A SURVEY OF INDOOR LOCATION SYSTEMS ANTENNAS

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Abstract – **Indoor location systems is nowadays a huge area of interest not only at academic but also at industry and commercial level. The correct location of these systems is strongly influenced by antennas performance which can provide gain, bandwidth, polarization and radiation pattern diversity due to large variety of antennas types and formats. The improvement of antennas performance can be greatly improved by the use of Electromagnetic Band-Gap (EBG) metamaterials and Micro Electro Mechanical Systems (MEMS) switching technology. This paper presents the state of art of antennas used nowadays in diverse indoor location systems. It is described the importance of choosing an appropriate antenna according to systems requirements, a brief explanation of common antennas types used for location, metamaterials advantages, smart antennas and MEMS technology.**

Index Terms – **indoor location systems, antennas, smart antenna, EBG, MEMS, reconfigurability.**

INTRODUCTION

In last decades location systems become a huge area of interest, not only at academic level but also at diverse industry and commercial areas such as: automation, robotics, consumer electronics, medicine, security, among others. Tracking become the solution for several problems we face nowadays: children tracking, used already in public places such as the Tivoli Gardens in Copenhagen, or Aalborg Zoo in Denmark; personal guider support for blind persons; find a doctor or a special device in an hospital for emergency situations; several domotic solutions; is just a question of imagination.

Nowadays there are several technologies implemented for indoor location systems being the main used: Radio-Frequency Identification (RFID); Ultra Wide Band (UWB); Wi-Fi, Bluetooth and ZigBee [1]. Referred technologies are based in some techniques of location, such as: proximity, received signal strength identification (RSSI), Time of Arrival (ToA), Time difference of Arrival (TDoA), Angle of Arrival (AoA) or either hybrid solutions. These technologies and techniques are well described in [1][2].

To provide and guarantee a good performance of all these technologies, or further, of all wireless technologies, the choice of a proper antenna is a crucial issue to have in consideration. More detailed, providing a better antenna performance, the gain of the Low Noise Amplifier (LNA) or the Power Amplifier (PA) could be reduced leading to a smaller power consumption and consequently to higher battery life time; smaller interference and undesired radiation, if "smart" antenna are implemented, providing a manipulation of directivity and radiation pattern; this would mean in a location system a chance to reduce the overall system tags number leading to cheaper location systems.

When we desire to design an antenna we need to have in mind that there are no perfect antennas, broadband isotropic with high gain antennas doesn't exist!!! We always need to do a tradeoff of parameters. So, the main step before designing an antenna is always to define the requirements of the selected system. The main important parameters we need to take in attention before designing an antenna are [3]:

Frequency of operation – the central frequency we will use in our system, knowing that the dimension of the antenna is proportional to the wavelength, or by other words, smaller frequency demand bigger antennas;

Bandwidth requirements – the system can operate in a unique channel, or either to be prepared to work in several channels or different bands, demanding a bigger bandwidth and a proper design;

Coverage extension – the scenario (rural, urban, and interior) and the coverage demands an antenna chosen by appropriate radiation pattern and directivity;

Mobility of the terminal – the mobility of the user, fixed positioning or with free movement, will imply a careful choice for antenna polarization requirements;

Power level – for a mobile device the maximum power transmitted is ruled by legislation, caring about prevention of nocive radiation levels to human bodies and minimization of interference with other systems;

Size and cost – dimensions and cost of the final product and manufacturing costs are always a crucial point to take care when designing an antenna;

Antenna position – the position where we will implement the antenna in a Printed Circuit Board (PCB) influences the performance of the antenna, we should take this in attention before practical implementation of it;

By all these reasons we can say that to project an antenna is extremely hard and have a lot of variables, being the trade off of essential parameters the main point of designing an antenna.

ANTENNAS - HISTORY

The story of antennas was first inaugurated at more than one century and half ago, in 1842 by Joseph Henry, being in that moment just a wire. In 1886, H. Hertz, was using a dipole and loop antennas to transmit radio waves. From here until 1900's was probably made the biggest advances in history for antenna's design, parabolic reflectors, lenses, horn antennas, waveguide radiators were introduced and arraying were already proposed [4]. Until 1940's almost no advances in antennas design were made, except the origin of the Yagi and Uda antenna in 1926 and the slot antenna in 1939 [4]. With the World War 2 (WW2) a big pressure for invention of microwave sources were made, leading to the development of the klystron and the magnetron. This obviously provided a big reducement of antenna's size, but more important for the WW2, made possible the detection of much smaller objects with the use of radars. With the invention of the transistor in 1947, the "electronic era" born and a big improvement in computers were made, providing the essential support for methods of analysis and numerical methods in early 60's. In 1970's a fundamental radiating element was developed, was the origin of the microstrip antenna.

