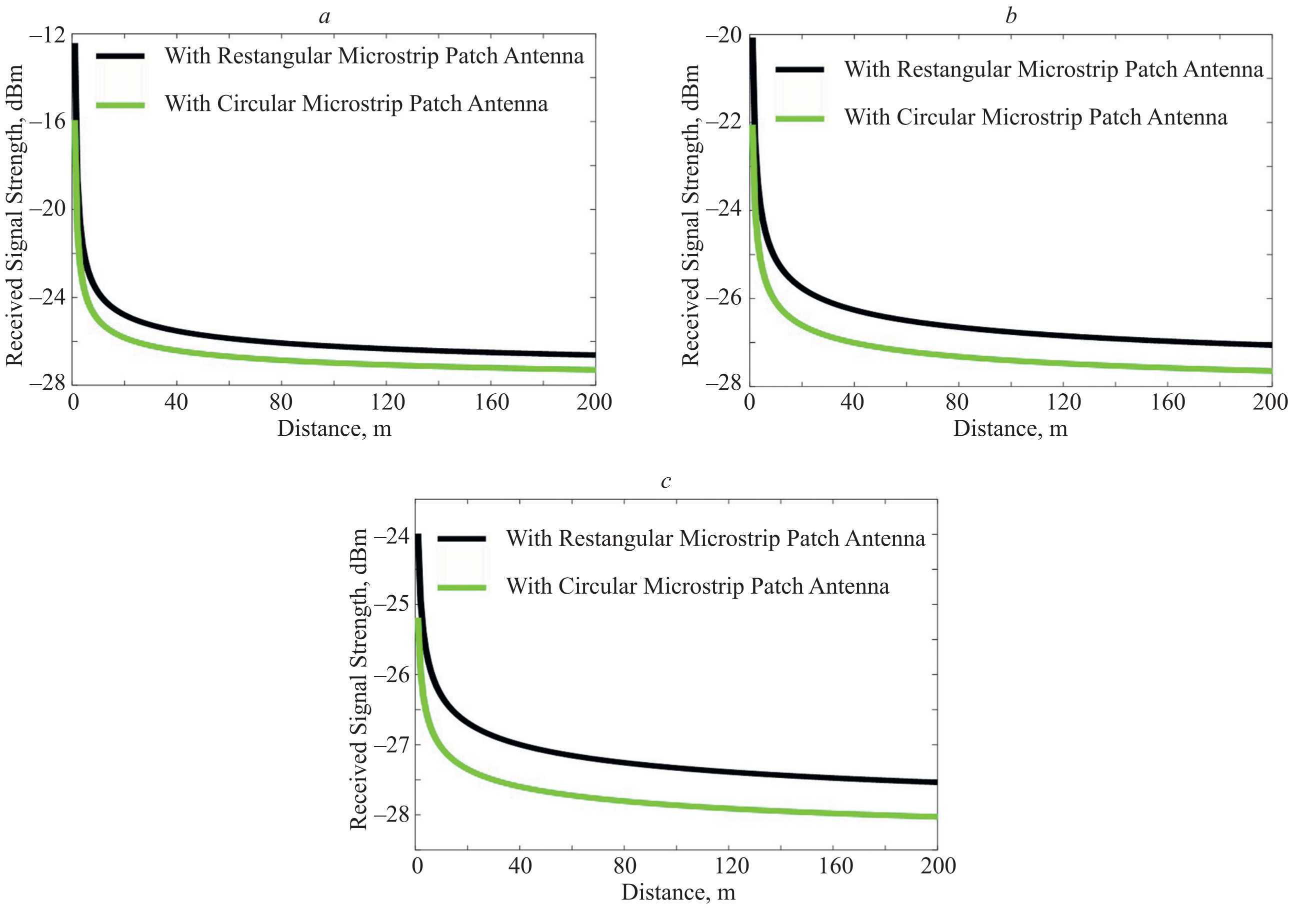

Fig. 5. The level of the received femtocell signal for both rectangular and circular microstrip patch antenna, designed for 2.55 GHz, taking into account the number of: walls = 1 and floors = 1 (*a*), walls = 1 and floors = 5 (*b*), walls =5 and floors = 1 (*c*)

Conclusion

In telecommunication, one of the major factors for network problem is path loss between transmitter and receiver. Among the many solutions, femtocell is one of the most important methods which improves network performances inside buildings and dead zone areas. This work analyzes received signal strength of femtocell deployed inside buildings which is one of performance indicator. This research finds received signal strength of femtocell by designing rectangular and circular microstrip patch antennas at 2.55 GHz on HFSS software. Various parameters like reflection coefficient $S11$, radiation pattern and gain of both antennas are analyzed. Accordingly, reflection coefficient, total gain, and radiation pattern of rectangular microstrip patch antenna are better than that of circular antenna. With the help of calculated antennas gain, the received signal strength of femtocell is manipulated. The results reveal that the received signal strength of femtocell is better when rectangular microstrip patch antenna is used compared to circular antenna. Generally results show that the obtained values in this work are observed to be in agreement with theoretical concepts.

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Author

Hurissa Dejene — Master of Science (MSc.) in Communication Engineering, Bachelor of Science (BSc.) in Electrical Engineering, Lecturer at Hawassa University Institute of Technology, Hawassa, Ethiopia https://orcid.org/0000-0001-8532-8416, dejcomh11@gmail.com, dejeneh@hu.edu.et

Автор

Хурисса Дежен — магистр, преподаватель, Университет Хавасса Технологического института, Хавасса, Эфиопия, https://orcid.org/0000-0001-8532-8416, dejcomh11@gmail.com

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