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Site-specific wideband indoor channel modelling using ray-tracing software

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Indexing terms: Ray tracing, Indoor radio

Ray tracing (RT) software has been used to develop a site-specific autoregressive (AR) model for an indoor radio channel. A comparison is carried out between this model and that derived from the channel measurements. To enhance the congruence between the two models, an interpolation technique is applied to the RT raw data. It is concluded that a two-pole AR model can be derived from the RT software instead of the channel measurements. Results obtained from RT software avoid expensive and time consuming measurement process.

Introduction: The indoor wireless systems are expected to be deployed on a large scale in the near future. Site-specific propagation characterisation will then be important for deployment planning and performance evaluation using software tools. Many wideband statistical models have been proposed for characterising the indoor radio channels in the time- and frequency-domains [1]. These models are derived from the extensive propagation data for wide variety of buildings. Time-domain models represent the time response as a tapped delay line. The values and statistics of the model coefficients are derived from the measured time response of the channel profiles [1]. Frequency-domain models represent the frequency response as a site-specific autoregressive (AR) system driven by white noise [2]. The locations and statistics of poles of the model are derived from the frequency response of the channel. The method for finding the poles of an AR model, given a channel profile of a radio channel, is presented in [1] where it is shown that an indoor channel could be modelled by up to 5 poles. Furthermore, results in [2] concluded that it is sufficient to use the two most significant poles only, thus, the number of coefficients required is less than for the time-domain models. Therefore, it is easier to implement this model in block oriented software. The AR model is further extended in [4] to include the Doppler spectrum to the AR model.

Statistical models, in general, are simple and computationally efficient and therefore commonly used in computer simulation. However, they lack accuracy since they are not based on the specifics of the place where the deployment is intended. A good example of non-site-specific models is the JTC model [4]. To improve the statistical models, we suggest deriving them from site-specific propagation information, therefore, we call them site-specific statistical models. There are two main methods to attain the site-specific propagation information. The first is by carrying out numerous measurements for the time or frequency response of the site in question [1]. This is the most accurate method for characterising the channel, but it is very costly and time consuming. The second method is to use simulation software developed for calculating the radio channel profiles, such as the ray tracing (RT) software. The accuracy of the RT method has been examined and found satisfactory when compared with the actual measurement [3]. The advantage of RT over measurements is that the results are obtained faster and more economically [1].

In this Letter, we find the equivalent AR poles for the channel profiles generated by RT, and compare them with the poles derived from the measurements. The criterion of comparison will be the statistics of the location of the two most significant poles. It is also shown that irregular interpolation of the raw RT channel profiles improves the agreement of the AR poles found from the measurements and the RT data.

Channel profiles and AR models: Two sets of channel profiles are collected: one set is from the actual measurements, and the other is generated by RT software. The RT software used in this research has been developed at the Centre of Wireless Information Studies (CWINS)-WPI [5]. It is based on the ray-shooting technique used to generate channel profiles for given transmitter/receiver locations. Throughout our research, we maintained the following parameters in both cases:
(i) the centre frequency of the channel is 1GHz, with a bandwidth of 200MHz
(ii) the number of profiles is 620, taken from different locations on the second floor of the AK Labs building.
The channel profiles can be expressed by

$$h(t) = \sum_{i=1}^{N} \beta_i \delta(t - \tau_i) e^{j\phi_i} \qquad (1)$$

$h(\tau_i) = \beta_i$, τ_i, and ϕ_i, are the magnitude, path time delay, and phase of the ith path, respectively. Using eqn. 1, samples of the frequency correlation function of the channel frequency response are obtained from:

$$R(k) = \sum_{i=1}^{N} |h(\tau_i)|^2 e^{j2\pi k \frac{\tau_i}{T}} \qquad (2)$$

Substituting $R(k)$ in the Yule-Walker equation, the coefficients of the AR model are determined [1, 2, 4]. These coefficients are related to the location of the poles of the process with the following equation:

$$\frac{1}{1 - \sum_{i=1}^{p} a_i z^{-i}} = \prod_{i=1}^{p} \frac{1}{(1 - p_i z^{-1})} \qquad (3)$$

a_i and p_i, for $i = 1, 2, ..., 5$ are the coefficients and the poles of the AR model, respectively.

