Influence of Polarization on
30 GHz Broadband Radio Channels

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Abstract

"Radio in the Local Loop" for ATM transmission is expected to become economically important if transmission channels prove to be sufficiently well behaved. Using a PRBS channel sounder we have measured channel impulse responses at 29.940 GHz with a 5 ns temporal resolution for distances up to 3.8 km. We have further investigated the influence of polarization on fading and delay spread. Results obtained so far suggest "Radio in the Local Loop" should support ATM transmission over distances of a few hundred meters, but fading caused by multipath propagation may cause severe problems at larger distances along streets with heavy traffic load.

Motivation

"Radio in the Local Loop" is eagerly expected because it will enable new operators to compete against subscriber line owners in deregulated telecommunication markets, and generally will slash last km, inner city, and subscriber premises cabling cost. Bandwidth for 155.52 Mb/s ATM transmission or higher is available only above 20 GHz. On the other hand it is desirable to operate below 40 GHz for minimum path attenuation and remote terminal equipment cost. While appropriate electronics is clearly feasible this potentially widespread, economically important service critically depends on the prevalence of acceptable channel properties.

Cost per subscriber is influenced by a number of issues: Movements of cars make impulse responses time-variant and may mandate adaptive equalizers. If pronounced zeros appear in the channel frequency response OFDM rather than simple TDM must be adopted. The longer the permitted transmission distances are, the higher is the central office sharing factor.

A few broadband channels have been assessed [1]-[6]. Doppler spectra have been investigated both at lower frequencies and quasi-statically for an indoor channel [7], [8]. Recently, a first indoor Doppler measurement has been reported for 60 GHz channels [9]. For other applications (indoor 60 GHz, short-range 5.8 GHz), investigations concerning polarization have been made by simulation [10] and measurement [11]. However, there are no conclusive results concerning above-mentioned issues.

We have recently measured a number of impulse responses and Doppler spectra of broadband channels [12], [13], but only for vertical polarization in all cases. Here we present impulse responses and fading observed for different polarizations.

Channel sounder

Correlation of pseudo-random (PRBS) or similar bit sequences is routinely used for channel sounding [3]-[5]. Signal sampling and subsequent correlation via FFT is practical only at moderate data rates and updating rates [7]-[9], [14]. For high data rates, PRBS in TX and RX are generally clocked at slightly different frequencies [4], [5]. Here only 1/M parts of the signal are exploited if a length 2^{N-1} PRBS is transmitted. This impairs measurement quality because again PRBS length must be short, SNR is low, and/or impulse responses are obtained at a low updating rate.

We have therefore realized a dedicated 800Mb/s PRBS channel sounder (Fig. 1) [12], [13]. The pattern generators are freely programmable. In the RX subsequent PRBS periods are given different starting positions. This allows to sweep over the interesting part of the impulse response without losing time in the long remainder of the period. TX and RX clock frequencies are identical. In order to speed up measurement further a number of correlators (presently 2× 4) process the received signal simultaneously but again with different pattern delays. If one I&Q correlator is plugged in for every τ -sampling point there is – independent of PRBS length – no intrinsic SNR or measurement speed disadvantage compared to FFT correlation.

PRBS with guard bands and a carrier are transmitted alternately. TX frequency and TX clock rate are phase-locked, and so are recovered IF carrier, LO frequency, and RX (= correlation) clock frequency.

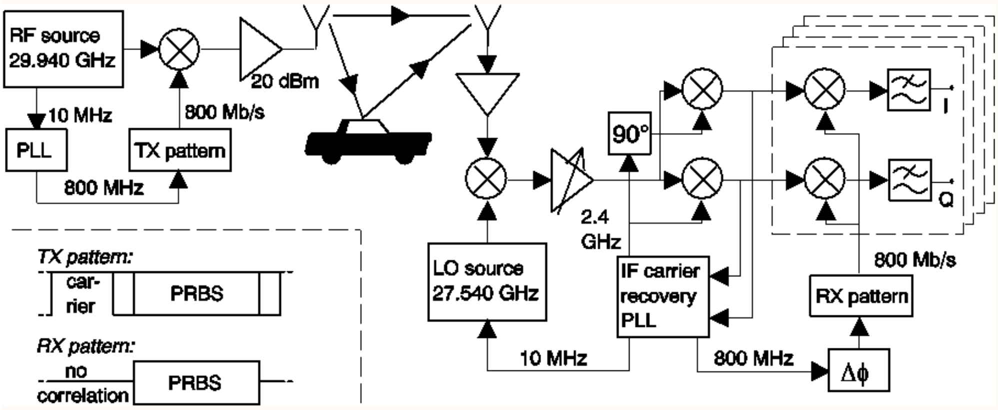

Fig. 1: Channel sounder block diagram (but actual data rates are chosen lower, limited by available permission); *inset:* TX and RX bit patterns

