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MICROWAVE MONITORING SYSTEMS – DESIGNING SLOT COUPLED PATCH ANTENNA WITH LINEAR POLARIZATION

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Microwave signal positioning systems have new features used for an increasingly complex range of purposes. Particularly, applications would require location devices capable of wider and wider coverage, while having high transmission rates and as few as possible errors. In order to increase this range and use more sophisticated modulation algorithms as well, the life of a battery pack is greatly reduced. This paper shows the design of a linearly polarized slot coupled patch aerial. Main applications are focused on remote/long distance payments and intelligent transport systems.

Keywords: microwave ID system, data communications, coupled patch antennas

1. Introduction

Traffic management and public transportation systems for passengers cannot operate usually without communications. As an exception, traffic management systems using distributed processing, may still achieve local traffic optimization, but all junctions are working isolated, so there is no functioning as a whole system. As a result, communication is a very important part in understanding the operation of UTC[4] or PTM[5] [1], [2] systems. In fact, PTM-type systems require the most diverse and complex communication functions, since they contain both the infrastructure (ground) equipment, as well as the on-board one. These devices need to transfer data back and forth, permanently exchanging information, in order to ensure the system operation as a whole. Most communication systems characteristics are divided into radio features and data transmission specifications. Radio characteristics may include: operating frequency, bandwidth, spectrum and degree of availability. Data transmission

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[4] UTC - Urban Traffic Control
[5] PTM – Public Transport Management

specifications may be: transmission capacity (bits per second), message type (text, image), accuracy of the incoming messages and eavesdropping protection [2], [3], [4].

For the last few years, radio identification systems are very much used in industrial automation, transportation and supply techniques, personnel administration and their security, as well as in any other area where objects must be identified by attaching transmitters or aerials.

2. Data Communication

Usually, traffic management and public transportation systems for passengers do not operate without communication [2]. These communications can be of several types, using few criteria; here, there is a brief classification, by:

- type of information to be transmitted;
- type of signal used as the carrier of information;
- type of physical medium used for transporting the signals;
  - fixed communication networks;
  - mobile communication networks;
- coverage area;
- technologies used;
- Transmission purposes.

Certain radio systems or radio networks support a specific type of application or can be dedicated to a specific target group. The following shall describe in short such special radio systems, which have applicability in the field of transportation and traffic management [3],[4]. DSRC systems, WLAN, Bluetooth are carried out in particular for local applications or in the organizational environment of an enterprise [2], [4]. However, these devices can also be used outside this framework, for transportation and traffic management applications.

DSRC[6]

DSRC *(Dedicated Short-Range Communication)* is a standard that has been developed for supporting communication type systems ITS (Intelligent Transport systems). DSRC is suitable for short-range communication, limited to about 30 m. It may apply in particular to road traffic, for communication between so-called RSE (Road Side Equipment) - the ground equipment, located on the side of the road and OBE (On-Board Equipment) – the on-board equipment. RSE are radio beacons, located above or along the way. The DSRC standard describes

[6] DSRC - Dedicated Short-Range Communication

exclusively the communication systems between the side equipment and the vehicle [4].

WLAN[7]

To achieve mobility and flexibility, such as the extension of a wired computer network, more and more local wireless networks come to mind: wireless LAN (WLAN). There are currently a number of standards of choice for these systems; they include the American IEEE 802.11 and the European HIPERLAN. To connect the devices there is another special standard: Bluetooth. Various parts of the frequency spectrum have been reserved for these cases: 2.4 GHz and 5 GHz ISM[8] bands.
License-free frequency spectra are: 2.4 GHz (2.4-2.484 GHz)/5.2 (5.15-5.35 GHz) / 5.8(5.75-5.825 GHz). This spectrum can be used without licensing, as long as maximum output power [4] is not exceeded. The limited power for emission makes these radio systems to be exclusively suitable for short distance connections, in the range of maximum hundreds of meters, in areas where there is no other way of achieving this. Inside buildings or whenever the emitter-receiver line of sight is blocked, the distance for a link drops to only tens of meters.

