A.1 Complex Amplitude Derivation

For each path, the complex amplitude $\Gamma_{pmn}^{(P_r)}$ can be derived from the dielectric properties of the front and interior walls and the corresponding angles of incidence and refraction. A path $P_r$ consists of two partial paths, $P'_r$ and $P''_r$, describing the propagation from the transceiver to the target and from the target back to the transceiver, respectively. Therefore, the complex amplitude associated with the total path equals the product of the complex amplitudes of the two partial paths, each consisting of one transmission coefficient associated with the front wall and one reflection coefficient, resulting in [Bal89]

$$\Gamma_{pmn}^{(P_r)} = \Gamma_{pmn}^{(P'_r)} \Gamma_{pmn}^{(P''_r)} = \gamma^{(P'_r)} \Lambda^{(P'_r)} \gamma^{(P''_r)} \Lambda^{(P''_r)}.$$

The following equations hold for vertical polarization. Similar expressions can be found for the horizontally polarized case. The reflection coefficient $\Lambda^{(\cdot)}$, associated with a particular partial path, is given by [Bal89]

$$\Lambda^{(\cdot)} = \begin{cases} \frac{\cos \theta_{\cdot,pmn}^{(1)} - \sqrt{\varepsilon_r} \cos \theta_{\cdot,pmn}^{(1)}}{\cos \theta_{\cdot,pmn}^{(1)} + \sqrt{\varepsilon_r} \cos \theta_{\cdot,pmn}^{(1)}}, & \text{for multipath via interior wall} \\ 1, & \text{otherwise.} \end{cases}$$

Further, $\gamma^{(\cdot)}$ is the total transmission coefficient for a wave traveling through the front wall. The refraction on the first and second interface, respectively, and $b$ reverberations within the wall are considered [Bal89]

$$\gamma^{(\cdot)} = \frac{2 \cos \theta_{\cdot,pmn}^{(1)}}{\cos \theta_{\cdot,pmn}^{(1)} + \sqrt{\varepsilon_r} \cos \theta_{\cdot,pmn}^{(1)}} \times \frac{2 \sqrt{\varepsilon_r} \cos \theta_{\cdot,pmn}^{(1)}}{\cos \theta_{\cdot,pmn}^{(1)} + \sqrt{\varepsilon_r} \cos \theta_{\cdot,pmn}^{(1)}} \times \left( \frac{-\cos \theta_{\cdot,pmn}^{(1)} + \sqrt{\varepsilon_r} \cos \theta_{\cdot,pmn}^{(1)}}{\cos \theta_{\cdot,pmn}^{(1)} + \sqrt{\varepsilon_r} \cos \theta_{\cdot,pmn}^{(1)}} \right)^2 b.$$

In all of the above equations, $\theta_{\cdot,pmn}^{(1)}$ and $\theta_{\cdot,pmn}^{(1)}$ are the incident (in air) and refracted (in the medium) angles of the wave and $\varepsilon_r$ is the relative permittivity of the interior wall. In the case of wall ringing multipath $b$ is larger than zero, otherwise it is zero. A more detailed derivation of the path loss coefficients can be found in [SAA11].
A.2 Justification of the Invariance of Complex Amplitude Across the Array

In the derivation of the multipath exploitation scheme, the complex path weights are assumed invariant across the array elements and, therefore, can be replaced by a common weight. This approximation generally holds for far-field conditions, where all angles are approximately equal across all target/array element pairs. The approximation also holds to a certain extent for the near-field case. To demonstrate this property, the error for monostatic near-field imaging is examined. The array length is chosen as 1.5 m and the imaged region is within a 4 m by 5 m room, whose center is at 4.5 m down-range. For the whole image grid, the individual path loss coefficients associated with a propagation path $P_r$ are calculated according to (A.1). Subsequently, the relative errors are calculated for every target, path and array element. The relative error is defined as

$$\xi(P_r)_{pmn} = \left| \frac{\Gamma(P_r)^p - \Gamma(P_r)_{pmn}}{\Gamma(P_r)_{pmn}} \right|, \quad (A.3)$$

where $m=0, \ldots, M-1$, $n=0, \ldots, N-1$, $p=0, \ldots, P-1$, $r=0, \ldots, R-1$. The common amplitude factors $\Gamma_{p}^{(P_r)}$ are chosen as the mean,

$$\Gamma_{p}^{(P_r)} = \frac{1}{MN} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} \Gamma_{pmn}^{(P_r)}, \quad p=0, \ldots, P-1, \, r=0, \ldots, R-1. \quad (A.4)$$

A relative error threshold of 10% is assumed acceptable. The ratio of relative errors meeting this criterion is calculated, i.e., $\#\{\xi(P_r)_{pmn} < 0.1, m=0, \ldots, M-1, n=0, \ldots, N-1, p=0, \ldots, P-1\} / (MNP)$.

For the multipath associated with the back wall and the back right corner, the error of using $\Gamma_{p}^{(P_r)}$ instead of $\Gamma_{pmn}^{(P_r)}$ is sufficiently low for all cases. Hence, no significant errors are experienced when using the above assumption. However, the approximation is less accurate when considering the multipath via the left side wall. For these paths, due to the higher variation in incident and reflection angles, only 90% of the approximation errors stay below the threshold. This approximation error is still comparably low and will probably not affect the performance of the multipath exploitation scheme in near-field scenarios. Note that the reflection coefficients are purely real for perfect dielectric slabs. This alleviates the problem further, as the beamformer is less susceptible to amplitude errors as compared to phase errors.

References


Curriculum Vitae

Name: Michael Leigsnering
Address: Woogsstr. 26, 64367 Mühlthal
Date of birth: 18.07.1984
Place of birth: Karlsruhe
Family status: married

Education

10/2005–11/2010 Technische Universität Darmstadt, Germany
Dipl.-Ing. Electrical Engineering and Information Tech.
08/2008–05/2009 Nanyang Technological University, Singapore
Integrated exchange program
05/2009 Eichendor-Gymnasium (College), Ettlingen, Germany
High school degree (Abitur)

Work Experience

12/2010–04/2015 Research associate
Signal Processing Group
Technische Universität Darmstadt, Germany
03/2014–05/2014 Visiting researcher
03/2013–06/2013 Radar Imaging Lab, Center for Advanced Communication,
03/2012–05/2012 Villanova University, Villanova, PA, USA
Visual and Audio Signal Processing Lab, ICT Research Institute, University of Wollongong, Wollongong, NSW, Australia
06/2009–09/2009 Internship
Robert Bosch GmbH, Stuttgart-Feuerbach, Germany
Erklärung laut §9 der Promotionsordnung