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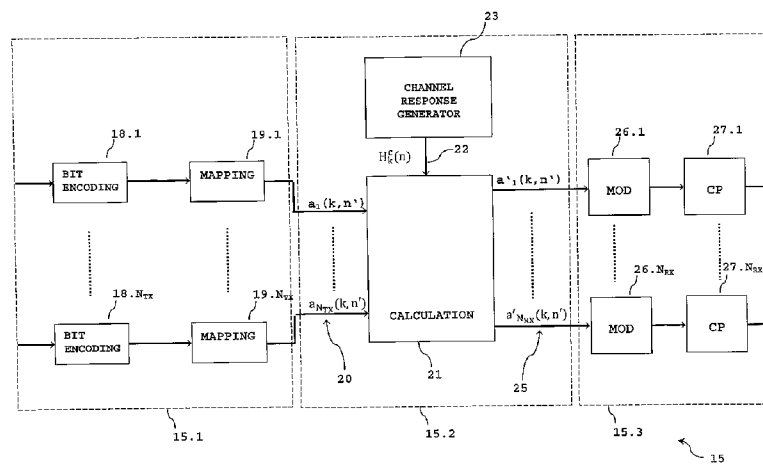
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- (54) Title: SIGNAL GENERATING DEVICE WITH INTEGRATED FADING GENERATING UNIT AND SIGNAL GENERATING METHOD

Fig. 4



- (57) Abstract: The invention relates to a signal generating device for generating a signal including simulated channel fading characteristics. The signal generating device comprises a fading simulating unit, a signal generating unit and a modulating unit. The signal generating unit generates a first number of symbols according to a number of transmitting means for a simulated transmission to a device under test. The fading simulating unit calculates from the first number of symbols a second number of faded symbols, wherein a number of signals to be output corresponds to a number of receiving means of the device under test, based on a set of filter parameters, and provides the calculated second number of faded symbols to the modulating means; and the modulating unit generates modulated signals to be output from the second number of faded symbols.

Signal generating device with integrated fading generating unit and signal generating method

5 The invention relates to a signal generating device for generating a signal including simulated channel fading characteristics. In particular the invention refers to a device and a method for generating a signal for testing of devices of a wireless transmission system that may be
10 characterised by multiple carriers and multiple input and output antennas, the testing taking fading characteristics of a wireless channel into account.

In order to meet an ever increasing demand for data
15 services in cellular mobile applications, wireless communication standards characterised by high spectral efficiency and making use of a spatial dimension in transmitting information between base stations and mobile terminals are defined and the requirement for testing the
20 performance characteristics of devices operable under such standards increases.

Orthogonal frequency division multiplexing (OFDM) is one of the spectrally efficient transmission schemes, being
25 employed for example in wireless communication under the standards long term evolution (LTE) for a fourth generation cellular wireless system or some of the IEEE 802.11 series for wireless local area networks (WLAN).

30 Encoded bit streams to be transmitted are divided into plural data streams with reduced bit rate, the bit information is mapped onto constellation symbols for transmission. Then each partial data stream is modulated onto a carrier signal, wherein the carrier frequencies are

orthogonal to each other, the modulated carrier signals comprising the constellation symbols of said partial data streams are added to form a transmission signal and converted to a transmission frequency.

5

An improvement in transmission efficiency is further achieved by employing multiple antennas both at base stations and wireless devices, thereby defining multiple input multiple output systems (MIMO). An encoded bit
10 stream for transmission may be distributed onto different antennas of the transmitting device as sources and transmitted on the same frequency to a receiving device as destination. Hence multiple different transmission paths, either direct paths or indirect paths including reflected
15 transmission signals reduce losses being inflicted due to superposition of signals received via multiple signal path propagation. Hence increased data rates at an advantageous receive signal quality are achieved by employing MIMO techniques.

20

Testing of devices for multicarrier systems and even more when also testing of MIMO capabilities is concerned, requires dedicated test equipment for reproducible tests under realistic test conditions. The external influences
25 on signal transmission in a real world communication system between a base station as an example for a signal source and the device under test (DUT) are simulated by a signal generator and a channel simulator. In known test systems the channel simulator modifies the test signal
30 generated by a signal generator in the time domain according to given channel characteristics and provides the modified signal to the DUT. The computational requirements for executing the required calculations in

the channel simulator are large particularly when taking multicarrier systems into account.

DE 10 2008 055 759 A1 proposes to integrate a channel
5 simulator unit into a test device for testing a mobile communication terminal. The channel simulation is implemented by distorting one or more of the modulated carrier signals by employing a static and frequency selective channel model in the frequency domain. Time
10 variant effects on the transmission signal are excluded by the test device of DE 10 2008 055 759 A1 and in particular examination of fading effects on test signals are therefore not sufficiently addressed in the cited reference.

15 Accordingly, the object of the present invention is to provide a signal generator for generating faded test signals to a device under test with reduced complexity and reduced computational effort requiring advantageously
20 reduced implementation effort.

The object is solved by the inventive signal generating device according to claim 1 and the corresponding signal generating method. The dependent claims contain further
25 developments.

A signal generating device according to the invention comprises an integrated fading simulation unit. The signal generator comprises a signal generating unit configured to
30 generate a first number of symbols according to a number of transmitting means for a simulated transmission to a device under test for example antennas of a base station. In the signal generating unit the encoded bits are mapped to constellation symbols to generate the first number of

symbols. The fading simulation unit is configured to calculate from the first number of symbols a second number of faded symbols based on a set of filter parameters, wherein the second number corresponds to a number of test
5 output ports, each test output port being connectable to a receiving means of the DUT. The receiving means of the DUT are for example receiving antennas of the DUT. The set of filter parameters may be elements of a matrix comprising filter parameters. The fading simulation unit then
10 provides the calculated second number of faded symbols to the modulating means of the signal generating device. The modulating means is configured to generate modulated signals from the faded symbols provided by the channel simulating means.

15 The inventive signal generating device solves the technical problem by integrating the channel simulating means into the signal generator, by simulating the wireless channel by modifying the first number of symbols, the first number of symbols corresponding to the number of
20 simulated transmitting means or transmit antennas and to subsequently modulate the second number of faded symbols in a modulating means after channel simulation. Accordingly a reduction in computational requirements is achieved, as the modulation means is required to modulate
25 the number of symbols only for a number of receive means or antennas, as typically the number of receive antennas , e.g. of a mobile phone, may be smaller than the number of transmit antennas, e.g. of a base station, in MIMO systems. The requirements, e.g. with respect to data rates
30 on an internal data bus in the channel simulator and the signal generator device, are also reduced when compared to an external channel simulator. The inventive signal generation with integrated fading simulation nevertheless provides a time variant consideration of multipath

propagation effects in a multicarrier communication system although providing advantages in complexity and costs over the state of the art.

- 5 Preferably the signal generating device takes into account, that a transmission channel is defined between each of the transmitting means of a signal source and each of the receiving means of a real system to be simulated. The number of transmission channels taken into
- 10 consideration for channel simulation is then given by the product of the first number of transmitting means and the second number of receiving means. The transmitting means or the receiving means may be simulated transmit antennas or receive antennas of the DUT according to an applicable
- 15 communication standard.

- Preferably the fading simulator unit comprises a transform parameter generating means configured to generate a set of channel response parameters from a set of channel impulse
- 20 responses each characterising a particular transmission channel and a calculation means configured to calculate the second number of faded symbols from the first number of symbols using the set of channel response parameters. The channel response parameters are in one embodiment
- 25 dynamic channel response parameters taking account of time variant properties of the simulated transmission channel.

- Advantageously the transform parameter generating means of the fading simulator unit comprises plural sample
- 30 generating means configured to generate filtered complex samples by filtering independent and identically distributed complex samples. The independent and identically distributed complex samples are generated by plural (pseudo-) random number generators. A distribution

means of the fading simulator unit is advantageously configured to rearrange the filtered complex samples to generate a sample sequence for each transmission channel. Each sample in the sample sequences is multiplied with a value. A multiplying means is configured to multiply then the one or more transmission channel sample sequences with a correlation matrix to generate the set of channel impulse responses. A transforming means of the fading simulator unit is configured to calculate the set of channel response parameters by transforming the set of channel impulse responses into the frequency domain.

According to an embodiment of the signal generating device of the invention, the transforming means is configured to transform the set of channel impulse responses into the frequency domain based on a predetermined frequency spacing.