1.1 Microwave monitoring systems

Monitoring systems using microwave signals have new features and can be used for a range of purposes, increasingly complex. Particularly, applications would require location devices capable of wider and wider coverage, while having high transmission rates and as few as possible errors. In order to increase this range and use more sophisticated modulation algorithms as well, the life of a battery pack is greatly reduced [5], [6]. Thus, in order to extend the battery lifetime, target size being as large as possible and production cost minimal, the system must be efficient while operating at low supply voltages. There are essentially two types of identification systems: (1) radio frequency ID systems using coupling inductance and operating at frequencies above 30 MHz, and (2) monitoring systems using microwave signals, based on *backscatter* modulation and transmitting data to a reception aerial located at close proximity.

Radio frequency identification systems based on coupling inductance usually have a low transfer rate of information and work over distances much smaller than monitoring systems using microwave signals (usually around 0.5 m) [7]. Many applications which do not require permanent maintenance make use of radio frequency identification systems built on such coupling inductance systems, since

[7] WLAN - Wireless Local Area Network
[8] ISM - Industrial, Scientific and Medical radio bands

reception devices are powered by the reception aerial carrier [6]. Microwave signals monitoring systems are more often used to identify large objects such as containers, trucks, etc, in particular where the object has a high speed and the environment is very dense. 2.4 GHz band, specific for industrial, scientific and Medical (ISM) applications, battery-powered positioning systems usually have an average distance of transmission up to 4 m, using 25 mW of effective isotropic radiated power (EIRP[9]). More modern locating devices use such low power, that a batteries may be used up to 10 years [5],[6].

1.2 Slot coupled patch antennas used in ID applications

Fig. 1 shows an aerial structure patch engaged through the slots, having an adaptable direction of polarization. It is composed of three layers - the patch layer, the one with slots, and the supply layer respectively. The slot-coupled patch antennas are specifically designed to meet the needs of transponder antennas, due to a multi-layer structure which allows for optimization of the radiation characteristics (label substrate) and an increase in the base network (power/supply substrate), independently [6], [7].

The basecoat containing the patch is located on a substrate with relative permittivity εr_1 and power network is engraved on the bottom of the substrate with a relative permittivity ε_{r2}. These substrates are separated by a common ground plane showing slots with a certain shape, trying to effectively engage the micro strip line to the patch. The middle layer slots, shown in Fig. 2, consist of two orthogonal cuts, energized by two open circuits: hybrid 3dB/ 90º lines. This branch-line coupler, in the form of a branched line, generates fields with equal amplitude and a 90º phase shift from the central frequency [6], [7]. Each terminal of the input hybrid circuit has an opposite circular polarizing direction. The length of the open micro strip circuit line ends, which extend beyond the opening slots, can be used, by impedance matching, for widening the band.

[9] EIRP - Equivalent Isotropically Radiated Power (EIRP)

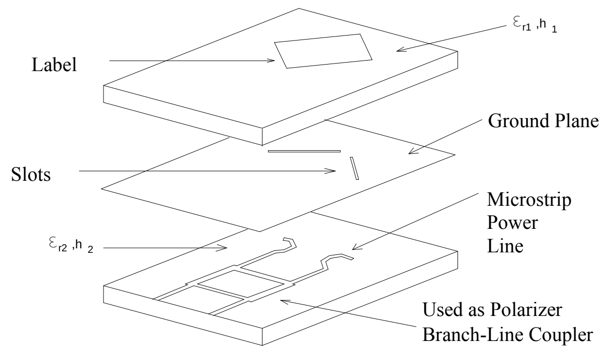


Fig. 1. The structure of a slot-coupled patch antenna with adaptable direction of polarization [7]

This line end, as well as the width of the slot, controls the input impedance for a very large range of values. Therefore, the lack of an additional adaptive network and the ability to choose a thin power substrate help to minimize the base network dimension. Besides, a thick substrate which the patch is attached on, having a low relative permittivity, can be used to increase the impedance bandwidth [5], [6].

The slot coupled patch aerials also have a high front/rear rate because of the intermediate ground plane. This feature presents a good shielding for radio frequency electronic devices on the front of the equipment (RF detectors, switches Rx/Tx and active modulator) as well as for signal processing electronic devices in the rear part of transponder's aerial. Therefore, the patch aerials coupled through the slots have increased production costs, when compared to the classical patch type aerials, and their advantages in terms of radiation performance and antenna size make them a viable alternative for microwave transponder antennas [7].

