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A NOVEL APPROACH OF SATELLITE-TO-INDOOR CHANNEL CHARACTERISATION AND MEASURING

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Abstract *A new model for the satellite-to-indoor channel is presented, it gives account for the diffuse character of the electromagnetic field. Results of measurements having the purpose to give further data on the satellite to indoor channel are described. In the measurements the satellite was simulated by a helicopter.*

1. INTRODUCTION

Mobile satellite systems such as IRIDIUM, GLOBALSTAR, ODYSSEY and others being close to realisation foresee applications. Indoor penetration is one of the key problems in personal wireless communications. Due to extreme distances and extreme attenuation resulting from these it is not even sure that this type of service will be provided by S-PCS (Satellite Personal Communication System) operators [1]; on the other hand such service is highly desirable.

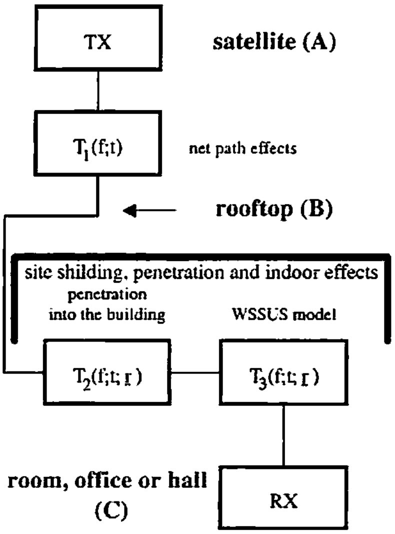

Fig. 1: A conceptual representation of satellite-indoor channel

To gain knowledge of the system requirements in such services, characterisation of the channel is of basic importance of the satellite-to-indoor channel.

2. CHANNEL MODEL

In Fig. 1 the general model of the satellite to indoor channel as introduced in [2] is repeated. In the figure downlink situation is assumed; T_i-s represent time-dependent transfer functions of three blocks of the path.

A-B, i.e. satellite to rooftop of the building; of penetration through the walls; and of the interior of the building. Note that point B is a point on the rooftop of the building, as long as the satellite is in the line of sight; if the satellite is shadowed, B is a "virtual" point close to the building top. Transfer functions of blocks 1-2-3 will be defined in the sequel.

Block No 1 represents net path effects, i.e. the loss that would be observed if the building were removed. Its transfer function can thus be written as a first order approximation.

$$T_1(f,t) = F\exp\left[j\frac{2\pi f}{c}\int_0^t V_r(t_x)dt_x\right]$$

$$T_1(f,t) = F\exp\left[j\frac{2\pi}{\lambda}\int_0^t V_r(t_x)dt_x\right]$$

(1)

Here F is square root of the reciprocal value of the NPL (net path loss),

$$F^2 = \frac{G_r}{L_p}\frac{\lambda^2}{8\pi^2 R_E^2(1-\cos\gamma)} = \frac{G_r G_t}{L_p}\frac{\lambda^2}{(4\pi D)^2}$$

$$F^2 = \frac{G_r G_t}{L_p}(FSL)$$

(2)

with $V_r(t)$ the satellite radial speed, c the speed of light, D the distance between transmitter and receiver, G_r the receive antenna gain, G_t the transmit antenna gain, R_E the Earth radius, γ the Earth central angle of the cell illuminated by the satellite, L_p the power loss due to polarisation mismatch and FSL is the free space loss.

Blocks 2 and 3 are randomly time, frequency and location variant.

It is reasonable to partition block 2 in two sub-blocks, according to Fig. 2.

Block 21 represents the long term average of the time and location variability, it is thus a slowly time (and location) variant system.

$$T_{21}(f,t,\mathrm{r}) = T_{21}(f,\mathrm{r},\varphi,\vartheta) \qquad (3)$$

in which expression time dependence is dropped and φ and ϑ are the satellite azimuth and elevation angles, respectively.