The transform parameter generating means according to an embodiment comprises a transform means configured to transform the set of channel impulse responses into the frequency domain for a subset of the used subcarrier frequencies as the predetermined frequencies only. The subset of subcarrier frequencies accordingly comprises a reduced number of the plurality of subcarrier frequencies; and the channel response parameters for the subcarrier frequencies of the plurality of subcarrier frequencies not included in the subset may be determined by interpolation. Hence the set of channel response parameters may be even more efficiently determined for sake of a further reduction in computational effort.

Preferably the signal generating device is characterised by the correlation matrix including parameters describing

the characteristics of each single transmission channel and/or interactions or correlations between the transmission channels.

- 5 The transform parameter generating means advantageously comprises filter means configured to filter the complex samples in order to define an autocorrelation function and further also Doppler characteristics of the filtered complex samples.

10

In an embodiment a distribution means is provided and configured to generate sample data streams for each transmission channel by arranging a third number of filtered complex samples in a number of filtered complex data sequences corresponding to the first number times the second number.

15

The method may be implemented in a computer program with program-code means for executing the method steps. The method may be implemented in form of a computer program-product with program-code means stored on a machine-readable medium for executing the necessary steps.

20

The inventive method can also be implemented on a signal processor or even in hardware, for example in a field programmable gate array (FPGA).

25

The inventive method can also be implemented in a combination of hardware and software components.

30

An exemplary embodiment of the invention is now further explained with respect to the drawings as a non-limiting example, wherein

- Fig. 1 shows a state of the art fader in the time domain;
- Fig. 2 shows a measurement setup using a signal generator and a fader according to prior art;
- Fig. 3 shows a signal generating device with an integrated fading simulator according to an embodiment of the invention as a block diagram in a measurement setup;
- Fig. 4 depicts a signal generating device according to the embodiment of the invention as a block diagram;
- Fig. 5 shows a block diagram of a channel response generating means according to an embodiment of the invention;
- Fig. 6 shows an 8×2 MIMO fading profile based on a LTE scenario;
- Fig. 7 shows a MIMO correlation matrix R_{HIGH} for high spatial correlation for an LTE scenario; and
- Fig. 8 depicts a flowchart describing a signal generating method according to an embodiment of the invention.
- First, along Figs. 1 and 2 the underlying technical problem and the general principle of the present invention are presented.

Fading simulators as known from prior art are generally implemented as time variant filters for filtering input signals in the time domain. The time variant filters may comprise a finite number of discrete filter taps N_{TAP} . Each
 5 filter is characterised by its time variant impulse response $h(\tau, t)$

$$h(\tau, t) = \sum_{k=1}^{N_{\text{TAP}}} \sigma_k(t) x_k(t) \delta(\tau - \tau_k(t)) \quad (1)$$

10

wherein N_{TAP} denotes the number of discrete filter taps, $x_k(t)$ is a random process with unit variance, $\sigma_k(t)$ is the standard deviation and $\tau_k(t)$ is the delay time of the tap with the number k , while $\delta(t)$ refers to the discrete delta
 15 function and t denotes the time. The discrete delta function is defined according to

$$\delta(t) = \begin{cases} 1 & \text{für } t = 0 \\ 0 & \text{für } t \neq 0 \end{cases} \quad (2)$$

20

wherein t denotes the time in equations (1) and (2). In most practical applications, the standard deviation $\sigma_k(t)$ as well as and the time delay $\tau_k(t)$ can be regarded as being independent from the time t , so that equation (1)
 25 may be simplified to as

$$h(\tau, t) = \sum_{k=1}^{N_{\text{TAP}}} \sigma_k x_k(t) \delta(\tau - \tau_k) \quad (3)$$

30 Generally the random process $x_k(t)$ is chosen as Gaussian random process with a classical Doppler power spectral

density (hereinafter abbreviated to PSD). If the fading process is further described in the digital base band, equation (1) may be also written in the form

$$h(\tau, n) = \sum_{k=1}^{N_{TAP}} \sigma_k(n) x_k(n) \delta(\tau - \tau_k(n)) \quad (4)$$

In equation (4) $x_k(n)$ denotes a complex random process with unit variance, wherein imaginary part and real part of $x_k(n)$ each are independent random processes. The parameter n is a discrete time index. If the standard deviation $\sigma_k(n)$ and the delay $\tau_k(n)$ do not vary in time, the filter model according to equation (4) can be rewritten as

$$h(\tau, n) = \sum_{k=1}^{N_{TAP}} \sigma_k x_k(n) \delta(\tau - \tau_k) \quad (5)$$

In case a MIMO transmission system 1 according to Figure 1 with a first number of N_{TX} transmit antennas 2, 3 and a second number of N_{RX} receive antennas 4, 5 is addressed, between each transmit antenna and each receive antenna one transmission channel 6, 7, 8 with transmission channel index c is formed. Each transmission channel 6, 7, 8 can be modeled each as a filter $h^c(\tau, n)$ with

$$1 \leq c \leq N_{TX} \times N_{RX} \quad (6)$$

Looking at figure 1 it can be seen that for obtaining an output signal at a receive antenna 4, the output signals of N_{TX} transmit antennas have to be convolved with the corresponding filter impulse responses $h^c(\tau, n)$ of the

transmission channels ending at an antenna 4 and the results of all filter outputs have to be added in an adder 9. Figure 1 shows this addition explicitly for a 2×2 MIMO transmission system comprising two transmit antennas and two receive antennas, e.g. $N_{TX}=2$ and $N_{RX}=2$. The dots in Figure 1 show that of course systems with more (or less) transmit and/or receive antennas are possible. The number of transmission channels to be taken into account increases significantly with the number of transmit antenna and receive antenna to be regarded. For $N_{TX}=1$ and $N_{RX}=1$ a single input single output (SISO-) transmission system is given.

Figure 2 shows a test setup for testing a DUT 10 in a $N_{TX} \times N_{RX}$ - MIMO transmission system in the time domain according to prior art. A test signal is generated in the signal generator 11 and provided in N_{TX} parallel transmit signals 12.1,...12. N_{TX} destined for N_{TX} transmitting antennas. The N_{TX} parallel antenna signals 12,...12. N_{TX} are supplied to the fading simulator 1, and in the fading simulator 1 simulated faded N_{RX} receive antenna signals 13.1,...13. N_{RX} are calculated and provided to the DUT 10. The connection 14 shows a reaction of the DUT to the faded test signals, e.g. a transmission quality indicator determined by the DUT 10 and intended for evaluation of the simulated wireless channel based on the received faded test signals at the DUT 10. A measurement unit 17 can be provided for receiving the reaction of the DUT 10 on the received faded test signal 13.1,...13. N_{RX} over connection 14. In Figure 2, the signal generating device 11 and/or the fading simulator 1 and/or the measurement unit 17 can be formed by one integrated test device as indicated by the dotted and dot-dash lines.

The fading simulator 1 can operate in the baseband, in an intermediate frequency band or in the radiated frequency band of a communications system. The fading simulator 1 operates in the time domain.

5

Figure 3 provides an overview of the test measurement setup according to an embodiment of the invention in a $N_{TX} \times N_{RX}$ MIMO transmission system in the time domain. A signal generating device 15 according to the invention
10 generates a faded test signal comprising signals 16.1,... 16. N_{RX} for each of N_{RX} receive antennas of the DUT 10. A measurement unit 17 may be provided for receiving a reaction of the DUT 10 on the received faded test signal 16.1,...16. N_{RX} . In Figure 3, the signal generating device
15 15 and the measurement unit 17 can be formed by one integrated test device as indicated by the dotted lines.

In Figures 2 and 3, the test signals are preferably provided from a number of N_{RX} test outputs to respective
20 N_{RX} ports of the DUT via test cables. The connection 14 is not necessary and not characterizing for the inventive generating of a signal including fading characteristics in the signal generating device 15.

25 Figure 4 shows the signal generating device 15 according to the embodiment of the invention as a block diagram. Comparing the signal generator 15 according to the invention with prior art, the fading simulation is implemented in the frequency domain. The fading simulation
30 can accordingly be implemented by a matrix multiplication in the signal generating device 15 and is according to the invention performed before modulating the signal for generating the test signal to be transmitted to the DUT 10. Hence no external fading simulator or additional

fading simulation module is required in the signal generating device 15 when compared to the signal generator 11 in Figure 2.

- 5 The signal generating device 15 comprises a signal generating unit 15.1, a fading simulating unit 15.2 and a modulating unit 15.3. Further subassemblies of the signal generating device not shown in Figure 4 are discussed below in the description of the embodiment.

10

The channel response generator 23 in Figure 4 corresponds to the transform parameter generating means in the attached set of claims. The fading simulating unit 15.2 in Figure 4 further includes a calculation means 21. The term
 15 "symbols" in the attached claims corresponds to the constellation symbols in the I/Q-plane used when discussing Figure 4.