The IF carrier recovery exploits the time-multiplexed residual carrier. This enables RX signal acquisition without need for ultra-stable reference frequency sources. In contrast, nonlinear carrier recovery techniques (Costas loop, decision-directed loop) would deliver insufficient SNR at low RX signal power levels. Mixer/demodulator output offsets, also detrimental at low power levels, are compensated via lock-in techniques (not shown).

A combined phase and frequency detector in the IF carrier recovery PLL is able to memorize a number of 2π periods. Noise bandwidth of the residual carrier recovery PLL in the receiver can therefore be switched down to 5 Hz or lower, in order to allow channel sounding also at substantial distances. Likewise, channel or source phase noise is not being peaked by the IF carrier recovery PLL, even at low power levels. This feature will be particularly useful at higher TX frequencies where high frequency multiplication factors increase the phase noise delivered by the microwave sources.

Prior to measurement the main peak of the impulse response must be moved into the delay measurement window. This is accomplished by a digitally controlled endless clock phase shifter. Compared to the alternative of reprogramming the PRBS generator in the RX this procedure is faster and offers a finer temporal resolution.

Table 1: Technical data of channel sounding experiments

	Doppler mode [12]	High-resolution mode [13]	Fading mode
Bit rate; τ -resolution	100 Mb/s; 10 ns	200 Mb/s; ≤ 5 ns	200 Mb/s; 5 ns
τ -sampling period	10 ns	1.25 ns	N/A
PRBS length	1023	2047	2047
Detectable, though aliased, Doppler bandwidth	~ 25 kHz		
Modulation	2-PSK		
TX frequency	29.940 GHz		
TX power	20 dBm		
TX antenna	sector horn, 13 dB gain, mounting height 3 ... 25 m		
transmission distances	120 m ... 3.8 km		
RX antenna	horn, 24 dB gain, mounting height 2.7 ... 5,2 m		
RX noise figure	8 ... 9 dB		
IF	2.4 GHz		
Correlators	4 each for I & Q	1 each for I & Q	
Impulse response length investigated (τ)	200 ns	160 ns	N/A
Updating period (t), alias-free Doppler bandwidth	204.8 us 2.5 kHz	5.12 ms 200 Hz	41 us ... 10 ms 12 kHz
Number of sampling points (t)	512	128	8192
Measurement time (t)	105 ms	655 ms	320 ms .. 80 s

Measurements

We have investigated channels at various locations of different types:

- 10 straight streets bordered by buildings in different densities, with variable traffic conditions and distances ranging from 120 m to 3.8 km
- Residential areas fed from a base station with 25 m antenna height
- Several non-LOS scenarios

The three operation modes of the channel sounder have been used to characterize these channels:

'Doppler mode'

Here a fast updating rate provides alias-free detection of 2.5 kHz Doppler shifts. Since one sampling point takes only ~ 20 μ s the detected, though aliased, Doppler bandwidth is ~ 25 kHz, and this holds also for the '*high-resolution mode*' and '*fading mode*'.

Secondary paths affected by Doppler shift occur most likely in streets with medium or heavy traffic. We have therefore performed >100 Doppler measurements in four such scenarios. Doppler frequency shifts were observed to be rare, and did not contribute significantly to the total received power. The strongest Doppler path was ~ 40 dB weaker than the LOS path. 75 % of all measurements did not show any Doppler components above -65 dB below the LOS path. More data and time-resolved Doppler spectra have been presented in [12].

'High-resolution mode'

This mode with 1.25 ns impulse response sampling time allows to view impulse response details. Several hundred impulse responses have been measured. In three locations, where relatively strong postcursors were observed, we have investigated the influence of polarization on delay spread. Transmitter and receiver were placed at distances of 120 m (streets D and E) or 200 m (street F) along a street with two to four story buildings closely lined up on both sides. Traffic density was low. Postcursors were probably caused by reflections between buildings or, in street D, between parts of an irregularly shaped building (inset Fig. 2, top).

Fig. 2, top shows an exemplary impulse response obtained with diagonal polarization at street D. Two secondary paths can be distinguished at relative delays of 3.5 ns and 15 ns.