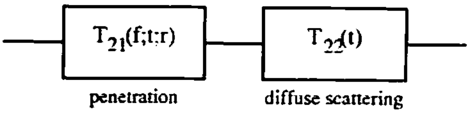

Fig. 2: Partitioning of block 2

To characterise block 22 take into account that due to the effect of the walls electromagnetic field penetrated into the building is fully or partially diffuse. This means that an additional loss can be observed in the interior: diffuse field is incident at various angles; thus for each component only the angle-of-incidence dependent antenna surface is apparent.

$$P_r = \iint\limits_{(4\pi)} A(\vartheta,\varphi)\,S(\vartheta,\varphi)\,d\Omega \qquad (4)$$

with A(ϑ,φ) the antenna surface seen from angle of incidence ϑ and φ, S(ϑ,φ) the power density arriving from these angles and Ω solid angle

$$d\Omega = \cos\vartheta\, d\vartheta\, d\varphi \qquad (5)$$

Or, the same, the received power can be expressed by the gain function $G_{rec}(\vartheta,\varphi)$

$$P_r = \frac{\lambda^2}{4\pi}\iint\limits_{(4\pi)} G_{rec}(\vartheta,\varphi)\,S(\vartheta,\varphi)\,d\Omega \qquad (6)$$

A (maybe: time dependent) loss, L_d can thus be assigned to block 22:

$$L_d = \frac{G_r S_0}{\iint\limits_{(4\pi)} G_{rec}(\vartheta,\varphi)\,S(\vartheta,\varphi)\,d\Omega} \qquad (7)$$

with S_0 the integral power density, i.e.

$$S_0 = \iint\limits_{(4\pi)} S(\vartheta,\varphi)\,d\Omega \qquad (8)$$

and, again, G_r is the maximal receiver antenna gain. (By the way: $S = P_t\, G_t / 4\pi D^2$; P_t : transmit power).

The two extreme values of L_d appear if the wave is concentrated at one direction on one hand, whence $L_d=1$; and if $S_0=S/4\pi=$ const., i.e. the field is fully diffuse on the other hand. (The term completely diffuse is used for the case in which the angle of incidence is uniformly distributed over the whole space.) In this case

$$L_d = \frac{G_r S_0}{\frac{S_0}{4\pi}\iint\limits_{(4\pi)} G_{rec}(\vartheta,\varphi)\,S(\vartheta,\varphi)\,d\Omega} = G_r \qquad (9)$$

as the integral in the denominator results in 4π, due to the conservation of energy. All this means that

$$1 \le L_d \le G_r \qquad (10)$$

Thus comparing Eqs (2) and (8-10) it can be seen that in the case of a plane wave the received power is proportional to the receive antenna gain, while the power of a received fully diffuse field is independent of the receive antenna gain. The actual magnitude of L_d has to be determined experimentally. Measurements in one office building (building V2 of Budapest Technical University) were made; results are described in Section 3.2.

For polarisation loss of Eq (2)

$$1 \le L_p \le \infty \qquad (11)$$

Of course, penetration through the building walls etc. can change the state of polarisation. Thus we can write for the received electrical field strength

$$\mathrm{E}_r = |\mathrm{E}_r|(\alpha \mathrm{e}_p + \beta \mathrm{e}_0) \qquad (12)$$

where e_p and e_0 are unit vectors representing the original polarisation state of the input field and orthogonal to it, respectively; α and ß are random variables with

$$\alpha^2 + \beta^2 = 1 \qquad (13)$$

It can be derived that the apparent polarisation loss

$$L_{pa} = \frac{L_p}{2\alpha^2 - 1 + L_p\beta^2} \qquad (14)$$

In the extreme case of fully diffuse field α=ß can be assumed, leading to a polarisation mismatch loss of 3 dB. Thus in such cases polarisation mismatch causes no loss right as antenna gain doesn't cause real gain.

Block 3 is responsible for short term random variations of the received signal. It is regarded as a WSSUS (Wide-Sense Stationary Uncorrelated Scatterers) model.