At end of 1980's started the first studies of Electromagnetic Band Gap (EBG) structures and in early 1990's MEMS switches were introduced, providing better efficiency and reconfigurable antennas characteristics [5]. Also in early 1990's smart antennas were born [6]. Recently, and due to size requirements of indoor location systems, chip antenna were developed providing a small antenna solution for location systems.

With the huge research made in antennas and the maturity of arrival technologies, the idea firstly presented by Joseph Mitola in 1999, the cognitive radio, appear not anymore as a dream but instead, as a near reality of our times.

INDOOR ANTENNAS TYPES

Due to the demands of size, height, cost and short range, not all antennas type are appropriate to indoor location systems. In literature was found several antennas used for indoor location, although due to this huge topic, is not possible to describe all, so, in this paper it will be just discuss monopoles, dipoles, loop antennas, Inverted F antennas (IFA), microstrip and chip antennas. For further knowledge about this issue, in [7] are described slot antennas and in [8] is well presented and explained also other antennas types and a full chapter of antennas applications.

Dipole antenna

The dipole is one of the most basic antennas and is commonly referred as half-wavelength (λ/2) dipole. The dipole is made of conductive elements cut in the center and fed by a two wire transmission line, where the two currents in the conductive elements are of sinusoidal distribution, equal in amplitude, but with opposite phase [8].

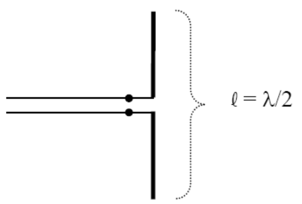

Figure 1: **Dipole representation**

The input impedance of the λ/2 dipole is 73+j42,5Ω, this is the reason normally the antenna is shorted a little to provide a purely resistance of value near 73 Ω.

The directivity of the λ/2 dipole is 2,15dBi (1,64) with a typical gain near 2dBi and a bandwidth of about 10%. The radiation pattern in free space has a shape of a doughnut with dips along the direction of the wire, although, changes in the size of the dipole will result in other different shapes presented in *Figure 2*.

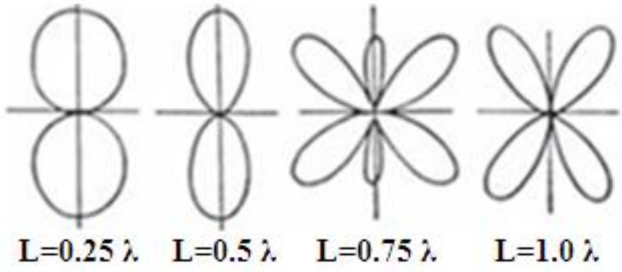

Figure 2: Dependency of radiation pattern with dipole wavelength (azimuth plan) [8]

These dips are in several applications undesired. Several configurations are possible to make to avoid them, reducing at the same time the antennas size, such as:

- Bend the outer ends of the antenna;
- Replace some of the wire length with loading coils;
- Fold the dipole into a meander pattern;
- Capacitive loading of the dipole ends;
- Hairpin or coil loading of the center.

At present, dipoles with different shapes are widely used in location system based on UHF (Ultra-High Frequency) RFID and WLAN technologies. Two famous location system based in RFID are the SpotOn [9] working at 916MHz and the LANDMARC [10] working at 308MHz. At frequency near 900 MHz, we would expect a λ/2 dipole of around 17 cm. But for typical RFID passive tags what we see is dimensions much smaller, shown in *Figure 3*. These reduce of dimensions were made based in: folding the dipole in a meander pattern and with capacity loading of the dipole ends.