For all combinations of six different polarizations and five receiver mounting positions spaced by successive 1.5 m laps along the street the impulse responses have been measured. Mean delay spread is given in Table 2. In this particular scenario horizontal polarization minimizes delay spread whereas vertical polarization is least desirable.

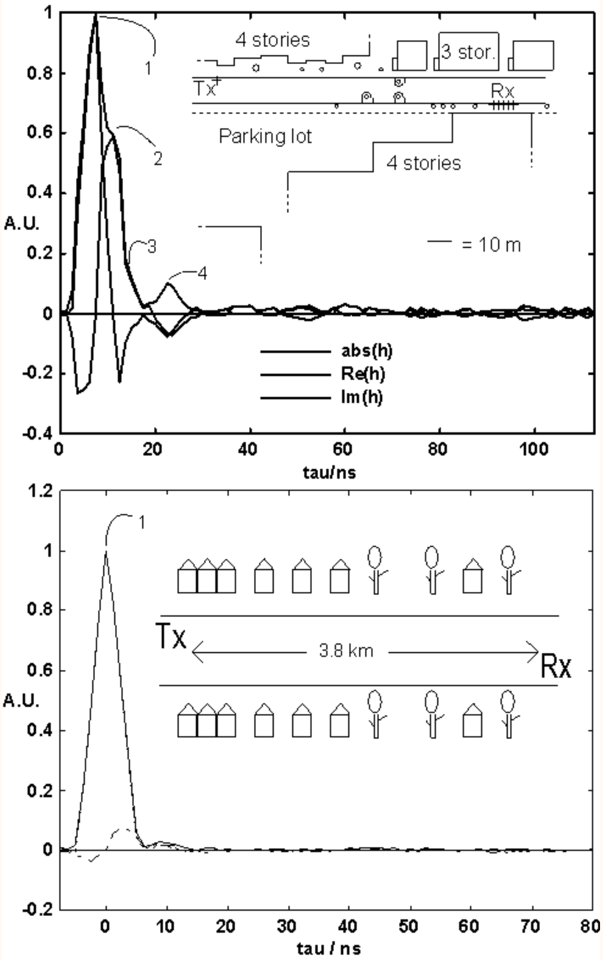

Fig. 2: Exemplary impulse responses

Top: Diagonal polarization in a street D with irregular shaped buildings.

Bottom: Vertical polarization in street A with heavy trafic load over a distance of 3.8 km

Table 2: Mean delay spread observed in street D (5 receiver mounting positions), street E (5) and street F (3) for different polarizations.

Polarization	mean(σ τ) street D	mean(σ τ) street E	mean(σ τ) street F
	3.5 ns	1.1 ns	1.3 ns
	0.4 ns	0.7 ns	1.0 ns
	2.0 ns	1.0 ns	0.9 ns
	0.7 ns	0.9 ns	1.0 ns
	1.9 ns	1.3 ns	---
	1.8 ns	0.9 ns	---

In streets E and F the different mounting positions were chosen at fixed distances from the transmitter, but at varying distances to the houses on either side of the streets. Impulse responses obtained at a particular receiver mounting position in street E (on the same side of the street as the transmitter) using four different polarizations are shown in the top and middle part of Fig. 3 in logarithmic scale. The limited dynamic range of the measurements is indicated by hatched areas. In this case again received power is highest and delay spread lowest for horizontal polarization, but at other mounting positions other polarizations were better. The mean values are also given in Table 2.

The only difference between the measurements shown in the bottom and middle left plots is a transversal movement of the receiver antenna by ~ 5 cm. The effect is a 5 dB reduced LOS signal power and three additional paths that can be distinguished. Note that, although the nominal resolution of a 200 Mb/s measurement is 5 ns, five paths can be distinguished within the first 20 ns of the impulse response.

Just to give an impression, the two bottom plots show the same data in linear (real part, imaginary part and magnitude) and in logarithmic scale.

