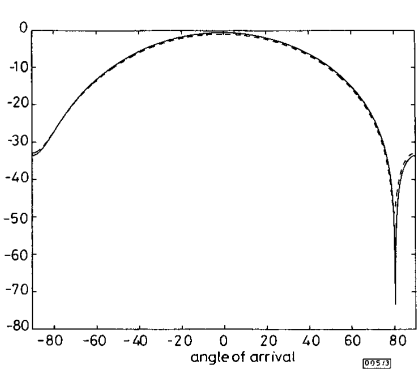

Fig. 3 *Beam pattern response*

---- full-band beamformer
——— modified and original QMF-MSAB

full-band in terms of convergence speed and cancellation quality. This confirms that the reduction of the number of adaptive processors achieved by the new structure does not result in any degradation in the performance of QMF-MSAB.

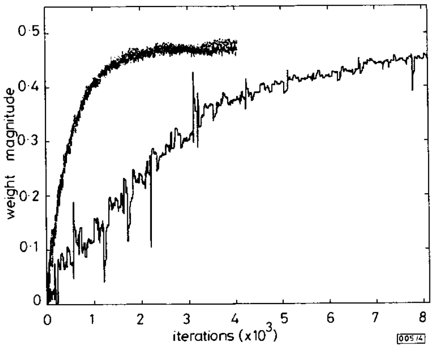

Fig. 4 *Convergence properties*

——— full-band beamformer
---- lower sub-band modified and original QMF-MSAB
········ upper sub-band modified and original QMF-MSAB

Conclusions: In this Letter, a modified QMF-based multirate sub-band adaptive beamforming technique (QMF-MSAB) has been presented. The new technique offers considerable reduction in hardware requirements while at the same time maintaining the superiority of the multirate/sub-band approach over full-band beamforming.

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References

1 KHALAB, J., and IBRAHIM, M.: 'Novel multirate adaptive beamforming techniques', *Electron. Lett.*, 1994, **30**, (15), pp. 1194–1195 (erratum **30**(23), p. 1993)
2 JOHNSTON, J.: 'A filter family designed for use in quadrature mirror filter banks'. Proc. ICASSP, April 1980, pp. 291–294
3 WIDROW, B., and STEARNS, S.: 'Adaptive signal processing' (Prentice-Hall, NJ, USA, 1985)

Frequency domain model for standard simulation of wideband radio propagation for personal communications

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Indexing terms: Mobile radio systems, Telecommunications

Recently, the Joint Technical Committee (JTC) has proposed a time domain model for simulation of the statistical wideband characteristics of the indoor and outdoor radio propagations for personal communication applications. The Letter presents a method to find an equivalent AR model for the channels characterised by the JTC. Since the AR model requires fewer parameters to represent the channel, it is easier to implement with custom blocks available in standard signal processing software packages. To compare the results of simulation from the JTC and the AR model, the cumulative probability distribution function (CDF) of the RMS delay τ_{rms} is used.

Introduction: For computer aided design and evaluation of wireless communication systems, a statistical model for the simulation of the wideband characteristics of the radio channel is necessary. There are two basic models to simulate the multipath characteristics of the radio channel: time domain models [1] and frequency domain models [2]. Time domain models assume that the channel impulse response is in the form of a time-varying discrete trasversal filter, whereas frequency domain models are based on reproducing the frequency response of the channel that is realised by an autoregressive AR process. It has been shown that the efficient reproduction of the channel frequency response can be achieved with an AR model using only a few poles [2]. The frequency domain AR model has fewer parameters tha the time domain model and it is easier to be implemented in block oriented software.

In this Letter we show a method to find a surrogate model to channels proposed by the Joint Technical Committee (JTC) that has adopted the time domain approach. τ_{RMS} is taken as the parameter to verify that both AR and JTC models are equivalent. This is justified by the fact that τ_{RMS} is the parameter which decides the bit rate of the channel.

JTC and AR models: The JTC has developed a model for simulation of radio propagation in indoor and outdoor environments used for personal communication applications. The goal of the JTC is to provide a practical radio propagation model used in radio link simulations [3]. This model assumes that the channel is wide-sense stationary uncorrelated scattering (WSSUS) and it is characterised by a profile represented by a wideband tapped delay line (TDL). Different classes of indoor and outdoor environments are represented by separate profiles. Each profile is described by a table providing the delay between the taps, average tap power and the spectrum of the tap gain variations. In this way the multipath spread and the Doppler spectrum of the signal is shaped for different environments.

This Letter shows how to find an equivalent AR model for a given JTC profile such that both models have an equivalent CDF of τ_{RMS}. The channel profile can also be described in the frequency domain by using an AR model [1]. The frequency response is interpreted as the output of an AR process. The poles of the AR process are obtained by solving the Yule-Walker equation for the channel frequency response. To develop the model, we first determine the location of the poles for each measurement and then we find the statistics of the location of the poles over a set of measurements. To simulate the frequency response of the channel in one location, we generate the poles according to the measured statistics and we drive a AR process using these poles with a WGN. The output of the AR process is interpreted as the reproduction of the frequency response of the channel [1].

In this Letter we show the possibility of finding poles and their statistics of an AR model from a JTC profile. This way the channel can be simulated with the statistics of the location of the poles using the AR model rather than a table describing delay and the statistics of the arrival of the paths.