1.3 Analysis of a patch type, slot-engaged, linear polarization antenna

This chapter will discuss some aspects related to the design of a patch type aerial, coupled through the slot and linearly polarized. Analytical expressions have been developed for analysis of the coupling mechanism in case of such an antenna. The opening is located at $x=0$, in the middle, under the label. A simple theory of the coupling mechanism through the slot may be laid down when the dominant resonance mode of the label TM_{100} is considered. The inside cavity fields, formed by the patch and the magnetic walls [6], [7] (the magnetic current proportional to the tangential electric field) along the edge of the patch are given by the relationships:

$$E_z(x) = \frac{k_0^2}{j\omega \cdot \varepsilon_0} \cdot \cos\left(\frac{\pi}{l_p} \cdot x\right) \tag{1}$$

$$H_y(x) = \frac{\pi}{l_p} \cdot \sin\left(\frac{\pi}{l_p} \cdot x\right) \tag{2}$$

where l_p is the resonant dimension of the antenna (along x-axis in Fig. 3), and $k_0 = 2\pi/\lambda_0$.

Because the field components are not dependent of the y coordinate, the slot of the plate can be moved under patch in the y direction and thus having a negligible effect in coupling mode TM_{100} from moving along the x axis. There has been a checking of the results we obtained, by means of an offsetting the slot in the x direction. For an infinitely long micro strip line, it has been demonstrated that the electric and magnetic coupling coefficients, C_P and C_M, between the cavity fields and line, complies with and verifies the relationship [5], [7]:

$$C_P \approx \sin\left(\frac{\pi}{l_p} \cdot x\right) \tag{3}$$

Electrical coupling is at a maximum at the end plate (x = - lp/2 or x=lp/2), and minimum is reached in the middle (x= 0). Magnetic coupling has opposing positions for maximum and minimum, respectively. Therefore, by slot movement along the X axis, the dominant coupling mechanism can be changed from a purely electric, to a purely magnetic coupling effect. It can be shown that C_{Mmax} (maximum magnetic coupling) is many times higher than C_{Pmax} (maximum electric coupling).

$$C_M \approx \cos\left(\frac{\pi}{l_p} \cdot x\right) \tag{4}$$

Therefore the magnetic coupling mechanism is preferred and the slot opening should be at x=0 in the center of the label to maximize the effect. However, when circular polarization is required, the slot must be moved along the resonant dimension of the label, in order to generate two supply points. Slot-engaged patch-type antenna can also be adapted with an open circuit consisting of one end of the line that has a length approximately λ/4. If the length of the line is L_S, the transformation for the series resistance is given by the relation (5) below:

$$Z_{in} = Z - j Z_c \cdot ctg\left(\beta_m \cdot L_s\right), \tag{5}$$

where
Z is the equivalent series impedance of the patch and slot, respectively.
Z_C is the characteristic impedance

β_m propagation constant for the microstrip line [5].

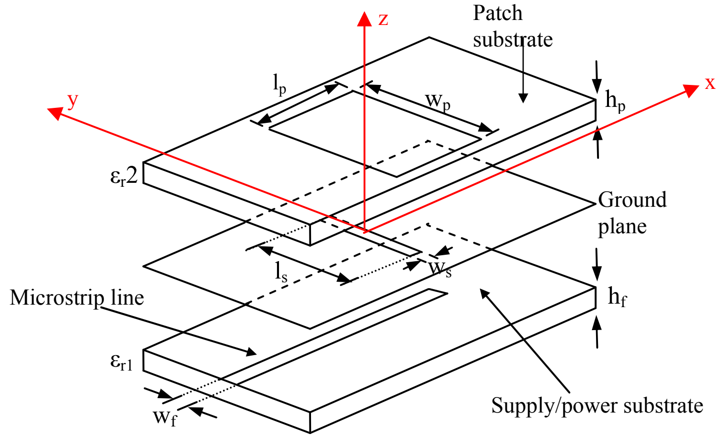


Fig. 2 The geometry of a label-type antenna, slot-coupled, with liniar polarization

The equivalent circuit of a linearly polarized antenna is showed in Fig. 3.