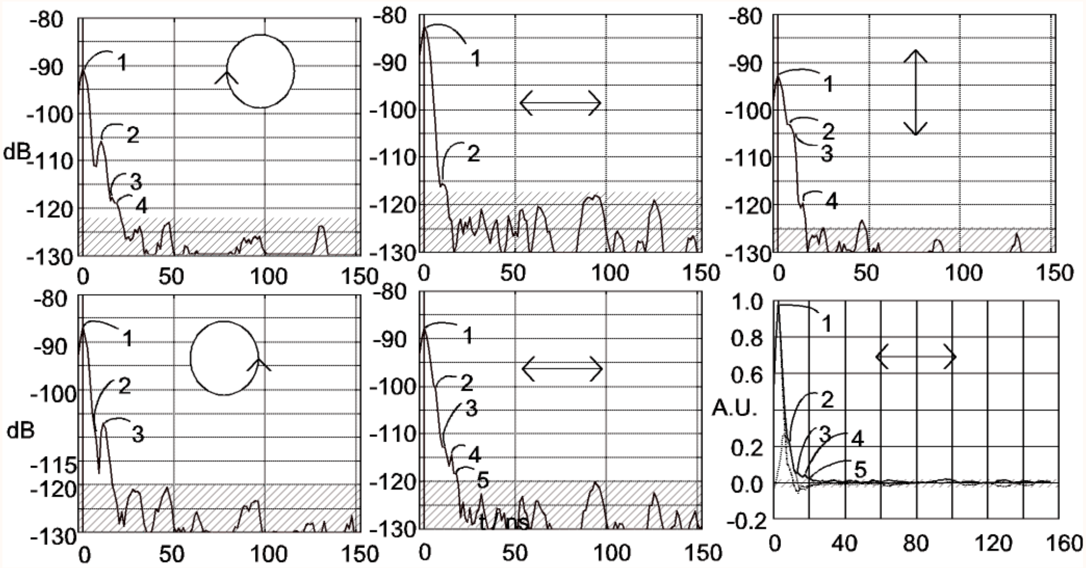

Fig. 3: Impulse responses measurements obtained in street E (120 m, buildings on both sides, low traffic density). Levels where measurement is less accurate are hatched. The top four measurements differ only with respect to polarization. Shifting the receiver antenna mounting position transversally by only 5 cm changes the impulse response substantially, as can be seen in the left bottom plot (bottom right: same data as left, but plotted with linear scale).

From the data of Table 2 it cannot be firmly concluded which polarization minimizes intersymbol interference (ISI) or delay spread in general, although in all three cases horizontal polarization is a relatively good choice. A remarkable first result is that for all polarizations in all streets mounting positions could be found where no significant postcursors were detectable. In long streets with heavy traffic load, but few buildings, like street A (Fig. 2, bottom), usually no postcursors can be detected when measuring at 200 Mb/s.

'Fading mode'

It offers the highest updating rate and measures only the complex amplitude of the LOS path. As expected, channels along streets with heavy traffic over large distances proved to be most critical concerning fading. Two possible reasons are destructive interference of multiple paths and, at low antenna height, also partial obstruction of the first Fresnel ellipsoid.

Fig. 3 presents different fading measurements along two streets (A and B) with heavy and one street (C) with medium traffic load. Distances were 2 km (street A), 350 m (street B) and 500 m (street C). Spaces between buildings were very small in streets B and C, and relatively large in street A. For different polarizations, four to nine 82 s long runs with 10 ms sampling periods have been recorded in all three streets.