Method for mapping: To find the equivalent AR model for a given JTC profile we need to map the table describing a JTC profile in the time domain to the location of the poles of the AR model in the frequency domain. The JTC table provides samples of the delay power profile $|h(\tau_i)|^2$ at certain τ_i in the time domain. Therefore, the samples of the frequency correlation function of the channel frequency response are given by

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

The Yule-Walker equation [1] can be set up according to the expected order of the AR model as follows [4]:

$$\begin{bmatrix} R(0) & R(1) & \cdots & R(M-1) \\ R(-1) & R(0) & \cdots & R(M-2) \\ \vdots & & & \vdots \\ R(1-M) & R(2-M) & \cdots & R(0) \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_M \end{bmatrix} = \begin{bmatrix} R(1) \\ R(2) \\ \vdots \\ R(M) \end{bmatrix} \quad M \leq 5 \qquad (2)$$

where the a_is are the coefficients of the AR process. These coefficients are related to the location of the poles of the process by the following equation:

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

where p_i, $i = 1, 2, \ldots, p$ are the poles of the process. Using eqns. 1–3 we can map the JTC table in the time domain to the location of the poles of the AR process in the frequency domain.

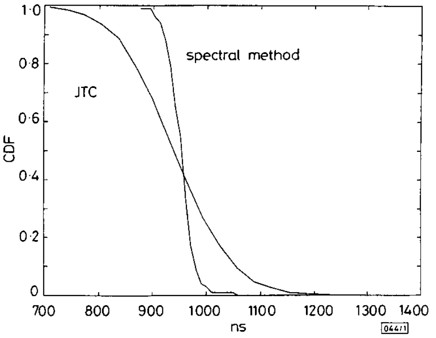

Fig. 1 *Outdoor urban-channel-B and residential-channel-C low antenna delay RMS using JTC and AR models*

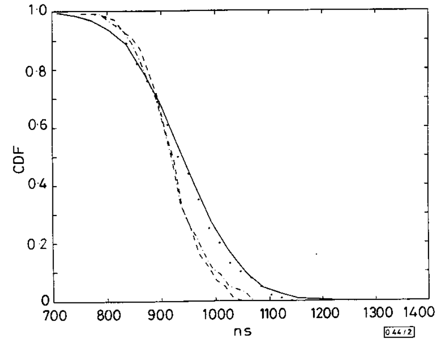

Fig. 2 *Delay RMS of JTC model against AR model with third pole Gaussian random variable*

——— JTC
- - - - STD 0.05
-·-·-· STD 0.07
·········· STD 0.1

Result and discussion: Outdoor urban-channel-B and indoor residential-channel-C, with low antenna [3] is taken an example to illustrate the method explained in the preceding Section. If we solve eqns. 1–3 we obtain the following poles for a third order model:

$$p_1 = 0.9239 + j0.0156,\ p_2 = 0.2885 + j0.5787 \text{ and}$$
$$p_3 = -0.4293 - j0.4259$$

Fig. 2 shows the CDF of the delay RMS generated for the AR model and the JTC model. It is obvious that the case suffers concavity mismatching. This problem can be solved by adding a small complex Gaussian random variable to the poles [1]. Fig. 2 shows the results for various standard deviations (STD) of 0.05, 0.07 and 0.1 to pole p_3. Obviously, when $STD = 0.1$, it gives the closest fit to the JTC model. To achieve a desired Doppler spectrum, as defined in the JTC model, we must shape the spectrum of the complex Gaussian noise that drives the AR process by a shaping filter. This filter has the desired Doppler spectrum by adjusting the gain for each channel impulse response. Fig. 3 depicts the complete system that can be equivalent to the JTC model.

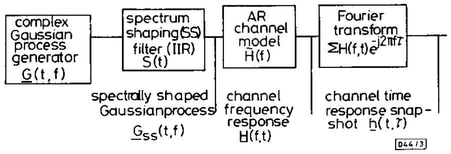

Fig. 3 *Autoregressive (AR) frequency domain model*

Conclusion: It was shown that it is possible to find an equivalent AR frequency domain model from a JTC time domain model. The CDF of the τ_{RMS} was taken as the criterion to examine the closeness of the results of simulations obtained from the AR and the JTC models. It was found that at least three poles for the AR model are necessary to closely fit the results of simulations. However, the tails of the CDFs of the AR model diverge from the results of simulation using the JTC model. This problem has been solved by introducing a Gaussian randomness to one of the poles of the AR model.

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References

1 HOWARD, S., and PAHLAVAN, K.: 'Autoregressive modeling of wideband indoor radio propagation', *IEEE Trans.*, 1992, **COM-40**, (9), pp. 1540–1552

2 GANISH, R., and PAHLAVAN, K.: 'Statistic of short time and spatial variations in wideband indoor radio channels', *IEE Proc. H*, 1993, **140**, pp.

3 Joint Technical Committee of Committee T1 R1p1.4 and TIA R46.3.3/TR 45.4.4 on Wireless Access: Draft Final Report of RF Channel Characterization, Paper No. JTC (AIR) / 94.01.17-238r4, 17 January 1994

4 HAYKIN, S.: 'Adaptive filter theory' (Prentice-Hall, Englewood Cliffs, NJ, 1991, 2nd Edn.)