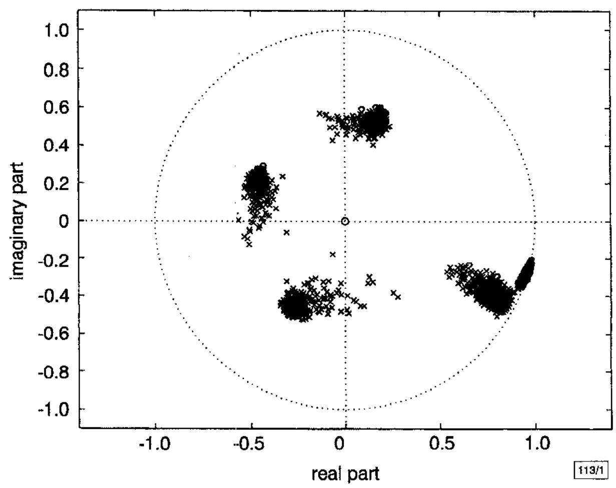

Fig. 1 *Complex z-plane scatter plot for measurements AR model*

Pre-processing of the results of RT: As we will see in the following Section, direct use of the result from RT in eqn. 2 does not provide a satisfactory result, hence we need to pre-process the RT profiles. There are two reasons for performing a pre-processing step on the RT data prior to evaluation of eqn. 2. First, the profiles obtained from RT are generally a group of irregularly delayed impulses; i.e. $\tau_i \neq i \cdot \Delta t$. Second, the measurement profiles are band-limited, in contrast to the RT profiles. Hence, we need a method for estimating regularly delayed profiles from the original results of RT. This can be achieved by irregular signal interpolation, which is based on the following general equation:

$$h(\tau_i) = \sum_{n=0}^{N-1} h(nT_s) \mathrm{sinc}(\tau_i - nT_s) \qquad \text{for } i = 1, 2, ..., M \qquad (4)$$

Where, $\mathrm{sinc}(t)$ (= $\sin(t)/t$) is the sinc function, $h(nT_s)$ are the regular samples, and $h(\tau_i)$ are the irregular samples. To attain a bandwidth of 200 MHz for the regular samples, T_s must be 5ns. Furthermore, N and M are related such that $NT_s \leq \tau_M$.

The solution of eqn. 4 involves inversion of an ill-conditioned matrix, $[\text{sinc}(\tau_i - nT_s)]$, which can be solved by using the adaptive weight conjugate gradient [5].