20

In Figure 4 a $N_{TX} \times N_{RX}$ MIMO transmission system is used as an example for the signal generating device 15.

25

In the signal generating unit 15.1, streams of bit data out of N_{TX} parallel streams of bit data to be transmitted to the DUT 10 are each encoded in a bit encoding unit
 19.1, ..., 19. N_{TX} . The data streams of encoded bit data are then provided to a constellation mapping unit
 19.1, ..., 19. N_{TX} to be mapped to constellation symbols $a_1(k, n') \dots a_{N_{TX}}(k, n')$. The instant of time n' or time index n' refers to a time ΔT_{symp} which corresponds to a symbol
 30 length. The parameter k denotes a subcarrier index. All parallel data streams 1, ..., N_{TX} are processed in a corresponding manner. Hence, a first number of sequences of N_{TX} constellation symbols $a_1(k, n') \dots a_{N_{TX}}(k, n')$ are provided to a calculation means 21.

The signal generating unit 15.1 is described before for an embodiment of the invention comprising N_{TX} streams of bit data 18.1,...18. N_{TX} and the N_{TX} streams of bit data being
 5 processed in parallel. The invention is not limited to the embodiment described in Figure 4. It is also possible without deviating from the invention, to use a number of streams of bit data 18.1,...18. N_{TX} smaller than N_{TX} and to convert them to a number of N_{TX} sequences of constellation
 10 symbols 20 $a_1(k,n') \dots a_{N_{TX}}(k,n')$. This conversion from less than N_{TX} parallel streams of bit data 18.1,...18.($N < N_{TX}$) to a number of N_{TX} $a_1(k,n') \dots a_{N_{TX}}(k,n')$ can be implemented by multiplying with a beamforming matrix, for example.

15 The fading simulating unit 15.2 comprises the calculation means 21 besides a channel response generating means 23.

In the calculation means 21 the constellation symbols 20 $a_1(k,n') \dots a_{N_{TX}}(k,n')$ at each instant time of a vector
 20 $\underline{a}(k,n')$ are multiplied with a dynamic filter matrix (DFM-matrix or DFM) and at the output of the calculation means 21 a second number of N_{RX} faded constellation symbols 25
 $a'_1(k,n') \dots a'_{N_{RX}}(k,n')$ is given for each instant of time. The calculation means 21 establishes the DFM Matrix from a set
 25 of channel impulse responses.

At the output of the calculation means 21, the second number of faded constellation symbols $a'_1(k,n'), \dots a'_{N_{RX}}(k,n')$
 25 after multiplying the first number of symbols with the DFM corresponds to the number of receive antennas N_{RX} of
 30 the DUT 10. The faded constellation symbols 25 are then supplied to the modulation units 26.1.. 26. N_{RX} forming part of the modulating unit 15.3. The faded constellation

symbols 25 are modulated in the N_{RX} parallel modulating units 26.1.. 26. N_{RX} . After modulation optionally a cyclic prefix (CP) may be inserted into each of the modulated signal parts in optional CP inserting units 27.1,.. 27. N_{RX} of the modulating unit 15.3. After modulation and cyclic prefix insertion the test signal comprising test signal parts 16.1,.. 16. N_{RX} are generated in subsequent subassemblies of the signal generating device 15 not shown in Figure 4. The modulated and faded test signals are then supplied via N_{RX} test ports to the DUT 10. The embodiment in Figure 4 is a mere example of a part of the claimed signal generating device 15 with N_{TX} and N_{RX} parallel signal branches. Another architecture maintaining the gist of the inventive signal generating device with integrated fading simulation is also viable.

Figure 5 shows a block diagram of a channel response generator 23 according to an embodiment of the invention. In Figure 5 the random number generator 28.1 and the filter 30.1 constitute together an example of a sample generating means in the attached claims. The distribution means in the attached claims corresponds to distribution unit 32 in Figure 5. The correlation matrix unit 40 in Figure 5 is an example of the multiplying means in the attached claims. The transforming means in the attached claims correspond to the Reduced Fourier Transform Matrices units 38 (RFTM-units) in the embodiment depicted in Figure 5.

When discussing the channel response generator 23, the parameter c denotes a transmission channel index and the parameter "tap" denotes a filter tap index. The named parameters are included in the following parameter ranges

$$1 \leq c \leq N_{TX} \times N_{RX} \quad (7)$$

$$1 \leq \text{tap} \leq N_{TAP} \quad (8)$$

with N_{TX} referring to the number of transmit means or transmit antennas, N_{RX} referring to the number of receive means or receive antennas and N_{TAP} referring to the number of filter taps of the digital filter representation of the transmission channel model.

In the description of the embodiment only the term "random number" is used. It is self explanatory that not only true random numbers but also "pseudo-random numbers" are to be understood thereby.

The channel response generating means 23 comprises $N_{TX} \times N_{RX} \times N_{TAP}$ random number generators 28.1... 28. $N_{TX} \times N_{RX} \times N_{TAP}$. Each random number generator is configured to realize a random process and to output independent and identically distributed complex samples 29 $x_{\text{tap}}^c(n)$ at each instant of time n . The time index n refers to a time interval ΔT_{update} , where ΔT_{update} is a time interval, for which the channel response parameters $H_k^c(n)$ can be regarded as constant. Advantageously the time ΔT_{update} is chosen taking account of the coherence time of a fading model selected for the fading simulation to be implemented. The real part as well as the imaginary part of each sample $x_{\text{tap}}^c(n)$ is respectively independent and identically distributed. Further the complex samples of different random number generators 28.1,... 28. $N_{TX} \times N_{RX} \times N_{TAP}$ are also independent from each other. The complex samples 29 of each random number generators 28.1,... 28. $N_{TX} \times N_{RX} \times N_{TAP}$ each are provided to one corresponding filter 30.1... 30. $N_{TX} \times N_{RX} \times N_{TAP}$ corresponding to

the random number generator 28.1,..., 28.N_{TX}×N_{RX}×N_{TAP}. The respective outputs 31.1... 31.N_{TX}×N_{RX}×N_{TAP} of the filter 30.1,...,30.N_{TX}×N_{RX}×N_{TAP} is given by the equation

$$y_{\text{tap}}^c(n) = \sum_{r=0}^{L-1} f_{\text{tap}}^c(r) x_{\text{tap}}^c(n-r) \quad (9)$$

wherein $y_{\text{tap}}^c(n)$ is the filter output, L denotes the length of the filter impulse response $f_{\text{tap}}^c(n)$. The filter 30.1,... 30.N_{TX}×N_{RX}×N_{TAP} define the autocorrelation function (abbreviated ACF) and the power spectral density (PSD) of the random process $y_{\text{tap}}^c(n)$ at the filter output.

The filtered complex samples 31.1,... 31.N_{TX}×N_{RX}×N_{TAP} output by the filters 30.1,... 30.N_{TX}×N_{RX}×N_{TAP} are supplied to the distribution unit 32. The distribution unit 32 is configured to set up N_{TX}×N_{RX} impulse responses, one for each transmission channel. The output of the distribution unit 32 is one sample sequence at each instant of time for each transmission channel 6, 7, 8. The sample sequence for each transmission channel 6, 7, 8 is generated by rearranging the filter outputs $y_{\text{tap}}^c(n)$ so that each of these sequences 33.1,...,33.N_{TX}×N_{RX} output by the distribution unit 32 comprises N_{TAP} samples. The processing in the distribution unit 32 is a mere distribution of input sample sequence streams to output sample sequence streams, each output sample sequence having N_{TAP} samples. Each of the N_{TAP} filter outputs $y_{\text{tap}}^c(n)$ within one data sequence is fed to a multiplier unit 34.1,... 34.N_{TX}×N_{RX} to be multiplied with $\sigma_{\text{tap}}^c(n)$

$$y'_{\text{tap}}^c(n) = y_{\text{tap}}^c(n) \sigma_{\text{tap}}^c(n)$$

(10)

with

$$1 \leq \text{tap} \leq N_{\text{TAP}}$$

(11)

- 5 wherein tap denotes a tap index running from 1 to N_{TAP} ,
 $y'_{\text{tap}}^c(n)$ is the output signal of the multipliers
 34.1, ..., 34. $N_{\text{TX}} \times N_{\text{RX}}$ and $y_{\text{tap}}^c(n)$ refers to the respective
 elements of the input data sequences to the multipliers
 34.1, ... 34. $N_{\text{TX}} \times N_{\text{RX}}$. For each sequence there is provided one
 10 multiplier 34.1, ... 34. $N_{\text{TX}} \times N_{\text{RX}}$ for multiplying $y_{\text{tap}}^c(n)$ with a
 value (standard deviation) $\sigma_{\text{tap}}^c(n)$ for scaling.