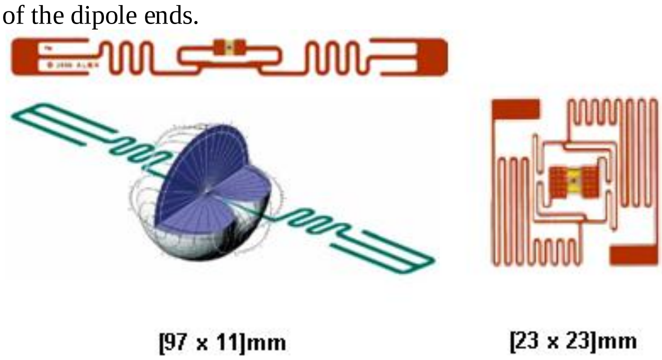

Figure 3: Two Passive UHF RFID tags [11][12]

For Wireless Local Area Networks (WLANs) technologies such as Wi-Fi, ZigBee, Bluetooth, it is common the use of external λ/2 dipole antennas. These kinds of antennas are easy confused with external monopole antennas, being the difference in the size and the balanced center feed, not seen externally.

Figure 4: External dipole antenna [13]

These antennas provide good performance characteristics, although, size and cost (requires a connector on the board) of these antennas are not proper in several applications for indoor location system. For these cases, dipole antennas are printed in PCB's reducing its cost and size, being referred further in this paper. Another quite used dipole antenna is the folded dipole commonly used as a PCB antenna. This antenna has advantages over the typical dipole due to being more wide banded and picking-up less noise.

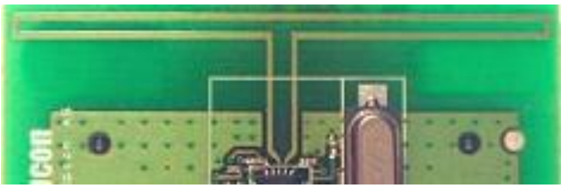

Figure 5: PCB Folded Dipole [14]

a) Monopole antenna

This antenna results from applying the image theory to the dipole. By this theory, if below of a single element of length *L/2* carrying current is placed a conducting plane, then the combination of the element and the plane will result in a "virtual" image below the plane, acting like this as a dipole of length *L*, except that the radiation occurs only in the space above the plane. Comparing with a $\lambda/2$ dipole, a $\lambda/4$ monopole has also the doughnut shaped radiation pattern, the directivity is doubled 5,16dB (3,28) and the radiation resistance is half (36.5ohms) [8].

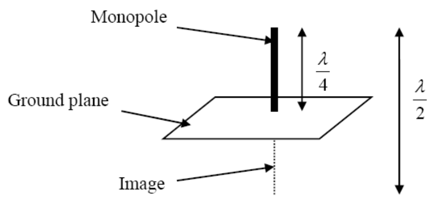

Figure 6: **Monopole representation**

The feeding point of a monopole is not balanced as the dipole, but instead, it is single ended (unbalanced). The conversion of balanced to unbalanced networks can be made with the help of baluns (BAlanced UNbalances transformers)[15].

This is really important parameter because a big part of RF circuits are unbalanced, having already a ground plane, making this type of antennas quite popular. A brief comparation between the two types of antenna is presented in Table 1.

Balanced	
Advantages	***Disadvantages***
• *need no ground plane* • *More immune to detuning caused by ground plane changes*	• *Twice the length of unbalanced antenna;* • *Bigger dimensions;* • *More expensive*
Unbalanced	
Advantages	***Disadvantages***
• *Small and low cost,* • *Easy to design and easy to drive from an unbalanced feed mechanisms* • *Has only one input terminal*	• *Need ground plane as part of the antenna;* • *Resize of ground plane also change antenna electrical characteristics, needing a new design*

Table 1: BALanced and UNbalanced systems comparation

For external antennas the most used monopoles for indoor location systems are the whip and tilted whip antennas [14], same shape as external dipoles represented in Figure 4.

To increase the bandwidth of monopole, planar elements can be used replacing the wire elements. These antennas are very useful for UWB technology, which requires GHz bandwidth. Rectangular planar monopoles and Vivaldi UWB antennas can be possible solutions for these requirements [16].

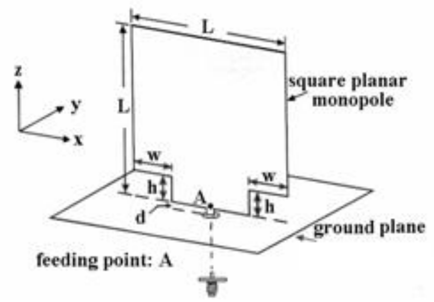

Figure 7: Planar monopole antennas [16]

b) Small loop antenna

Loop antennas can be divided as electrically small (with loop size typically smaller than 1/10λ) and electrically large [8]. Small loop antennas are also called magnetic loop antenna because in near field (Fresnel Zone, distance<2D²/λ, D-biggest dimension of the antenna) they show high magnetic field and low electric field, resulting in a low field impedance. With electrical antennas (dipoles, monopoles) happens the opposite, they show high electric field and low magnetic field, resulting in high field impedance, decreasing it with distance until archive the far-field impedance (377Ω). If we imagine a body (38-57Ω @ 0.03-3GHz) near the antenna, high impedance of the electric antenna will be short circuited by the body, where the loop antenna will be less affected.

