# MICROSTRIP ANTENNAS USED FOR WLAN SYSTEMS

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## ABSTRACT

With reference to the literature, after reciting the different types of microstrip antennas (MSAs) for WLANs, this paper describes the design considerations and experimental work performed on MSAs for fixed stations and passive detector / backscatters, which has been introduced into an electronic shelf label project and a complex permittivity monitoring system. Radiation pattern data and estimates of received signal strength are given for various kinds of arrangements. Experimental results are consistent with theoretical calculations.

## INTRODUCTION

A new concept is frequently used at microwave WLAN systems: there are passive terminal stations (e.g. IC-cards in [1]), acting as transponders in which no microwave power is generated, and there are fixed stations (FXS) where most of the microwave active functions are executed or transferred to a central station e.g. by means of a fiber optic link [2]. The latter case allows the microwave hardware in FXS to be very simple. From microwave point of view, only a single Schottky-diode is used at the passive terminal station, acting as a passive detector / backscatter (PDB), and using the modulated backscatter technology. Since a system normally has only a few FXSs but many PDBs, the most severe design constraints are on the PDB (portability, small size, long life and low cost).

The above mentioned technology offers inexpensive solutions for building low data rate wireless links, such as RF tag, Smart Card, radio frequency identification (RF/ID), electronic shelf label (ESL), electronic retail system (ERS), automatic vehicle identifier (AVI), road transport information (RTI) system, etc. Different types of microstrip antennas (MSAs) are used in these applications. A small-size dual-port slot antenna was designed to a wireless IC-card in [1], where the transmitter-receiver equipment was provided with a shaped beam circularly polarized patch array. A capacitively tuned thick patch radiator or a higher order mode rectangular MSA (introduced in [3]) is suggested to FXS, for broad-band operation. For diversity experiments, a modified inverted-F antenna was used, as a built-in MSA [4].

Circularly polarized microstrip antennas are used in WLAN-systems [8] and e.g. in microwave moisture sensors [5], eliminating the disturbing effect of the reflected waves from the near-enviroment. The directional terminal antennas used in mm-wave indoor radio networks, supress the outside cell interference, resulting in a significant capacity improvement [6]. The application of dual-polarized MSAs for polarization shift keying resulted 3dB improvement in signal-to-noise ratio in a microwave transponder [7]. The computer-aided design of a PDB-module at 5.8 GHz was described in [9]. The PDB consists of a specially formed rectangular patch antenna and a Schottky barrier diode. The realization of FXS and PDB-s in the industrial-scientific-medical (ISM) frequency bands are supported by low cost monolithic microwave integrated circuits (MMIC), [10]. Modified microstrip circular patch antennas are intruduced in [11], where coplanar feed line and a parasitic slot are used to improve the matching and to control the desired mode of operation. A four-element array of circular MSAs with circular polarization (see Fig.1.) is used in FXS at 5.8 GHz [12], producing a

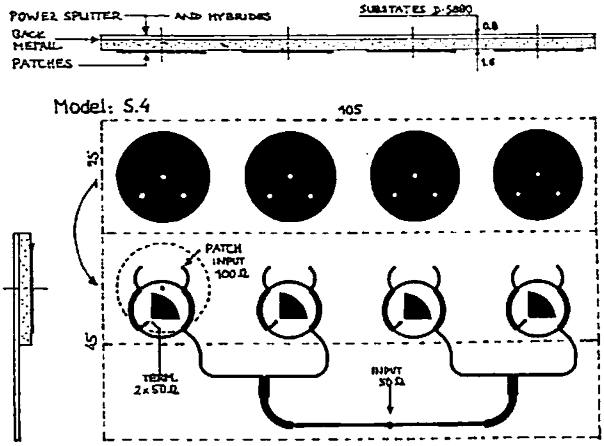

Fig.1 RHCP-array for FXS at 5.8 GHz.

shaped beam with a 3dB beamwidth of 22° and 82°. This paper describes the design considerations and experimental work performed on microstrip antennas for FXS and PDB-s which has been introduced into an electronic shelf label (ESL) project and a complex permittivity monitoring system.

## DESIGN CONSIDERATIONS AND REALIZATIONS

The basic arrangement of an electronic shelf label system for super stores is shown in Figure 2. In order to comply with FCC 15.247 (licence free operation), the FXS utilize direct sequence spread spectrum (DSSS) principle for the uplink and downlink communication with the PDB. The effective isotropic radiated power (EIRP) of the FXS is +36dBm. The PDBs, having individual codes, are interrogated (Downlink) successively by the 2.45 GHz transmitter using on-off keying (OOK) modulation.