- The multipliers 37.1, ... 37. $N_{\text{TX}} \times N_{\text{RX}}$ can be implemented as
 discrete elements. In an alternate embodiment the function
 15 performed by the multipliers 34.1, ... 34. $N_{\text{TX}} \times N_{\text{RX}}$ can be
 integrated with the filters 30.1, ... 30. $N_{\text{TX}} \times N_{\text{RX}} \times N_{\text{TAP}}$ by
 respectively scaling the filter transfer functions of the
 filters 30.1, ... 30. $N_{\text{TX}} \times N_{\text{RX}} \times N_{\text{TAP}}$.

- 20 The transmission channel sample sequences $y'^c_{\text{tap}}(n)$
 33.1, ..., 33. $N_{\text{TX}} \times N_{\text{RX}}$ are fed to the correlation matrix unit
 40 to be multiplied with a correlation matrix $C(n)$ in
 order to generate a set of channel impulse responses
 34.1, ..., 34. $N_{\text{TX}} \times N_{\text{RX}}$

25

$$h_{\text{tap}}^c(n) = \sum_{i=1}^{N_{\text{TX}} \times N_{\text{RX}}} y'^i_{\text{tap}}(n) C_{ic}(n)$$

(12)

- In equation (12), the $y'^i_{\text{tap}}(n)$ are the elements of the
 30 transmission channel sample sequences 36.1, ... 36. $N_{\text{TX}} \times N_{\text{RX}}$ as
 output signals of the multiplier units 34.1, ... 34. $N_{\text{TX}} \times N_{\text{RX}}$,
 $h_{\text{tap}}^c(n)$ are the channel impulse responses 37.1, ... 37. $N_{\text{TX}} \times N_{\text{RX}}$

at filter tap **tap** and instant of time n for transmission channel c , N_{TX} is the number of receive means, N_{RX} is the number of transmit means and $C_{ic}(n)$ are the respective correlation matrix entries $C_{ij}(n)$ for an instant of time n , i indexing the rows of the correlation matrix C and j indexing the columns of the correlation matrix with

$$1 \leq i, j \leq N_{TX} \times N_{RX} \quad (13)$$

The entries $C_{ij}(n)$ may be derived from the standard to be implemented or based on a developer's knowledge about a system of interest. An example will be given later. The correlation matrix $C(n)$ is configured to take the interactions between the transmission channels c into account. The correlation matrix $C(n)$ may be provided externally to the correlation matrix unit 40 from a storage.

The elements $C_{ij}(n)$ of the correlation matrix may be defined in a communication standard applicable for a communication to the device under test. As an example the correlation matrix R_{LTE} defined in the series of technical specifications for the 4th generation wireless communication system LTE is cited. In the present embodiment the elements $C_{ij}(n)$ may vary with time n , whereas in the cited LTE specifications the elements $C_{ij}(n)$ are constant in time. The elements $C_{ij}(n)$ may also be determined experimentally and/or by modeling a wireless channel to be simulated by the channel simulation. The present invention is not limited to either example given before.

The channel impulse responses $h_{tap}^c(n)$ 37.1, ... 37. $N_{TX} \times N_{RX}$ are then provided to transforming means 38.1, ... 38. $N_{TX} \times N_{RX}$. The

transforming means is also referred to as a reduced Fourier transform matrix units 38.1,... 38.N_{TX}×N_{RX} (RFTM units 38.1,... 38.N_{TX}×N_{RX}) in this embodiment. The RFTM units calculate channel response parameters 39.1,...

- 5 39.N_{TX}×N_{RX} by transforming the channel impulse responses $h_{\text{tap}}^c(n)$ 37.1,... 37.N_{TX}×N_{RX} into the frequency domain according to the equation

$$H_k^c(n) = \sum_{\text{tap}=1}^{N_{\text{TAP}}} h_{\text{tap}}^c(n) \exp(-j2\pi \times k \times \Delta f \times \tau(\text{tap}, n))$$

10 (14)

wherein in equation (14) $H_k^c(n)$ denotes the frequency domain channel response parameter for a subcarrier k , a transmission channel c and an instant of time n , N_{TAP} denotes the number of taps of the transmission channel filter model, Δf is the subcarrier spacing, c is the transmission channel index, j is $\sqrt{-1}$. Collecting the channel response parameters 39.1,...,39.N_{TX}×N_{RX} $H_k^c(n)$ at the subcarriers k with

20 $1 \leq k \leq N_k$ (15)

the above described calculation may be noted in matrix notification as multiplication

25 $\underline{H}^c(n) = W(n)\underline{h}^c(n)$ (16)

with a $N_k \times N_{\text{TAP}}$ matrix $W(n)$ whose entries in the i -th row and 30 the j -th column $W_{ij}(n)$ are given as

$$W_{ij}(n) = \exp(-j2\pi \times i \times \Delta f \times \tau(j, n))$$

(17)

wherein

$$1 \leq i \leq N_k \text{ und } 1 \leq j \leq N_{\text{TAP}}$$

5

(18)

and

$$\underline{H}^c(n) = \begin{bmatrix} H_1^c(n) \\ \vdots \\ H_{N_k}^c(n) \end{bmatrix} \quad (19)$$

10

$$\underline{h}^c(n) = \begin{bmatrix} h_1^c(n) \\ \vdots \\ h_{N_{\text{TAP}}}^c(n) \end{bmatrix} \quad (20)$$

The inventive matrix $W(n)$ is given a new term “reduced
 15 Fourier transform matrix” (RFTM) and provides an efficient
 method to determine the channel response parameters
 $39.1, \dots 39.N_{\text{TX}} \times N_{\text{RX}}$ by a matrix multiplication. But the
 described method is by no means intended to be limiting.
 It is also possible to calculate the channel response
 20 parameters $39.1, \dots 39.N_{\text{TX}} \times N_{\text{RX}}$ based on the symmetry
 properties of the $N_k \times N_{\text{TAP}}$ matrix $W(n)$ in equation (16) and
 use more efficient implementations of equation (16).
 Furthermore equation (14) uses the subcarrier frequencies
 $k\Delta f$. Other frequencies, even when not equally distanced,
 25 may of course also be used.

An alternate embodiment of the present invention does not
 calculate the channel response parameters $H_k^c(n)$ for all k
 subcarrier frequencies, but only calculates $H_k^c(n)$ for a
 30 subset of the subcarrier frequencies k . The other required
 channel response parameters $H_k^c(n)$ are then determined by
 means of interpolation. An interpolation unit not shown in

the figures may in this embodiment be arranged in each signal path in Figure 5, receiving as an input a reduced number N_k of calculated channel response parameters from part of the transforming means 38.1, ..., 38. $N_{TX} \times N_{RX}$ and

5 outputting as channel response parameters a number of $N_{k'}$ of interpolated channel response parameters which are computed in the interpolation unit. Hence $H_k^c(n)$ with $1 \leq k \leq N_k$ is transformed to $H_{k'}^c(n)$ with $1 \leq k' \leq N_{k'}$ with $N_k < N_{k'}$. Hence a further reduction in computational effort can

10 be achieved by further reducing the inventive RFTM-matrix.

The channel response generating means 23 of the fading simulating unit 15.2 is depicted in Fig.5 and described in the corresponding sections of the description as being

15 provided externally with the correlation matrix $C(n)$ and the values $\sigma_{tap}^c(n)$ only. Other subassemblies of the channel response generating means 23 than the correlation matrix unit 40 and the multipliers 34.1, ... 34. $N_{TX} \times N_{RX}$ are also adapted to be configured externally.

20

The calculation means 21 in Figure 4 is provided with the channel response parameters $H_k^c(n)$ 39.1, ... 39. $N_{TX} \times N_{RX}$ calculated in the channel response generating means 23 as discussed before. A dynamic filter matrix (DFM) is defined

25 as

$$DFM(k, n') = \begin{bmatrix} H_k^1(n') & H_k^{N_{TX}+1}(n') & \dots & H_k^{(N_{RX}-1)N_{TX}+1}(n') \\ \vdots & \ddots & & \vdots \\ H_k^{N_{TX}}(n') & H_k^{2N_{TX}}(n') & \dots & H_k^{N_{RX}N_{TX}}(n') \end{bmatrix}_{N_{RTX} \times N_{RX}} \quad (21)$$

for a subcarrier k at an instant of time n' , with

30 frequency domain channel responses $H_k^c(n')$ for a subcarrier k and a channel c at an instant of time n' . As already mentioned above the time index n' refers to a time ΔT_{synd}

which corresponds to the symbol length. Defining $H_k^c(t)$ with respect to a continuous time t as a segment-wise constant function according to

$$H_k^c(t) = H_k^c(n) \text{ for}$$

$$n \Delta T_{\text{update}} \leq t < (n+1) \Delta T_{\text{update}}$$

then $H_k^c(n')$ can be obtained from $H_k^c(t)$ by setting $t = n' \Delta T_{\text{synd}}$.