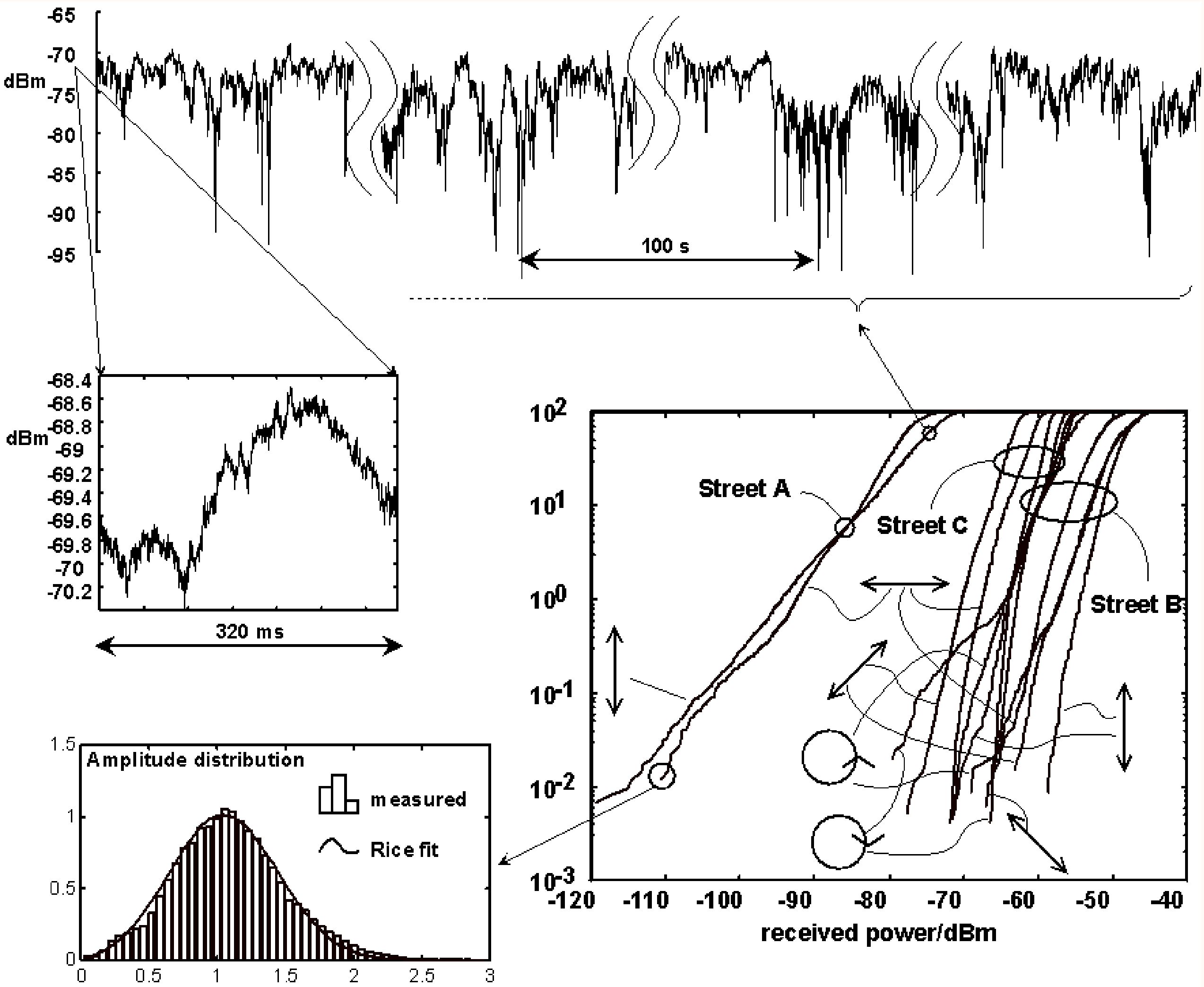

Fig. 3: Fading measurement results

Bottom right: Cumulative received power distribution. Value on ordinate equals percentage of time during which received power was lower than value on abscissa.

Bottom left: Amplitude distribution for horizontal polarization at street A compared to a Rice distribution.

Top: Received power versus time for vertical polarization in street A. Four runs over 82 s at 10 ms sampling period, 1 run over 320 ms at 41 μ s sampling period. Deep fades ($\geq$ 20 dB) have been observed.

Received LOS power versus time for four runs in street A, using vertical polarization, are shown in Fig. 3, top. Deep and short fades down to -20 dB below the average power level, and long-lasting fades (several seconds) down to -12 dB can be observed.

A fast fading measurement is shown in the left part of Fig. 3. Observation time was 320 ms at a sampling period of 41 μ s. Power variation within such short intervals was always less than 5 dB, typically 1 to 3 dB.

Cumulative LOS power distributions for different polarizations in all three streets are shown in the bottom right part of Fig. 3. The ordinate value equals the percentage of time during which the received power was lower than the abscissa value. Even if transmitted power were 10 to 20 dB higher than the 20 dBm actually used, and if receiver noise figure could be as low as 2 dB, the channel outage probability at 3.8 km distance in street A, for antenna heights of ~ 6 m (Tx and ~ 5 m (Rx) would still be in the order of 10%. This situation requires a protocol allowing for retransmission of lost packets. However, increased antenna mounting height or some kind of diversity may contribute to reduce fading in such scenarios.

For different channels average received power and typical fade depth depend strongly on polarization. In streets B and C, the powers available during 99% of the time differ by 10 and 8 dB, respectively. But there is no polarization that causes most or least fading in all cases.

In the bottom left part of Fig. 3 the amplitude distribution for the fading measurements with horizontal polarization in street A is compared to a Rice distribution. Since the fit is very good, multipath propagation affected by moving cars is believed to be the origin rather than partial obstruction of the first Fresnel zone.