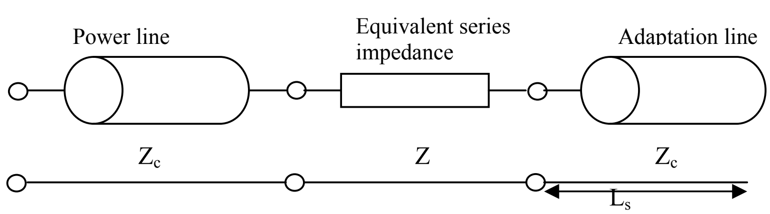


Fig. 3 The equivalent circuit of the linearly polarized antenna

1.4 Antenna Design

The patch antenna coupled through the slot may present both different forms as well as polarization, depending on applications, radiation characteristics, as well as the design constraints encountered for each circuit. In Fig. 4, the standard geometry of such an antenna is presented:

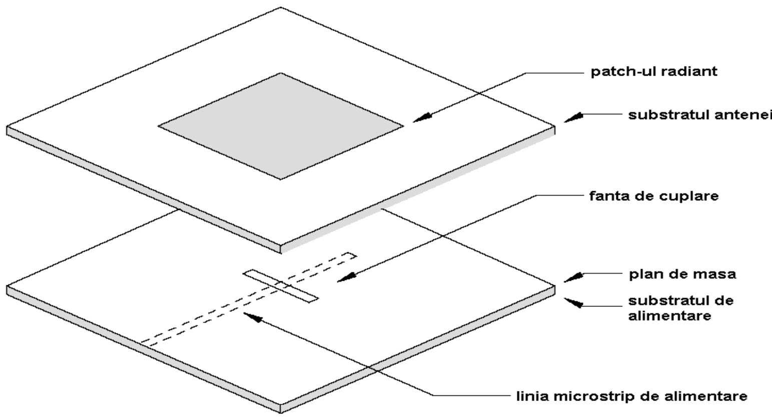


Fig. 4 The basic structure of a microstrip line powered slot coupled patch type antenna [7]

The design of such an antenna requires the study of each parameter. So, there are a few principles to be taken into account, such as [5], [7], [8]:

- Slot length (L_{slot}) determines the degree of coupling with the antenna patch located at the top, as well as the radiation characteristic, and must be optimized for impedance matching.
- Slot width (W_{slot}) is also important for the degree of coupling with the antenna patch, and is considered usually 1/10 of the slot length.
- Micro strip width (W_{micr}) determines the impedance characteristic of the supply line, which is normally 50 Ω.
- Patch position, relative to the slot, is of great importance in antenna design. For a maximum coupling, the patch should be located centrally over the cut. If the patch does move, relative to slot, in the H-plane (on y direction), an input impedance change can be observed, and if the movement is in the E-plane (on x direction), the degree of coupling decreases.

1.5 Antenna Parameters Calculation

Taking into account the above mentioned principles, the following mathematical formulas have resulted, for calculation of patch antenna and micro strip power line, respectively. Therefore [6]:

$$W_{patch} = \frac{3 \cdot 10^8}{2 \cdot F_C} \cdot \sqrt{\frac{2}{\varepsilon_r + 1}} \tag{6}$$

$$\varepsilon_{ref} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \cdot \sqrt{\frac{1}{1 + \frac{12 \cdot h}{W_{patch}}}} \tag{7}$$

$$\Delta L = 0.412 \cdot h \cdot \frac{\varepsilon_{ref} + 0.3}{\varepsilon_{ref} - 0.258} \cdot \frac{\frac{W_{patch}}{h} + 0.264}{\frac{W_{patch}}{h} + 0.8} \tag{8}$$

$$L_{patch} = \frac{3 \cdot 10^8}{2 \cdot F_C \sqrt{\varepsilon_{ref}}} - 2 \cdot \Delta L \tag{9}$$

$$W_g = 6 \cdot h + W_{patch} \tag{10}$$

$$L_g = 6 \cdot h + L_{patch} \tag{11}$$

Where:
ε_r – dielectric permittivity of the patch;
F_C - resonant frequency;
h - hight of the patch substrate
W_g - width of the ground (substrate dimension)
L_g – length of the ground (substrate dimension).
The substrate used for the antenna is FR4 with dielectric constant, ε_r=4.7, loss tangent 0.0019 and the thickness is 1.6 mm. The cooper thickness is 0.0035 mm. From the equations (6) – (11), the patch dimensions can be determined, for the resonant frequency of about 5 GHz.