10

The calculation means 21 receives a vector

$$\underline{a}(k, n') = \begin{bmatrix} a_1(k, n') \\ \vdots \\ a_{N_{\text{TX}}}(k, n') \end{bmatrix}_{N_{\text{TX}} \times 1} \quad (22)$$

15 comprising a number of N_{TX} constellation symbols for the N_{TX} transmit means at an instant of time n' and a subcarrier k . The vector $\underline{a}(k, n')$ is multiplied with the dynamic filter matrix $\text{DFM}(k, n')$ and outputted is a vector

$$\underline{a}'(k, n') = \begin{bmatrix} a_1^1(k, n') \\ \vdots \\ a_{N_{\text{RX}}}^1(k, n') \end{bmatrix}_{N_{\text{RX}} \times 1} \quad (23)$$

wherein the vector $\underline{a}'(k, n')$ comprises N_{RX} faded constellation symbols. Hence the input-output relation of the calculation means 21 can be expressed in matrix notation as

$$\underline{a}'(k, n') = \text{DFM}(k, n') \underline{a}(k, n') \quad (24)$$

30

with a dynamic filter matrix $\text{DFM}(k, n')$ being time variant.

For $N_{TX}=1$ and $N_{RX}=1$, a single input single output (SISO-) transmission system is regarded. The inventive signal generating device 15 nevertheless is also applicable in this case.

Fig. 6 and Fig. 7 are discussed with reference to an application example of an embodiment of the present invention. The example is chosen as an illustration for employing the signal generator 15 and the disclosed invention is not limited to the described embodiment.

In the LTE conformance test specification 3GPP TS 36521-1 10.4.0 a MIMO scenario with a number of transmit antennas of $N_{TX}=8$ and a number of receive antennas of $N_{RX}=2$ is described. The number of subcarriers is set to $N_k=600$ and the number of filter taps to $N_{TAP}=9$ in the shown scenario. Figure 6 gives the fading profile from the cited test specification. The first column of the table in figure 6 gives the tap index tap , the second column provides the respective delay τ_{tap} in nanosecond (ns), and the third column provides the respective value σ_{TAP} for the relative power in dB. The chosen model corresponds to the extended vehicular A model (abbreviated as EVA) in the cited specification defining a multipath fading model.

Figure 7 provides an example for a MIMO correlation matrix R_{high} for a MIMO scenario with high spatial correlation taken from LTE conformance test specification 3GPP TS 36521-1 10.4.0. The MIMO correlation matrix 41 as to be used into the correlation matrix unit 40 of the channel response generating means 23 in Figure 5 is determined by Cholesky decomposition of the correlation matrix R_{high} shown in Figure 7.

Each filter 30.1, ... 30.N_{TX}×N_{RX}×N_{TAP} would have the same filter impulse response

$$f_t^c(n) \rightarrow f(n) \quad (25)$$

The impulse responses can for example be obtained from a square root $\sqrt{S(f)}$ of a PSD $S(f)$ being defined by

$$S_t(f) = \begin{cases} \frac{1}{\pi f_d \sqrt{1 - \left(\frac{f}{f_d}\right)^2}}, & |f| \leq f_d \\ 0, & |f| \geq f_d \end{cases}$$

wherein f_d denotes the Doppler frequency, by sampling $\sqrt{S(f)}$ at N_{DFT} equidistant points and computing an inverse discrete Fourier transformation (IDFT). The thus obtained impulse responses can be shortened to a length $N_{\text{IR}} < N_{\text{IDFT}}$ by using a window function. One example of a window function to be used to this end can be a Kaiser-window.

The terms $\sigma_{\text{tap}}^c(n)$ 35 are in the given example time-invariant:

$$\sigma_{\text{tap}}^c(n) \rightarrow \sigma_{\text{tap}} \quad (26)$$

and can be drawn from the table in Figure 6. The correlation matrix $C(n)$ 41 would also be time invariant:

$$\mathbf{C}(n) \rightarrow \mathbf{C}$$

(27)

From $\mathbf{R}_{\text{high}}$ provided in the table of Figure 7 and using the
 5 equation (28)

$$\mathbf{R}_{\text{high}} = \mathbf{C}^H \mathbf{C}$$

(28)

the correlation matrix $\mathbf{C}$ may be determined by Choleksy
 10 decomposition of the MIMO correlation matrix $\mathbf{R}_{\text{high}}$ for high
 spatial correlation. In equation (28) $\mathbf{C}^H$ is the Hermitian
 matrix to $\mathbf{C}$. The subcarrier frequency spacing Δf is set to
 15 kHz in the present example. With the values given for
 Δf , and τ_{TAP} given by Figure 6 the reduced Fourier
 15 transform Matrix RFTM can be calculated in the
 transforming means 38.1, ..., 38. $N_{\text{TX}} \times N_{\text{RX}}$. The 50% coherence
 time of the fading model used in this example is given by

$$T_c = \frac{9}{16\pi f_d} = 35,8 \text{ ms}$$

20

(29)

with a Doppler frequency $f_d = 5 \text{ Hz}$ and accordingly an
 update time ΔT_{update} could be suitably chosen to be

25

$$\Delta T_{\text{update}} = 20 \text{ ms.}$$

(30)

A further advantageous embodiment reduces the
 computational complexity by not calculating the RFTM
 30 matrix for every subcarrier, but, for example, for every
 second subcarrier as subset of subcarriers. If the
 subcarrier spacing is much smaller than the coherence
 bandwidth of the fading profile employed in the channel

simulation, the interpolating unit after the reduced Fourier transform matrix units 38.1,... 38.N_{TX}×N_{RX} can be implemented in a simple manner. In this case the interpolating unit could be implemented by a sample-and-hold module. The interpolation executed by a sample-and-hold module corresponds to a 0th-order interpolation.

The computational advantages presented by the inventive signal generating unit 15 can be estimated by examining the transform parameter generating means 23 and the calculation means 21 characterising the signal generating device 15 with integrated fading simulation in comparison with the signal generator 11 of the state of the art with the external fading simulator 1.

The processing steps of the channel response generator unit 23 to the RFTM units 38.1,... 38.N_{TX}×N_{RX} are required in the state of the art fading simulation in the fading simulator 1 also. Hence for comparing the inventive approach for signal generating integrating fading simulation with the state of the art, the processing executed in the RFTM units 38.1,...,38.N_{TX}×N_{RX}, further the processing in the calculation means 21 and the different number of modulation units required in the signal generating device 15 has to be considered to estimate the improvement. The number of modulators for example is changed from N_{TX} to N_{RX} in the signal generating device 15. In most cases this is a significant reduction.

In the following section a short estimation for illustrative purposes is calculated.

Within one ΔT_{update} the RFTM units 38.1,...,38.N_{TX}×N_{RX} require

$$N_{TX} \times N_{RX} \times N_K \times N_{TAP} = 86.400 \text{ multiplications.} \quad (31)$$

The calculation means 21 requires

5

$$20 \times 14 \times N_{TX} \times N_{RX} \times N_K = 2.688.000 \text{ complex multiplications.}$$

(32)

10 The multiplier value of 20 results from a subframe length of 1 ms as applicable for example in the LTE specifications. Each subframe contains 14 OFDM symbols. Two modulators are required for an 8x2 MIMO system. The modulators may be implemented as inverse fast Fourier transform (IFFT) in case of LTE. This accounts for two 15 1024 point IFFTs for a 10 MHz LTE cell required per OFDM symbol. Hence within one ΔT_{update} the IFFTs account for

$$20 \times 14 \times 2 \times 1.024 \times \log_2(1.024) = 5.734.400 \text{ complex multiplications.}$$

20

(33)

In total, a number of

$$86.400 + 2.688.000 + 5.734.400 = 8.508.800 \text{ complex multiplications}$$

25

(34)

is estimated for the inventive approach. Contrary thereto the prior art approach requires 8 IFFTs for a 8x2 MIMO 30 system and at least 8 1.024 point IFFTs per OFDM symbol. Hence within one ΔT_{update} this accounts for

$$20 \times 14 \times 8 \times 1.024 \times \log_2(1.024) = 22.937.600 \text{ complex multiplications}$$