The major advantage of a loop antenna are the relatively insensitive to detuning by the surrounding environment and that uses its physical dimension more efficiently than monopoles or dipoles making it an excellent choice for hand-held devices, and Bluetooth earphone systems.

Low frequency RFID [17][18] (13.56 MHz and 125 KHz) technology work based on magnetic coupling. Such tags are of interest for applications which require penetration through liquids or dielectrics. RFID tags operating at High Frequency (HF) are near-field systems, being the reading range roughly limited by the diameter of the reader antenna.

Figure 8: HF RFID tag example (13.54MHz) [11]

Because inductive coupling is used, it is required antennas in the form of coils, requiring a large number of turns at theses frequency. A solution to reduce the number of turns is to have the small antenna coils wound on ferrite (increase magnetic flux), commonly used for tagging animals [17].

c) Small antennas formats

When size is a crucial issue, different shapes for monopoles/dipoles are common applied providing the decrease of size, usually called "Small Antennas" [8]. Normally is preferred the use of monopoles because practical antennas usually operate above a ground plane structure, and due to the high capacity reactance of the dipole, requiring more efficient tuning techniques.

With the decrease of frequency, also the radiation resistance is decreased. The radiation resistance and reactance of monopole for small antenna limit is given by [8]:

$$R_r \approx 40\pi^2 \left(\frac{h}{\lambda}\right)^2, \qquad X = j\left(\omega L - \frac{1}{\omega C}\right)$$

To efficiently operate with the small monopole in a typical 50Ω system, the input impedance need to be matched to 50Ω and the reactance need to be tuned to 0.

When we have small antenna, *-1/ωC* dominates the behavior of the reactance. So, to nullify the reactance we need to increase *L* or *C*. *L* can be increased adding conductor length while maintaining overall height of the antenna, being meandered, helical and spiral formats common used.

These shapes should be carefully chosen cause provide not only a reducement of antenna size, but also can be used to improve impedance matching, manipulate the radiation pattern or either the polarization. In all three shape cases, the radiation resistance, bandwidth, and efficiency drop off as size is decreased, and tuning becomes increasingly critical. The other solution is to increase the value of *C*. It can be done by adding a capacitive top-hat to the monopole [8].

Finally, the impedance matching to 50Ω can be done using a parallel (shunt) matching stub.

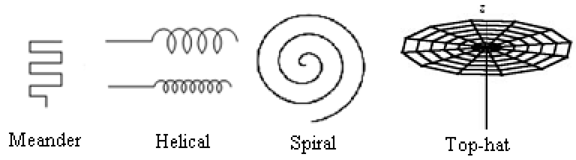

Figure 9: **Typical shapes of monopoles example**

d) Inverted-F Antenna

IFA (Inverted-F Antenna) is a variance of monopole format [19]. It can be seen as a monopole where the top part were folded becoming parallel with the ground plane reducing like this the height of the antenna. This parallel section introduces capacitance to input impedance of the antenna, which can be compensated by a short-circuit stub connected to the ground plane.

The omni-directional radiation pattern, reduced backward radiation and moderate to high gain in both vertical and horizontal states of polarization are its main advantages This is beneficial for indoor environments because depolarization is a dominant phenomenon making the choice of the best polarization difficult.

There are also other variations of IFA antennas, such as MIFA (meandered IFA), having the advantages of meandered formats and PIFA (Planar Inverted F Antenna) having the advantage of bigger bandwidth compared with IFA antenna.

Figure 10: IFA and MIFA antenna in PCB[14]

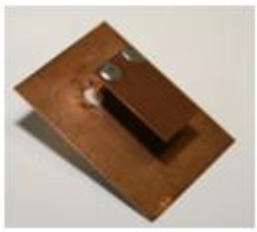

Figure 11: PIFA antenna [20]

e) Microstrip Antenna

A microstrip antenna is made by PCB manufacture techniques. In a simplified way, it consists in two parallel conductors' plates separated by a dielectric, called substrate. The substrate is characterized by a height *h*, a dielectric constant (ε_r) and tangent of loss *(tan δ)*. The top plate is the radiating elements (patch) and the bottom is called ground plane.