3 MEASUREMENTS ON THE SIMULATED SATELLITE-TO-INDOOR CHANNEL

3.1. Brief description of the measurement campaigns

We have performed two measurement campaigns and the third one has been being prepared.

In [2] results of the first campaign on some properties of the satellite to indoor channel were presented. The purpose of those measurements was to gain information about some general characteristics such as dependence on satellite elevation, on the number of floors above, on time variation etc. The second measurement, described in this paper had more specific objectives i.e. to get an idea on two characteristics: i. the dependence on the distance from the window and ii. the degree of diffuseness of the field.

The third campaign will be performed in March, 1996. It is devoted to wide band characterisation of the simulated satellite-to-indoor channel.

3.2 Narrow-band measurements (the first and the second campaigns)

Both narrow band measurement campaigns were performed between the helicopter and building V2 of BTU. The path of the helicopter approximated circles around the building at elevation of about 60° . Helicopter position vs. time was recorded in a computer, applying a GPS equipment.

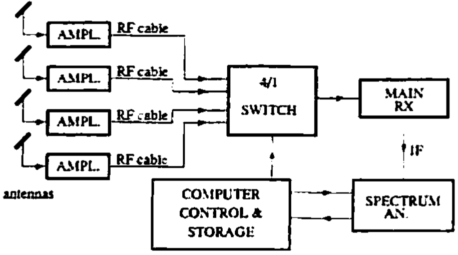

Fig. 3: L-band receiver system

Measurements were made at L band, 1620 MHz. The unmodulated crystal-controlled transmitter of power of about 2 W was placed on board the helicopter. Transmit antenna was a microstrip patch, designed for circular polarisation.

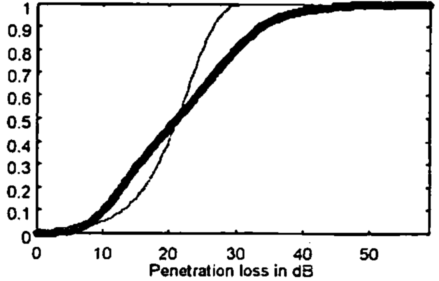

Fig. 4. cdf for overall data of the first campaign

In the receiver four L-band signals, received by antennas of different design were measured quasi simultaneously. Block schematic of the L-band receiver system is shown in Fig. 3.

In the first campaign the empirical commulative distribution functions of the penetration loss was determined. Here just one of them is repeated (Fig. 4), where the thick line (made of individual dots) is the actual measured results - the empirical cdf -, and the solid line is the theoretical Rayleigh pdf.

In the second campaign computer controlled receiver was placed in a hall of the sixth floor of the seven-story building (Lab. 603).

As already mentioned the main purpose of this campaign was to gain information about dependence of the field strength on the distance from the windows and also to get information on how much the field is diffuse. Not very much surprisingly it turned out the two questions are closely related to each other.

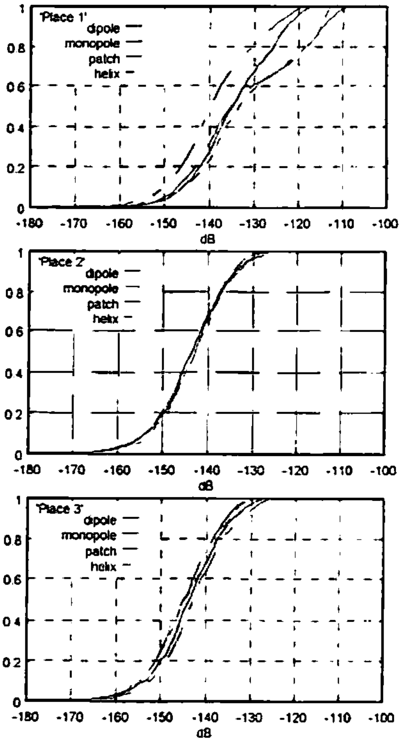

Fig. 5. Distribution of signals

Three points were measured: the first quite close to the window; the second about the centre of the hall - being at a distance of about 3 meters from the window; and the third close to the wall opposite to the window, about 6 meters from it. Four antennas of different gains and different polarisation characteristics were used: a three-turn helix of sense of revolution identical to the transmitter; the gain of the helix was about 6 dB higher than that of the patch; a microstrip patch, identical to the transmit antenna; a horizontally polarised dipole antenna; a vertically polarised monopole antenna.

