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Hrsg.: Prof. Dr.-Ing. Gerhard Fischerauer, Prof. Dr.-Ing. Ralf Moos

Iurii Motroniuk

Non-Destructive Material Parameter Determination Based on Microwave Communication Systems

Band 25

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Non-Destructive Material Parameter Determination Based on Microwave Communication Systems

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M. Sc. Iurii Motroniuk

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Editorial

The state of many electrochemical systems such as automotive catalysts or diesel particulate filters (DPF) can be inferred from the spatial distribution of electric material parameters. The direct measurement of such distributions, based on the interaction between microwaves and the electrochemical system, has been described quite thoroughly in the literature by now, but these results are based on equipment such as vector network analyzers (VNA) which cannot be used as field devices (e. g., in a vehicle) for cost and size reasons.

The present work investigates whether the method could be implemented on the basis of available communication systems. To this end, the catalyst is placed in the propagation path of a communication link, or rather the propagation path is confined to the interior of the catalyst housing. It is experimentally demonstrated that stochastic communication channel parameters such as the bit and packet error ratios, the signal-to-noise ratio, and the center of gravity of the transmit signal pulse mirror the material parameters in the propagation path.

In the course of the work, a UWB (ultra wideband) system was used by way of an example to investigate the fundamental practicability of the approach and to determine the influence of system parameter settings such as Tx power and data rate on measurement system characteristics such as uncertainty and measurement time. The test objects used in the studies were DPFs with different soot loads and discs of known material composition (PTFE, PE, PC, POM).

The investigations indicate that a proper choice of system settings is crucial for the measurement to produce useful results. Data rates on the order of 100 to 1000 kbit/s and Tx powers neither too small nor too large allow one to measure bit or packet error ratios with a relative uncertainty on the order of 1 % within measurement times on the order of 1 s. Higher data rates enable faster measurements.

The results corroborate the proposition that the monitoring of electrochemical systems in the field can be based on potentially inexpensive microwave communication systems.

Bayreuth, August 2018

Prof. Dr.-Ing. Gerhard Fischerauer, Prof. Dr.-Ing. Ralf Moos

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Contents

List of Abbreviations

ABS	Acrylonitrile-butadiene-styrene
AWGN	Additive white Gaussian noise
A-D	Analog-to-digital
BER	Bit error ratio
BPSK	Binary phase shift keying
DPF	Diesel particulate filter
FPGA	Field-programmable gate array
GUM	Guide to the Expression of Uncertainty in Measurement
MTBE	Mean time between bit errors
NDE	Non-destructive evaluation
PAN	Personal area network
PC	Polycarbonate
pdf	Probability density function
PE	Polyethylene
PER	Packet error ratio
POM	Polyoxymethylene
PTFE	Polytetrafluoroethylene
Rx	Receive
SCR	Selective catalytic reduction
TWC	Three-way catalytic converter
Tx	Transmit
UWB	Ultra-wideband
VNA	Vector network analyzer
WLAN	Wireless local area network
1G	1-st generation mobile networks
3D	Three-dimensional

5G	5-th generation mobile networks

List of Symbols

b_{0k}	one realization of the random function “received bit sequence with empty DPF”
B_0	received bit sequence with empty DPF
c	soot content
$\bar{c}$	estimate of the expected cross-correlation function.
c_{ij}	convolution of the time responses
C_{ij}	convolution of the frequency responses
c_k	normalized cross-correlation
D	biggest antenna dimension
$e(t)$	envelope of the time-domain response
E_b	energy per bit
E_s	energy per symbol
f	frequency
f_c	center frequency
f_c	carrier frequency
g	digital bit stream
g'	restored digital signal on the receiver side
g_{0k}	one realization of the random function “UWB time response with empty DPF”
g_{1k}	one realization of the random function “UWB time response with loaded DPF”,
G_0	UWB time response with empty DPF
G_1	UWB time response with loaded DPF
h_{0k}	realization of the random function of frequency “UWB frequency response with empty DPF”
h_{1k}	realization of the random function of frequency “UWB frequency response with loaded DPF”
H_0	UWB frequency response with empty DPF
H_1	UWB frequency response with loaded DPF
l	packet length
$n(t)$	random noise
N_0	noise power spectral density
p	relative frequency of bit errors
P	probability function
P_{Tx}	transmit power

$\hat{p}$	estimate of the bit error ratio
$r(t)$	received analog signal
R	distance from an antenna
$s(t)$	analog signal
$s_{\mathrm{b}}(t)$	signal baseband representation
$s_{\mathrm{p}}(t)$	bandpass waveform of a BPSK signal
S_{ij}	scattering matrix parameters
S_{11}	reflection coefficient
S_{12}	transmission coefficient
t	time
T_s	symbol duration
$u(t)$	signal time response
$\hat{u}(t)$	Hilbert transform of the signal time response
W	bandwidth
X	random variable
ε_{r}	relative permittivity
λ	wavelength
Δt	sampling interval
Φ_{ij}	cross-correlation
Φ_{ii}	autocorrelation

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