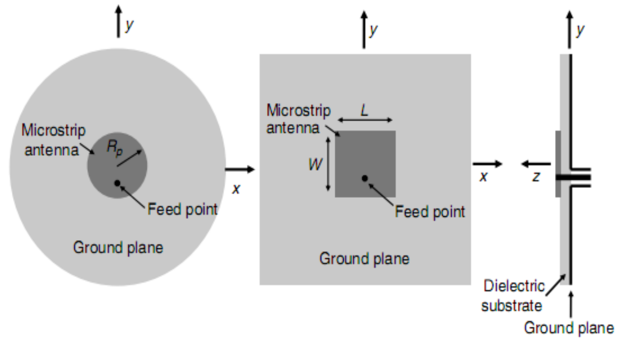

Figure 12: Microstrip antenna examples [21]

Microstrip antennas provide several desired advantages for indoor location systems such as [22][23]:

- Diversity of formats;
- Integration with microstrip technology;
- Light and inexpensive antenna;
- Polarization diversity (linear, elliptical right hand circular (RHCP), or left-hand circular polarization (LHCP));
- Easy use for antennas arrays.

Although, several disadvantages are also mentioned:

- Narrow bandwidth;
- Reduced gain;
- Great sensibility to used subtract, high permittivity implies low efficiency and low bandwidth;
- Excite superficial waves that decrease antenna efficiency.

If we want to improve bandwidth we can use several techniques such as [21]:

- Use thick and low permittivity subtract;
- Introduce close spaced parasitic patches on the some layer of fed patch;
- Use a stacked parasitic patch (multilayer);
- Introduce a U-shaped slot in the patch[24];

There are also several articles describing circular polarization designs, some of them are described in [25][26].

In [27] is shown a location system providing the location based in UHF RFID tags with patch antenna reader, used as smart conveyor belt detector and in [28] an indoor location system based in ZigBee using patch antennas as references nodes.

f) CHIP Antenna

The ceramic chip antenna (CCA) provides much smaller size than conventional whip or helical antennas, or even compared with PCB antennas, and are easy to fabricate [29][30]. However, it implies high dielectric constant, tending to a narrower bandwidth and low radiation gain [31][8].CCAs are normally based in several antennas design, such as helical, meander, patch or slot design.

One thing to take care in this kind of antenna to ensure proper operation is the need to strictly follow the manufacturer's recommendations, distance from ground or other elements, and the correct mounting of the chip. Even following manufacturer recommendations not always guarantee good performance due to de-tuning by nearby objects.

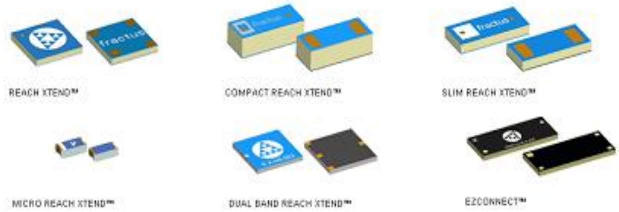

Figure 13: CHIP antennas variety [14]

By the loop antenna advantages referred before, a good choice for chip antenna would be a ceramic loop antenna, because it is relatively insensitive to detuning by the surrounding environment.

EBG MATERIALS

Electromagnetic band-gap (EBG) are metamaterials constituted by periodically dielectric or metallic structures that help or difficult the propagation of electromagnetic waves in a certain frequency bandwidth for all polarization states and incident angles. They act as Perfect Magnetic Conductors (PMC), it means, they exhibit high surface impedance and phase reflection (-90º to 90º) for the designed band-gap [32].

Nowadays usually ground planes are made of conductors acting also as reflectors, although, if the antenna is nearer than $\lambda/4$ the reflection will be made in opposition of phase leading to a destructive interference of incident wave. If we pretend constructive interference we should place the ground plane at distance closer than $\lambda/4$.

These materials have high importance to antennas design because provide smaller antennas, reduces backward radiation and can suppress the propagation of the surface wave of microstrip antennas, providing like this, better efficiency of the antenna, and closer distance to the ground [32][33].

In *Figure 14* is shown an arrangement of woodpile EBG material, surrounding the patch antenna, above the ground plane.