Diagrams of the commulative distribution functions of the received signals at the window

(Place 1), in the middle of the room (Place 2) and by the wall (Place 3) are shown in Fig. 5.

The data given these diagrams show that the sensitivity with regard to antenna gain and polarisation matching is important near the window, but far from it (say at a few metres) gain and polarisation does not matter at all. At the window the field is much stronger than inside of rooms; but the dependence on the distance inside the room is almost negligible.

This surprising properties can be explained by supposing that field is strongly diffuse in the building far from windows. Near the window polarisation matched antennas (helix and patch in our case) can have considerable gain.

3.3. Wide-band measurements

Our sounder is essentially based on the classical Cox's set-up but we are going to make some modifications to improve its flexibility.

Fig. 6. and Fig 7. show quite simplified block diagrams of our sounder system.

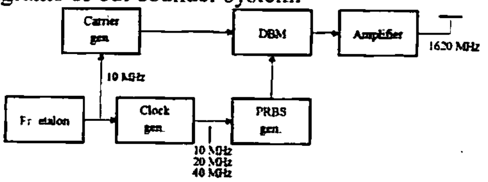

Fig. 6: The transmitter of the sounder

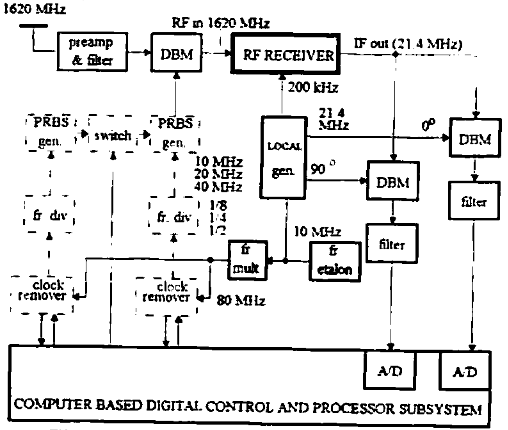

Fig. 7 The receiver of the sounder.

The functions implemented by XILINX module are shown with dotted border.

In our set-up clock pulse remove circuits are applied to perform the appropriate phase control. They operate at 80 MHz, therefore the minimum available time shift is 12.5 ns.

The IF signal is processed in the IQ processor formed by two DBMs (Double Balanced Mixers), filters, ADs and particular parts of the digital subsystem. The DBMs are driven by a quadrature pair of IF signals generated by the local IF generator.

The delay profile shown in Fig. 8 was measured in our laboratory to test the sounder and its software.

The channel was simulated by an attenuator and a piece of coaxial cable of 16m connected parallel to cause a reflection at delay of 160ns.

4. CONCLUSIONS

Results of measurements having the purpose to give further data on the satellite to indoor channel are given. The parameters of main concern were: the sensitivity with regard to antenna gain and of polarisation matching; the dependence on the distance from the windows.

Results have shown that in the building under investigation the received field close to the window is of quite different characteristic than at the interior of the building. In the former case both polarisation matching and antenna gain shows usual properties; in the latter case field seems to be strongly diffuse.

Although a few antenna-types can be considered as candidates for possible use in hand-held S-PCS transceivers (circularly polarised microstrip patch antennas, short axial-mode helixes and quadrifilar helixes) in diffuse wave field all of them supply the same receiving power, the received power does not depend on neither its gain nor its orientation, even its polarisation does not matter.

REFERENCES

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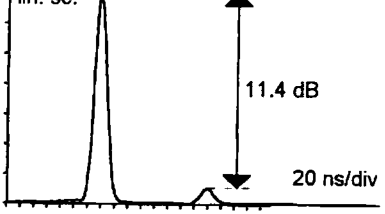

Fig. 8: Delay profile in a laboratory test