$$W_{patch} = \frac{3 \cdot 10^8}{2 \cdot 5 \cdot 10^9} \cdot \sqrt{\frac{2}{4.7 + 1}} \Rightarrow W_{patch} = 17.770\ mm;$$

$$\varepsilon_{ref} = \frac{4.7 + 1}{2} + \frac{4.7 - 1}{2} \cdot \sqrt{\frac{1}{1 + \frac{12 \cdot 1.6}{17.770}}} \Rightarrow \varepsilon_{ref} = 4.132;$$

$$\Delta L = 0.412 \cdot 1.6 \cdot \frac{4.132 + 0.3}{4.132 - 0.258} \cdot \frac{\frac{17.77}{1.6} + 0.264}{\frac{17.77}{1.6} + 0.8} \Rightarrow \Delta L = 0.72 mm;$$

$$L_{patch} = \frac{3 \cdot 10^8}{2 \cdot 5 \cdot 10^9 \sqrt{4.132}} - 2 \cdot 0.72 \Rightarrow L_{patch} = 13.318\ mm.$$

We reach the patch dimensions W_{patch}=17.770 mm and L_{patch}=13.318 mm.

Microstrip line width was determined using Microstrip Calculator application from Microwaves101.com and the length using Microstrip Line Calculator from emtalk.com. This facilitates the determination W_{micro} knowing microstrip line characteristic impedance is 50 Ω, allowing the degree of coupling with the patch to be as good : W_{micro} = 2.88 mm, L_{micro}=2.3 mm.

2. Experimental Results

2.1 CST simulation result and patterns

The proposed antenna was simulated using CST[10] Studio Suite 2011. When we simulated the antenna with the determined values, we obtained a resonant frequency of approximately 4.976 GHz. We multiplied the value of the patch length with the ratio of the resonant frequencies 4.976/5 and obtained a new patch length of L_{patch} =13.254 mm.

The reflection coefficient S11, also known as return loss should be maximum for better performance and wide band requirements. We impose the return loss to be -6 dB and we obtain the plot for the design antenna with aperture feed shown in Fig 5.

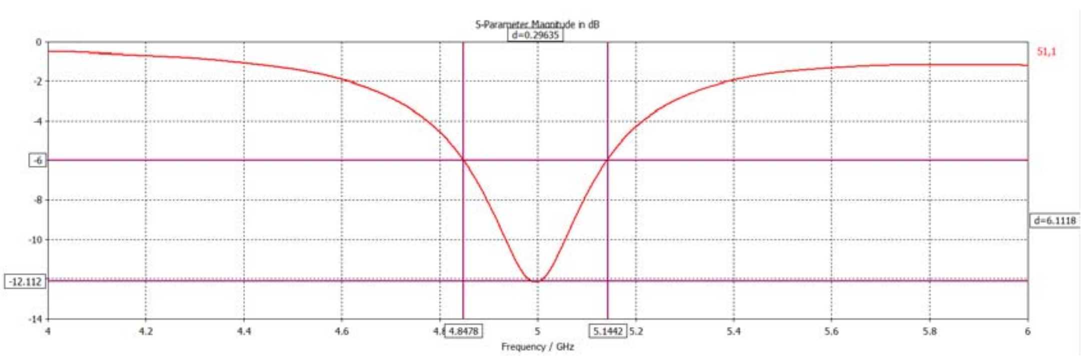
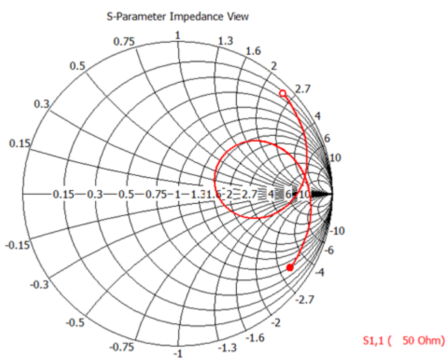


Fig. 5 Return loss

[10] CST- Computer Simulation Technology

The bandwidth in which the antenna is keeping the considered reflection coefficient is about 297 MHz (4.847 - 5.144 GHz). From the Smith chart witch result after the simulation we can conclude that the impedance is 50 Ohm, Fig. 6 and Fig. 7.