The Schottky diode detector of the PDB demodulates the signal and transfers the data to the digital circuits of PDB. The radar cross section (RCS or σ) of the PDB is changed by 10.7 MHz, so that the incoming CW-signal will be backscattered (Uplink) and binary-phase-shift-keying (BPSK) modulated and ultimately detected by the receiver of FXS. The single diode microwave circuit of the PDB offers simplicity, low cost and small dimensions. The HF-cable of FXS is suited to IF-RF communication between FXS and the other blocks of the system (multi cell controller, Ethernet-LAN, control PC).

To estimate the received power ($P_r$), set off the radar equation, using the designation of Figure 2,

$$P_r = \frac{P_t}{(4\pi)^3 R^4}[\lambda_0^2 \sigma(\vartheta,\varphi)\, G^2(\vartheta,\varphi)\Gamma^2 M] \quad (1); \qquad R = \sqrt{x^2+y^2+(H-z)^2} \quad (2);$$

$$\varphi = tg^{-1}(y/x) \quad (3); \qquad \vartheta = tg^{-1}\left[\sqrt{x^2+y^2}/(H-z)\right] \quad (4)$$

where $P_t$ is the transmitted power, $P_r$ is the received power, $\lambda_0$ is the free-space wavelength, $\sigma(\vartheta,\varphi)$ is the radar cross section of the PDB, $G(\vartheta,\varphi)$ is the gain of Tx and Rx antennas, $\Gamma$ is the reflection coefficient of RF-diode circuit in PDB, M is the BPSK modulation rate. Calculated values of $P_r$ versus x,y,z position of the PDB are shown in Figure 3, neglecting $\vartheta$ and $\varphi$-dependence of $\sigma$.

The design criteria for FXS-antennas are:

- appropriate radiation characterics, depending on the cell-structure of the WLAN system,
- sufficiently high gain (but this is determined by the radiation patterns),
- linear or circular polarization (LP or CP), depending on the system design,
- possibility of diversity reception,
- high isolation between Tx / Rx-MSAs,
- integration with Tx/ Rx equipment, etc.

To fulfill these challenges, we have designed, realized and measured the next models (see Figure 4):

S.1 A higher gain, 2.45 GHz single element MSA on a relatively thick substrate, which is suggested to WLAN systems with hexagonal ("flower") cell structure,

S.2 Dual-element MSA, to deploy the FXS-antennas in a straight line which may simplify installation considerably

S.3 Dual-beam MSA-array (with four elements), reducing the radiation under FXS, expanding the connection in aisle direction.

S.4 Shaped-beam CP-MSA array, used in our complex permittivity monitoring system [11] at the frequency of 5.8 GHz (see Figure 1).

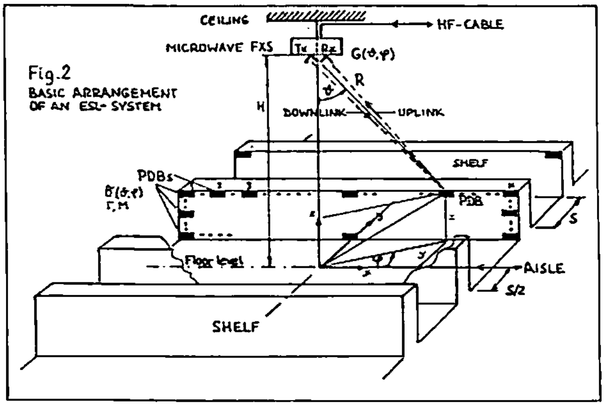
Fig.2 BASIC ARRANGEMENT OF AN ESL- SYSTEM

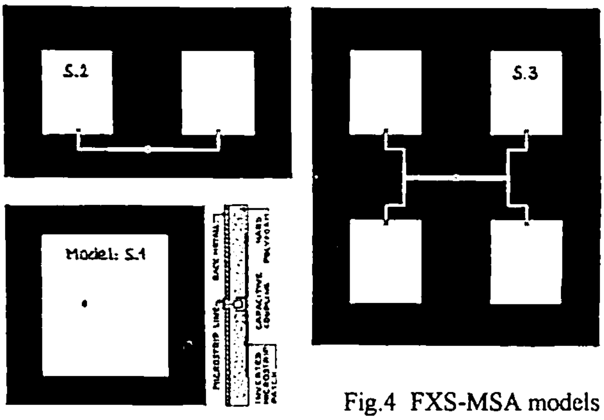

Fig.4 FXS-MSA models

The design criteria for PDB-antennas are:

- extremely small dimensions,
- polarization is the same as which was selected to FXS,
- broad-beam radiation in both main-plane,
- higher gain models at critical(shadowed) places
- many kinds of models are needed, partially compensating the variation of received signal,
- integration with Schottky-diode and its matching circuit, etc.