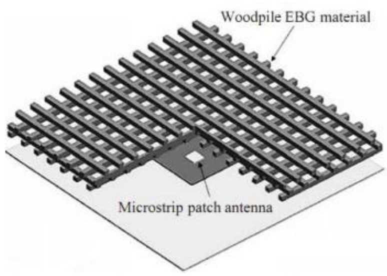

Figure 14: EBG structure example [34]

EBG structures are already used in diverse antennas applications for Wireless LAN[35] and RFID tags or

RFID readers improving size and antenna efficiency [36][37].

Although it was not found by the author any indoor location system with antennas based in EBG materials, these materials advantages can improve the performance of them, being the reason of the special attention and description of these materials in this paper.

SMART ANTENNAS

The term “smart antennas” [38] is nowadays quite usual, but when we speak about it we are referring in reality to smart antenna system. It is a system that combines an antenna array with a digital signal processing (DSP) to provide transmission and reception in an adaptative spatial sensitive manner. This means that these systems should automatically change the direction and radiation pattern shape, gain, polarization in response to some environment signal. There are two big categories of smart antennas:

Switched beam – provide a finite number of fixed, predefined patterns;

Adaptive array – provide an infinite number of radiation patterns adjusted in real time.

Smart Antennas provide several advantages such as:

- Better range/coverage;
- Increase system capacity;
- Multipath rejection;
- Less expensive systems (by reducing PA consumption and the number of need reference nodes).

Nowadays, there are a lot of devices sharing a confined space and bandwidth, such as the standards Wi-Fi, Bluetooth and Zigbee which can take advantages of smart antennas.

The future of indoor location systems will soon demand smart antennas, where the direction of the beam's main lobe can be changed with time, providing like this a directive scan. This direction variation can be done by mechanically rotating a single antenna or rotating an array with a fixed phase. Mechanical scanning has several disadvantages for a positioning system, which can be costly and the scan can be too slow for desired application. By these reasons, electronic scanning antennas, also known as phased array antennas are desired [39]. These antennas can sweep the direction of the main beam by electronically change the phase of the radiating elements, producing like this a moving pattern with no mechanical variation. Although these antennas are high desired, are not yet cost effective for indoor location systems.

Another solution is the use of sectorised antennas arrays (SAA), although don’t bring the full advantages of phased arrays, provide a cost effective control of radiation pattern.

Some examples of sectorised antennas arrays are presented in [40] and [41]. In [40] is presented a sectorised antenna array special design for UWB indoor applications with one centre element and six side elements arranged in a semi-spherical antenna array configuration providing omni-directional pattern. It was 7 driven patches with 4 parasitic patches above each of them, separated by a dielectric material. This technique provides the improvement of the bandwidth. All the sector of the SAA can be excited at the same time or individually depending on the desired applications.

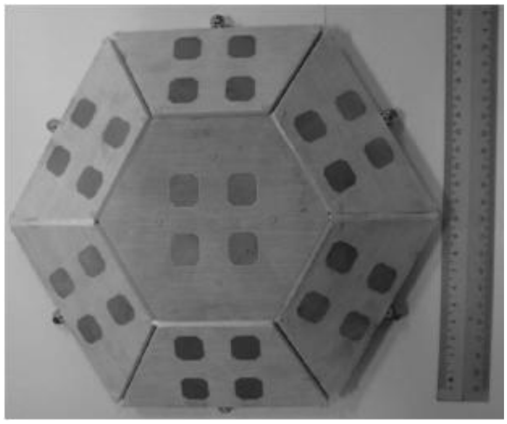

Figure 15: Proposed SAA prototype of [40]

Although these antennas are not exactly smart, provide the selection of transmitting and receiving direction. In [41] is presented a dodecahedra sectorised or switched beam array antenna that provides the selection of directional pattern, reducing like this interference and providing reusability of the space. This antenna was specially designed to work at frequency of 2.45GHz for indoor applications, providing its use for Wi-Fi, Bluetooth or either Zigbee systems. The antenna selection is made by the help of a multiplexer.