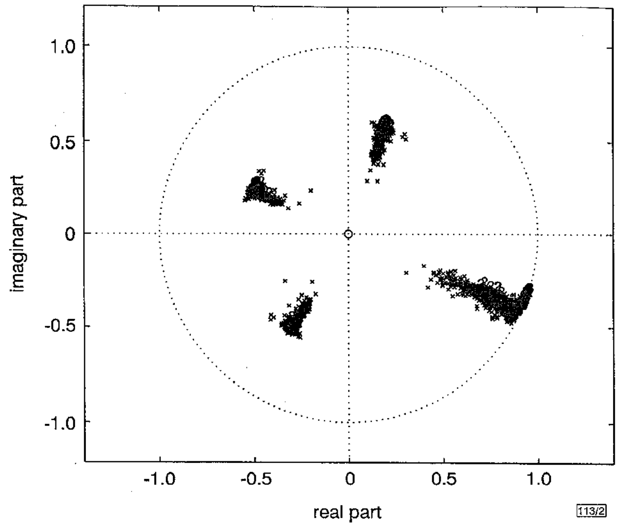

Fig. 2 *Complex z-plane scatter plot for RT AR model*

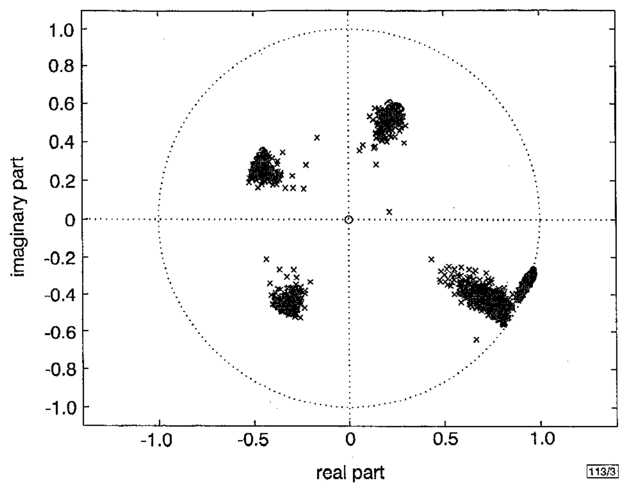

Fig. 3 *Complex z-plane scatter plot for RT AR model, after regular sampling interpolation*

Table 1: Statistics of two-pole AR models for the three cases

	Measurements	RT	RT with interpolation
Mean ($\|p2\|$) Std ($\|p2\|$)	0.86 0.074	0.816 0.12	0.845 0.09
Mean (angle($p2$)) Std (angle(p2))	–27 2.44	–24.77 2.03	–30.88 2.55
Mean ($\|p1\|$) Std ($\|p1\|$)	0.986 0.0057	0.988 0.0057	0.989 0.0069
Mean (angle (p1)) Std (angle(p1))	–18.5 1.41	–17.94 1.67	–21.17 1.567

All angles in degrees

Results and discussion: For each channel profile we find the poles of the equivalent AR model using the method described in the preceeding Section. This is carried out for both sets of 620 profiles from both measurements and RT to generate the fifth-order AR models. Figs. 1 and 2 show the z-plane scatter plots of poles for the AR models, as derived from measurements and RT, respectively. It is apparent that the two plots are similar, except for the second significant poles, for which the RT values of magnitude and angle are less than those obtained by measurement. To reduce this discrepancy, regularly sampled profiles need to be estimated from the original irregular RT profiles. Then, we estimate the corresponding AR models from regular profiles. Fig. 3 shows the result of this method. It is clear that we have a significant enhancement, especially for the second significant pole. Table 1 shows the key statistical parameters of the three cases.

Conclusion: We have presented the derivation of an AR model from RT channel profiles for the wideband indoor channel simulation. For comparison, scatter plots for the poles showed significant agreement between the two cases. To improve this agreement further, an interpolation technique is used to obtain regularly sampled profiles from the RT data. A two-pole AR model is also shown to be sufficient for representing an indoor channel.

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60 Gbit/s regenerating demultiplexer in SiGe bipolar technology

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Indexing terms: Silicon-germanium, Demultiplexing equipment

A 1:2 demultiplexer is presented which operates at up to 60 Gbit/s. This data rate is a record value for all ICs in any technology and has so far only been achieved by a time-division multiplexer recently presented by the authors [1]. The IC, which was fabricated in an SiGe bipolar technology and mounted on a simple measuring socket, is also well suited for retiming data streams, e.g. in the receiver of future fibre optic transmission systems.

Demultiplexers (DEMUX) are key components in communication systems and measuring equipments. In addition to the intrinsic demultiplexer function, the excellent retiming capability combined with a high input sensitivity predestinates a DEMUX as a decision circuit in the receiver of very-high-speed fibre optic transmission systems, especially if the operating speed of a single master-slave D-flipflop (MS-D-FF) is no longer sufficient [2, 3]. The highest operating speed achieved so far by DEMUXs in any IC technology is 46 Gbit/s and has been reported by the authors in [4].

In this Letter, the measuring results of a *mounted* DEMUX at an input data rate of 60 Gbit/s are presented. The speed improvement compared to [4] is mainly obtained by using a SiGe HBT technology [5] instead of a homojunction bipolar technology, but