Conclusions

We have measured time-variant outdoor channel impulse responses at 29.940 GHz with temporal resolution of $\leq$ 5 ns at eleven locations for distances up to 3.8 km. At six locations the influence of polarization has been investigated. Results obtained so far suggest that postcursors and Doppler shifts of secondary paths are less critical than might have been expected. However, over long distances fading due to multipath propagation with relative delays < 5 ns may cause serious problems. For a given channel, different polarizations show very different performance concerning delay spread and fading, but there is no polarization that works best in all cases. The clear advantage of circular polarization reported for other applications in [10] and [11] has not been observed in typical ‘Radio in the Loop’ scenarios examined so far.

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References

[1] Løvnes, G., Reis, J.J., Rækken, R.H.: ‘Channel Sounding Measurements at 59 GHz in City Streets’, *Wireless Networks – Catching the Mobile Future – 5th IEEE International Symposium on Personal, Indoor and Mobile Communications (PIMRC ´94), and ICCC Regional Meeting on Wireless Computer Networks (WCN)*, 1994, pp. 496-500

[2] Antonsen, E., Løvnes, G., Reis, J.J., Rækken, R.H.: ‘59 GHz Wideband Propagation Measurements’, *Telenor R&D Report*, Kjeller, Norway, 1994

[3] Violette, E.J., Espeland, R.H., DeBolt, R.O., Schwering, F.: ‘Millimeter Wave Propagation at Street Level in an Urban Environment’, *IEEE Transactions on Geoscience and Remote Sensing*, 1988, **26**, (3), pp. 368-380

[4] Mohamed, S.A., Løvnes, G., Antonsen, E., Rækken, R.H., Nigeon, B., Reis, J.J.: ‘Mobile Broadband System’, *CEC Deliverable R2067/BTL/2.2.2/DS/P/035.a1* , RACE project R2067 - MBS

[5] Wales, S.W., Richard, D.C.: ‘Wideband Propagation Measurements of Short Range Millimetric Radio Channels’, *Electronics & Communication Engineering Journal*, 1993, **5**, (4), pp. 249-254

[6] Truffer, P.: ‘Wideband Channel Sounder with Optical Antenna Feeding’, *MMMCOM*,, Dresden, May 12-13, 1997, pp. 80-83

[7] Kadel, G., Czylwik, A., Droste, H.: ‘Kanal- und Systemaspekte für mobile Breitband-Funksysteme’, *ITG-Fachbericht 141, "Auf dem Weg zur modernen Informationsinfrastruktur"*, 18.-19. Feb. 1997, Stuttgart, Germany, pp. 229-234

[8] Hermann, S., Martin, U., Reng, R. Schuessler, H.W., Schwarz, K.: ’High Resolution Channel Measurement for Mobile Radio’, *Signal Processing V: Theory and Applications*, (Torres, L., Masgrau, E., Lagunas, M.A. (eds.), Elsevier Science Publishers B.V., 1990), pp.1903-1906

[9] Droste, H.: ‘Influence of man-made shadowig on the properties of 60 GHz wideband indoor radio channels’, *MMMCOM* , Dresden, May 12-13, 1997, pp. 65-74

[10] Pfeiffer, G., Schrei, A.: ‘Investigations on Propagation characteristics of a short range radio link with statistical distributed reflectors’, *Proceedings of IEEE 44th Vehicular Technology Conference*, Stockholm, 1994, **3**, pp. 1728-1732

[11] Manabe, T., Taira, K., Sato, K. Ihara, T. Kasashima, Y. Yamaki, K.: ‘Multipath measurement at 60 GHz for indoor wireless communication systems’, *Proceedings of IEEE 44th Vehicular Technology Conference*, Stockholm, 1994, **3**, pp. 905-908

[12] Karthaus, U., Noé, R., ´Channel Sounding for Radio in the Local Loop: Impulse Responses and Doppler Spectra’, *MMMCOM*, Dresden, May 12-13, 1997, pp. 84-88

[13] Karthaus, U., Noé, R., ´High resolution channel impulse response measurements for radio in the local loop’, *ACTS Mobile Communications Summit*, Aalborg, Oct. 7-10, 1997, pp. 241-245

[14] Felhauer, T., Baier, P.W., König, W., Mohr, W., ‘Ein optimiertes System zur breitbandigen Vermessung des Mobilfunkkanals’, *Kleinheubacher Berichte*, U.R.S.I. and ITG meeting, Telekom, 1992, **36**, pp. 411-422