(35)

in case of the IFFT in the approach according to the state of the art with an external fading simulation. The time domain fading simulator has to run at least at the signal sampling rate f_s . In case of a LTE 10 MHz cell as an example $f_s = 15,36$ MHz is given. For each sample $N_{TX} \times N_{RX}$ filter outputs, one for each simulated transmission channel, require N_{TAP} complex multiplications each. Hence the time domain fading simulator 1 according to prior art within one ΔT_{update} requires

$$\Delta T_{update} \times f_s \times N_{TX} \times N_{RX} \times N_{TAP} = 44.236.800 \text{ complex multiplications.}$$

(36)

In total the comparison figure for the complexity of the prior art approach is calculated to

$$22.937.600 + 44.236.800 = 67.174.400 \text{ complex multiplications.}$$

(37)

Comparing the results of equation (34) with equation (37), only about 12,7% of the complex multiplications are required for the new approach comparing the decisive processing steps with the state of the art approach. This results from integrating the fading simulation into the signal generating and generating the number of N_{RX} data streams exactly as needed for test outputs to the DUT 10 and not the N_{TX} data streams as required for the external fading simulation with fading simulation processing in the time domain. This results in a significantly reduced data rate on an internal bus of the signal generating device 15 compared to a bus in the in the signal generator 11 state

of the art fading approach. Complexity and costs of the signal generating device are accordingly significantly reduced.

- 5 Figure 8 gives a flowchart for a signal generating method with included fading simulation according to an embodiment of the invention.

In a first step S1, a first number of symbols according to a number of transmitting means for a simulated
10 transmission to a device under test is generated. The first number of symbols corresponds, for example, to a number of N_{TX} transmit antennas in a MIMO system.

In a second step S2 a set of filter parameters is generated from a predetermined fading profile. The set of
15 filter parameters corresponds to a dynamic filter matrix DFM with matrix elements constituting frequency domain channel responses $H_k^f(n')$.

In step S2 further, a second number of faded symbols, the second number corresponding to a number of receiving means
20 N_{RX} of the device under test and hence to the output test signals 16.1, ... 16. N_{RX} based on a set of filter parameters according to the equation (24) is calculated.

In step S2, a transform parameter generating step (S2.1) of generating a set of channel response parameters from a
25 set of channel impulse responses characterising the transmission channels is included. The set of channel response parameters is used to generate a set of filter parameters in a following step of generating filter parameters (S2.2) from the set of channel response
30 parameters.

The transform parameter generating step S2.1 can further comprise four substeps S2.1.1 to S2.1.4.

In a plural sample generating step S2.1.1 filtered complex samples are generated by filtering independent and
5 identically distributed complex samples.

In a distribution step S2.1.2 the filtered complex samples are rearranged in order to generate a sample sequence sequence for each transmission channel 6, 7, 8. More specifically the distribution step S2.1.2 can comprise
10 generating sample sequence data streams for each transmission channel by arranging a third number of filtered complex samples sequentially, wherein the third number of complex samples corresponds to a number of taps for each transmission channel

15 Then the one or more transmission channel sample sequence streams are multiplied with a correlation matrix 41 to generate the set of channel impulse responses in a multiplying step S2.1.3. The sample generating step can comprise filtering complex samples to define
20 autocorrelation and Doppler characteristics of the filtered complex samples.

A transforming step S2.1.4 comprises calculating the set of channel response parameters by transforming the set of channel impulse responses into the frequency domain. The
25 transforming step S2.1.4 can comprise determining additional channel response parameters by calculating via interpolation.

After a second number of faded symbols according to the equation (24) is calculated, in step S2, in a following
30 step S3 the calculated second number of faded symbols are provided to the modulating units 26.1, ... 26.N_{RX}. In step

S4, modulated test signals for transmission to the device under test 10 are generated from the faded second number of faded symbols.

The invention is not limited to the examples and especially not to an OFDM communication standard. Other and different communication standards for multicarrier systems can be used. The characteristic features of the exemplary embodiments can be used in any advantageous combination of the features claimed in the claims and/or described in the description and/or drawn in the drawings.

Claims

1. A signal generating device comprising a fading simulation unit, a signal generating unit and a modulating unit

5 wherein the signal generating unit (15.1) is configured to generate a first number of symbols according to transmitting means for a simulated transmission to a device under test;

 wherein the fading simulation unit (15.2) is
10 configured to calculate from the first number of symbols a second number of faded symbols, wherein a number of signals to be output correspond to a number of receiving means of the device under test, based on a set of filter parameters, and to provide the calculated second number of
15 faded symbols to the modulating means; and

 wherein the modulating unit (15.3) is configured to generate modulated signals to be output from the faded symbols.

20 2. The signal generating device according to claim 1,

characterized in

 that a transmission channel is defined between each of the transmitting means of a signal source and each of the receiving means of a real system to be simulated.

25

3. The signal generating device according to one of claims 1 or 2,

characterized in

that the fading simulation unit (15.2) comprises
a transform parameter generating means (23)
configured to generate a set of channel response
parameters from a set of channel impulse responses

5 characterising the transmission channels;

a calculation means (21) configured to calculate the
second number of faded symbols from the first number of
symbols using the channel response parameters.

10 4. The signal generating device according to claim 3,
characterized in

that the transform parameter generating means (23)
comprises

sample generating means (28.1, 28.2,...; 30.1,
15 30.2..) configured to generate filtered complex samples by
filtering independent and identically distributed complex
samples;

a distribution means (32) configured to rearrange the
filtered complex samples to generate sample sequence
20 streams (33.1,..33.N_{TX}N_{RX}) for each transmission channel;

a multiplying means (40) configured to multiply the
one or more transmission channel sample sequence streams
with a correlation matrix to generate the set of channel
impulse responses;

25 a transforming means (38.1,..38.N_{TX}N_{RX}) configured to
calculate a set of channel response parameters by
transforming the set of channel impulse responses into the
frequency domain.

30 5. The signal generating device according to claim 4,

characterized in

that the transforming means (38.1,...38.N_{TX}N_{RX}) is configured to transform the set of channel impulse responses into the frequency domain based on a
5 predetermined frequency spacing.

6. The signal generating device according to claim 5,

characterized in

that the transforming means (38.1,...38.N_{TX}N_{RX}) is
10 configured to generate a reduced Fourier transform matrix, the reduced Fourier transform matrix configured for transforming the set of channel impulse responses into the frequency domain by multiplying the set of channel impulse responses with the reduced Fourier transform matrix.

15

7. The signal generating device according to claim 5 or 6,

characterized in

that the transforming means (38.1,...38.N_{TX}N_{RX}) is
20 configured to determine additional channel response parameters by interpolation.

8. The signal generating device according to one of claims 4 to 7,

25 **characterized in**

that the correlation matrix (41) comprises parameters describing the characteristics of each transmission

channel and interdependencies between the transmission channels.

9. The signal generating device according to any one of
5 claims 4 to 8,

characterized in

that each sample generating means (28.1,
28.2,...;.30.1,.30.2,...) comprises filter means
(30.1,.30.2,...) being configured to filter complex samples
10 to define autocorrelation and Doppler characteristics of
the filtered complex samples.

10. The signal generating device according to any one of
claims 4 to 9,

15 **characterized in**

that the distribution means (32) is configured to
generate sample sequence data streams for each
transmission channel by arranging a third number of
filtered complex samples sequentially, wherein the third
20 number of complex samples corresponds to a number of taps
for each transmission channel;

11. A signal generating method for generating a faded
25 modulated signal, the method comprising steps of

generating a first number of symbols according to
transmitting means for a simulated transmission to a
device under test (S1);

calculating from the first number of symbols a second number of faded symbols, wherein a number of signals to be output corresponds to a number of receiving means of a device under test, based on a set of filter parameters

5 (S2);

providing the calculated second number of faded symbols to the modulating unit (S3); and

modulating the faded symbols generate modulated signals from the faded symbols (S4).

10

12. The signal generating method for generating a faded modulated signal according to claim 11, the method further comprises

a transform parameter generating step (S2.1) by
15 generating a set of channel response parameters from a set of channel impulse responses characterising the transmission channels;

a calculating step (S2.2) of calculating the second number of faded symbols from the first number of symbols
20 using the channel response parameters.

13. The signal generating method for generating a faded modulated signal according to claim 12,

25 **characterized in**

that the transform parameter generating step (S2.1) comprises a

a sample generating step (S2.1.1) of generating filtered complex samples by filtering independent and
30 identically distributed complex samples;

a distribution step (S2.1.2) of rearranging the filtered complex samples to generate a sample sequence stream for each transmission channel;

5 a multiplying step (S2.1.3) of multiplying the one or more transmission channel sample sequence streams with a correlation matrix to generate the set of channel impulse responses;

10 a transforming step (S2.1.4) of calculating the set of channel response parameters by transforming the set of channel impulse responses into the frequency domain.