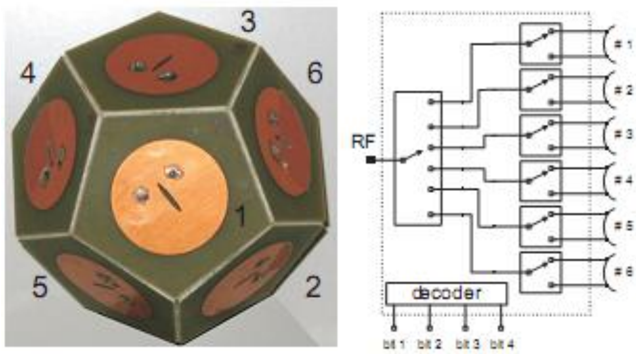

Figure 16: Switched beam directional antenna [41]

Another advantage of this antenna is that provides not only the selected working patch antenna, providing direction selectivity but also is able to operate with either left-handed or right-handed circular polarization (to mitigate multipath propagation).

MEMS TECHNOLOGY

Micro Electro Mechanical Systems (MEMS) in radiofrequency (RF) devices provides a big improvement for electrical tunable components such as inductors and capacitors compared to their integrated counterparts. The monolithic fabrication of antennas with these tunable components reduces the parasitic effect and power losses compared with integration of discrete components.

RF-MEMS switches provide big advantages compared with traditional electronic switches (GaAs-FET and PIN-diode) such as lower insertion losses, better isolation and power consumption [42].

MEMS technology provides huge advances in reconfigurability of antennas, providing the control of frequency, radiation patter and polarization [43].

a) Frequency

The most intuitive way to control the resonance frequency of an antenna is to change the length of the wire, patch, slot or more complicated shapes as fractal antennas using MEMS switches [43].

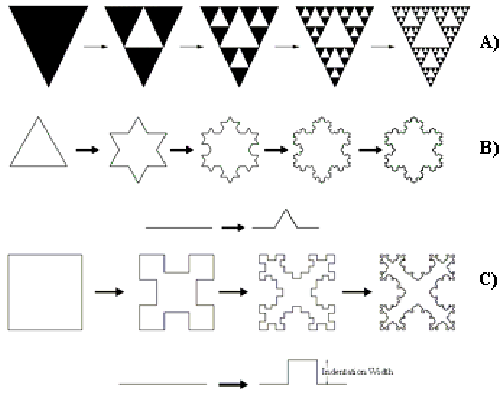

Figure 17: Fractal monopoles antennas, a) Sierpinski, b) Minkowski, c) Koch [44]

Fractal antennas have the advantage that the radiation pattern remains almost the same over a wide range of frequencies due to the self-similarity of the antenna. To reduce interference of DC biasing lines is common used switches with different actuation voltage, like this all the switches share a common dc feeding point not needing the use of dc bias lines that take space, losses and reduce the bandwidth of the device.

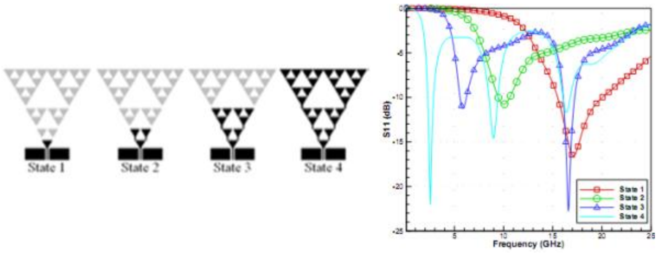

Figure 18: Frequency dependency with different stages of operation of fractal antenna [44]

b) Radiation pattern

To reconfigure radiation patterns in antennas using MEMS normally we can use three main ways:

- Connect one or several directional antennas together, pointing each of them to different directions;
- Activate parasitic radiators using MEMS switches providing with the selected combination of radiators the desired radiation beam;
- Play with the different operation modes for a single antenna;

c) Polarization

To reconfigure polarization in antennas using MEMS typically we can:

- Cuts the patch in proper places, with MEMS switches is possible to control the connectivity to these parts.
- Use spiral antennas, changing the rotation side to change between LHCP and RHCP.

About this technology it was also not found by the author any indoor location system with antennas based in MEMS, although they can highly improve the performance of them, being the reason of the special attention and description of this technology in this paper.

CONCLUSIONS

As described in this paper there is a wide variety of antennas used for indoor location systems. According with the location technique requirements of bandwidth, directivity or polarization, a carefully choice of the antenna should be made. Although are not yet implemented in general location systems, the use of smart antennas will be sooner or later a demand for better performance systems. As a future forecast, we strongly believe that the future of location systems antennas will be based in EBG materials, leading to higher efficient antennas; and MEMS switching technology, leading to a very important and desired characteristic, reconfigurability.

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