We have designed, realized and measured the next models (see Figure 5):

B.1 Lightened rectangular patch antenna for 2.5GHz with monolithic integration of the PDB
B.2 Printed dipole for 2.45 GHz. The Schottky diode PDB is integrated to the back side of the dipole,
B.3 Inverted F-antenna with PDB behind its back,
B.4 Slot antenna with PDB integration into the slot
B.5 Circular-patch with RHCP at 5.8 GHz (this is identical with one element of the array, shown in Figure 1), with backside integration of the PDB.

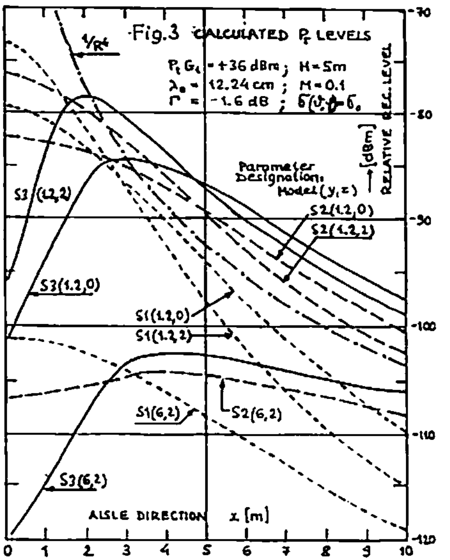
Fig.3 CALCULATED $P_r$ LEVELS

All these models were designed our self-made MSA-program. For hyperbolic impedance matching of the measured diode, we have made a special program (HYPMATCH). The power splitters of MSA-arrays and the microstrip circuit of PDBs has been designed with the aid of a microwave CAD (MMICAD, Optotek Ltd).

We have to make some comments on the selected models. To reach a relatively high gain and broadband operation, low permittivity thick substrate (e.g. hard polyfoam with a thickness of 6.4 mm at model S.1) was choosen. The inductive reactance of the coaxial fedthrough was compensated by a built-in series capacitor. The substrate material of some other models is the higher permittivity ($\varepsilon_r$ ~ 4) low cost FR-4 laminate, with the thickness of 1.4 mm. Using this substrate, the radiation pattern was broadened in the E-plane at model S.2, while the gain-specification was accomplished by the dual-element configuration. The antiphase excitation of patches in E-plane at model S.3 results the dual-beam operation. At minimal field direction (perpendicularly to the antenna sheet) the radiation level can be increased by changing the input power rate of the patches in E-plane. Low loss substrate (D-5880) was used at the higher frequency ISM band (5.8 GHz) at model S.4.

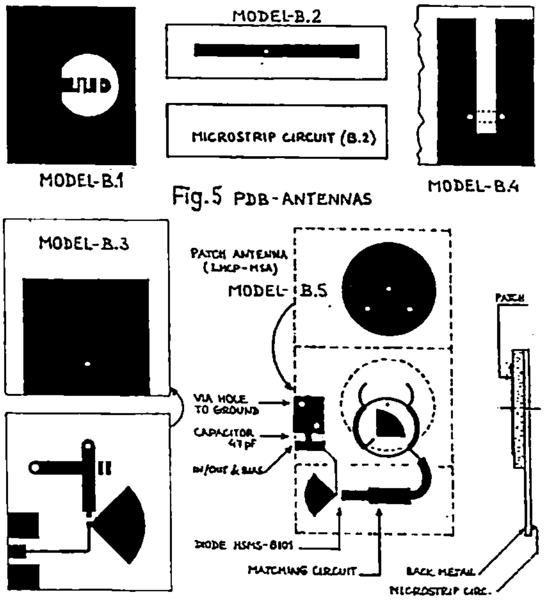
Fig.5 PDB-ANTENNAS

Table 1. Measured results of the realized microstrip antenna models.