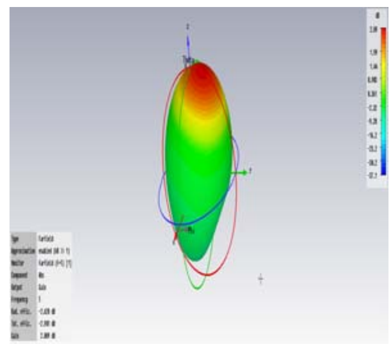


Fig.6 Smith chart

Fig. 7. 3D – Radiation pattern plot

The radiation pattern for the designed antenna which represents the radiation properties as a function of space co-ordinates demonstrates a gain of 2.89 dB at 5 Ghz frequency. It also reflects the directionality of the considered patch antenna witch depends in a tight manner with the used materials. It has been used FR4 material for the design antenna because of its electrical characteristics and also it is very important its low price. This fact makes possible the implementation of the design antenna at a large scale on an industrial level.

2.2 The structure and operation of a WLAN network

WLAN networking consists of a series of interconnected computers, not by way of a physical connection based on copper or fiber-optic cable, but instead, by making this connections using radio waves or infrared light; the medium of information transmittal is the air. This technology is preferable in the event of an information exchange in an environment where - for various reasons - cabling is either inadequate, or impossible to achieve.

In the event of an ad-hoc connection type, computers can be configured on the same communication radio channel. The advantage of this type of communication is in the fact that devices communicate directly and can have a high complexity, since no hierarchy is established at the network level. The advantages of using such a network are: mobility (users are allowed a real-time access to information anywhere in the network coverage area), low cost (antenna operation does not depend on installing antenna cables through walls), easy to set up (two types of network topologies can be configured, according to user needs: WLAN connection in both ad-hoc and infrastructure mode). Such a network has been implemented to check antenna characteristics studied in this work.

Fixed infrastructure WLAN can be represented by a computer network (Ethernet). At this level, central access points can be found, linking between the various ad hoc networks or even among other computer networks. In addition, fixed infrastructure WLAN networks show, unlike ad hoc networks, additional security capabilities [6], [7]. The network card using this considered aerial operates in a configuration ad-hoc and transmits in the 5GHz band using the IEEE 802.11n. The transfer speed for this standard is a max of 450 Mbps. This is only possible if the transmission is carried out in an undisturbed environment.

4. Conclusions

In the event that more crossroads using traffic lights are connected to each other using a centralized control system, data communications systems will give more efficient urban signaling systems. Also, communication equipment can achieve data connections with public transportation passenger vehicles, for the purposes of identifying and monitoring their passage through certain default points (e.g. crowded intersections).

The research motivation of this project is too well observation of microstrip patch antenna. The technological advancement of the microstrip antenna is increasing day by day. A lot of research work is going on microstrip antenna for its better utilization in the future. Many techniques are used for compensating the gain and bandwidth of the microstrip antenna; all are discussed in this paper. The survey shows that the microstrip antenna is one of the light weighted, compact size antenna that can be used for number of application as:

- Global Positioning System application;
- Radar application;
- Mobile and satellite communication system;
- Radio Frequency Identification (RFID) used in different areas like mobile communication, logistics, manufacturing, transportation and health care. RFID system generally uses frequencies between 30 Hz and 5.8GHz depending on its application;
- Reduced size microstrip patch antenna for Bluetooth application in this, the microstrip antenna operates in the 2400 to 2484MHz ISM band;

- Electronic toll collections - At toll collection stations on the highway, the automatic toll collection will collect the money using one sensing antenna and the signal processing unit with the help of computer interfacing. The technology will reduce the man power usage, time and cost with customer friendly environment.

Major **disadvantages** of this standard are: the existing interference /noise coming from other communication systems operating in frequency bands without a license mentioned above; a data transfer rate lower than that of other, better performing standards. As in the case of frequencies around 2.45 GHz, the frequency of 5GHz ISM is partially covered by that radio amateurs and radio-location services spectrum. Main applications are focused in the area of remote payments execution as well as *Intelligent Transport Systems* (ITS).

Microwave signals positioning systems with backscatter modulation operate in the S range of the ISM frequency. They partially overlap with frequency bands used by radio amateurs and radio-location services. Their propagation characteristics are quasi-optical. For data transmission between interrogating device and the transponder, a direct line of view is required, as obstacles attenuate very much the electromagnetic waves in that area of frequency spectrum. Signal attenuation due to free space propagation (approximately 40 dB at 1 m from the transmitter), make the power transfer very difficult, without the use of a cable, due to battery life limitations.

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