| MSA models for FXS and PDBs, Type: | | S.1 | S.2 | S.3 | S.4 | B.1 | B.2 | B.3 | B.4 | B.5 |
|---|---|---|---|---|---|---|---|---|---|---|
| Center frequency | $f_0$ [GHz] | 2.45 | 2.45 | 2.45 | 5.80 | 2.45 | 2.45 | 2.45 | 2.45 | 5.80 |
| Gain (to isotropic) | G [dBi] | 9.0 | 6.0 | 7.5 | 12.5 | 3.5 | 0 | 3.8 | -0.6 | 6.8 |
| Monostatic radar cross section | σ [cm$^2$] | 753 | - | - | - | 60 | 12 | 68 | 9 | 49 |
| Bandwidth (RL=10 dB) | B [MHz] | 233 | 60 | 140 | 130 | 56 | 40 | 134 | 200 | 130 |
| Relative bandwidth | b=100 B/$f_0$ [%] | 9.5 | 2.5 | 5.7 | 2.2 | 2.3 | 1.6 | 5.5 | 8.2 | 2.2 |
| Beamwidth, 3 dB, E-plane | $\Theta_E$ [deg] | 64 | 122 | 2x52 | 82 | 102 | 100 | 120 | 86 | 82 |
| Beamwidth, 3 dB, H-plane | $\Theta_H$ [deg] | 68 | 65 | 56 | 22 | 83 | 119 | 82 | 130 | 82 |
| Figure of Merit | $M=10^{-4} G \Theta_E \Theta_H$ | 3.5 | 3.2 | 3.3 | 3.2 | 1.9 | 1.2 | 2.4 | 1.0 | 3.2 |
| Antenna Volume | V [cm$^3$] | 32.3 | 8.4 | 16.8 | 8.0 | 1.6 | 0.8 | 5.0 | 0.8 | 2.3 |

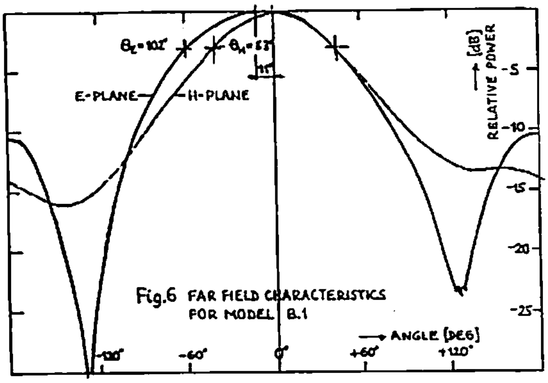

Fig.6 FAR FIELD CHARACTERISTICS FOR MODEL B.1

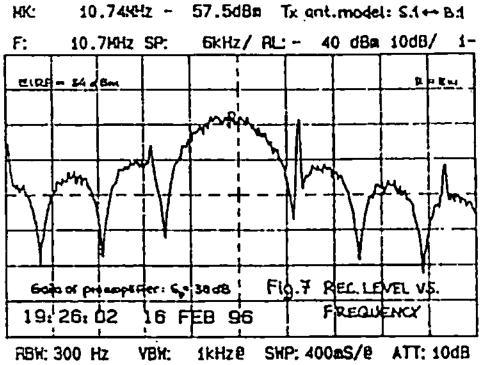

Fig.7 REC. LEVEL VS. FREQUENCY

A simple monolithic integration with PDB is realised at model B.1, where the meander-line is used as an optimal matching element of the diode. Model B.2 is the smallest one (0.8 cm$^3$). The inverted F-antenna B.3 is a more effective radiator. Slot antenna B.4 has the largest bandwidth. The circular patch B.5 with right hand circular polarization (RHCP) is useful in reflective environment.

## EXPERIMENTAL RESULTS

The measured results of the realized MSA-models are summarized in Table 1. The radiation patterns of model B.1 are shown in Figure 6, while Figure 7 shows the received and preamplified (gain: 38 dB) DSSS signal versus frequency characteristic.

## CONCLUSIONS

A variety of microstrip antennas used for WLAN systems has been introduced. For achieving a high isolation between Tx and Rx antennas, and for assuring nearly-uniform received power to consumers, the dual-beam FXS-antenna seems to be promising. The designer can select the appropriate PDB-antenna sample from the tested five. The received level of the DSSS signal was consistent with theoretical calculations using the radar equation and a simple geometrical model.

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