14. The signal generating method for generating a faded modulated signal according to claim 13,

15 **characterized in**

that in the transforming step (S2.1.4) additional channel response parameters are determined by interpolation.

20

15. The signal generating method for generating a faded modulated signal according to any of claims 12 to 15,

characterized in

25 that the sample generating step (S2.1.1) comprises filtering complex samples to define autocorrelation and Doppler characteristics of the filtered complex samples.

16. The signal generating method for generating a faded modulated signal according to any of claims 13 to 15,

30 **characterized in**

that in the distribution step (S2.1.2) sample
sequence data streams for each transmission channel are
generated by arranging a third number of filtered complex
samples sequentially, wherein the third number of complex
5 samples corresponds to a number of taps for each
transmission channel;

17. A computer program with program-code means for
executing the method steps according to one of claims 11
10 to 16, when the program is executed on a computer or
digital signal processor.

18. A computer program-product with program-code means
stored on a machine-readable medium for executing all
15 steps according to one of claims 11 to 16, when the
program is executed on a computer or digital signal
processor.

Fig. 1

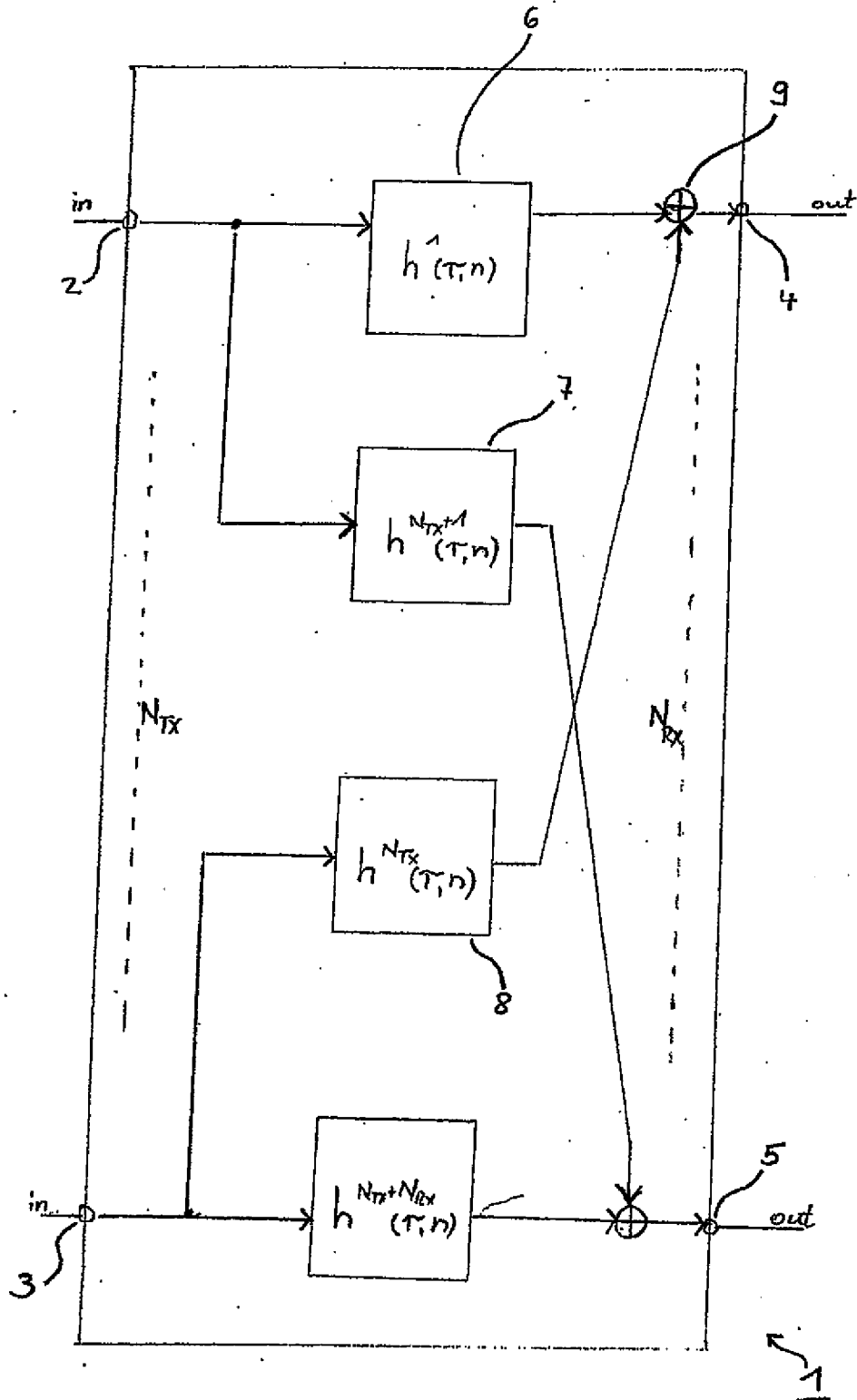


Fig. 2

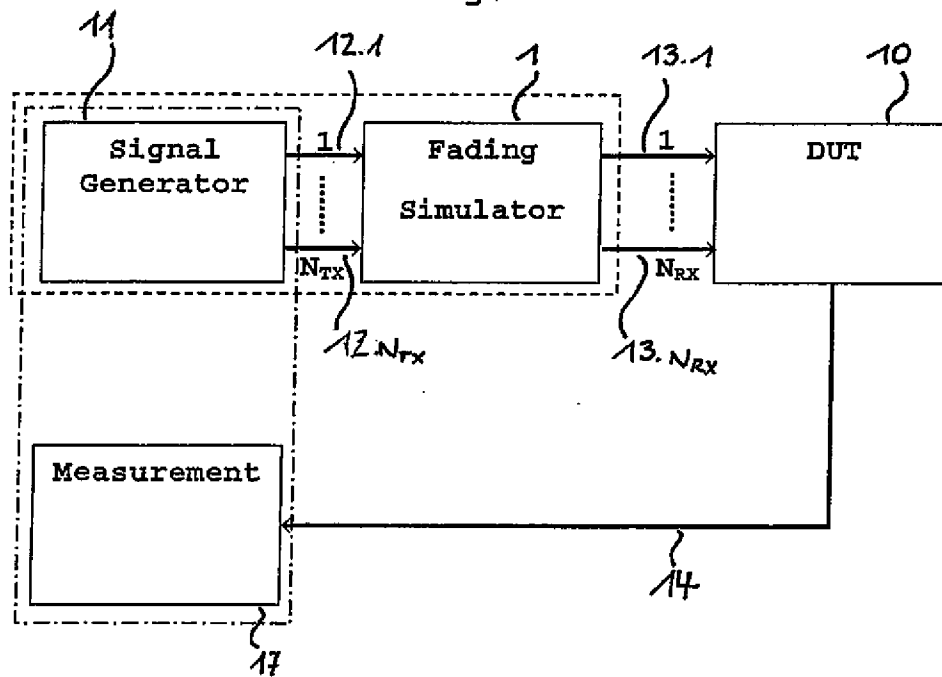


Fig. 3

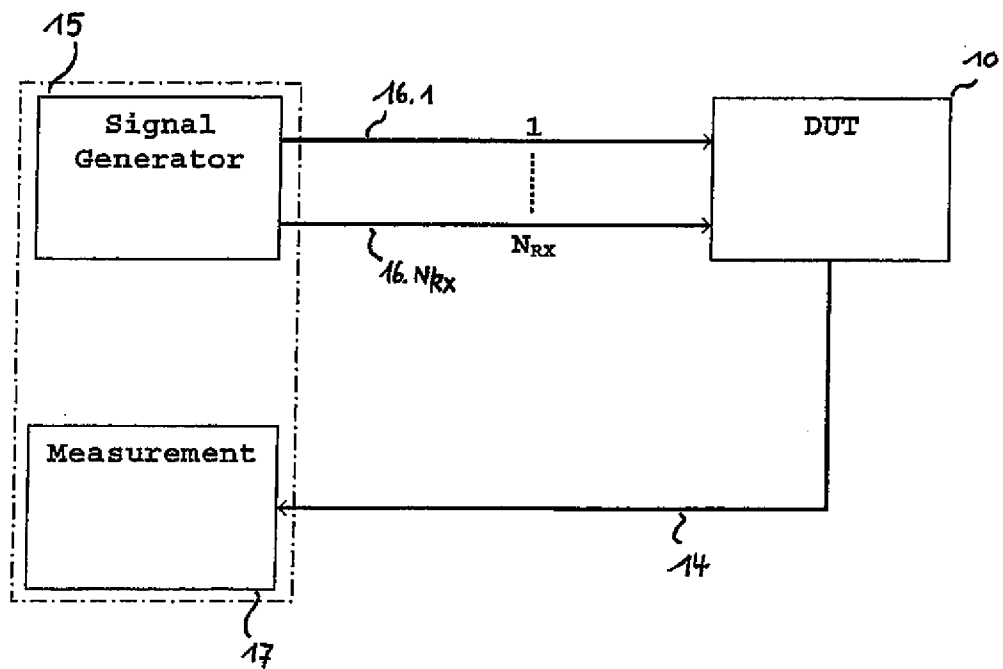
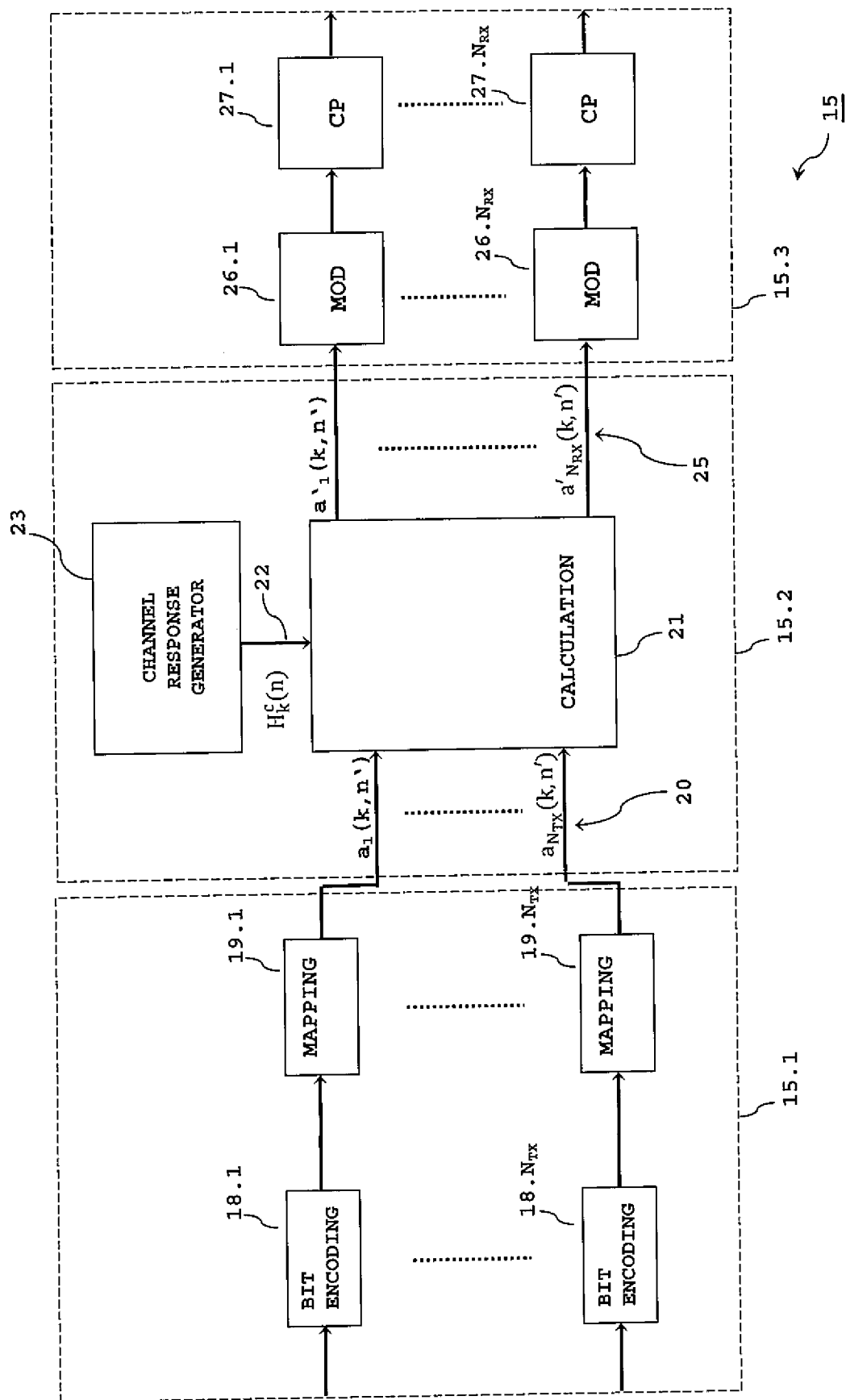


Fig. 4



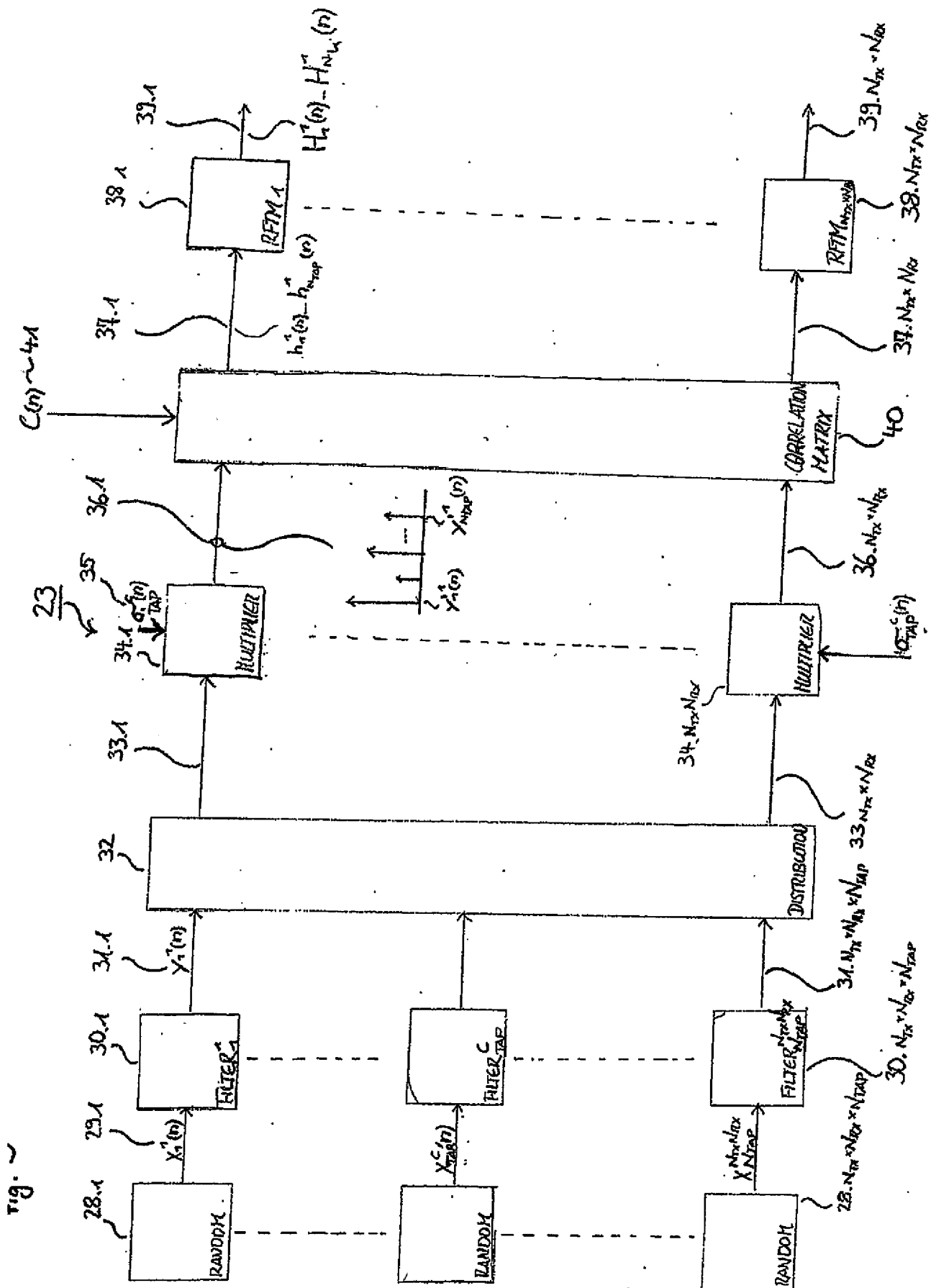


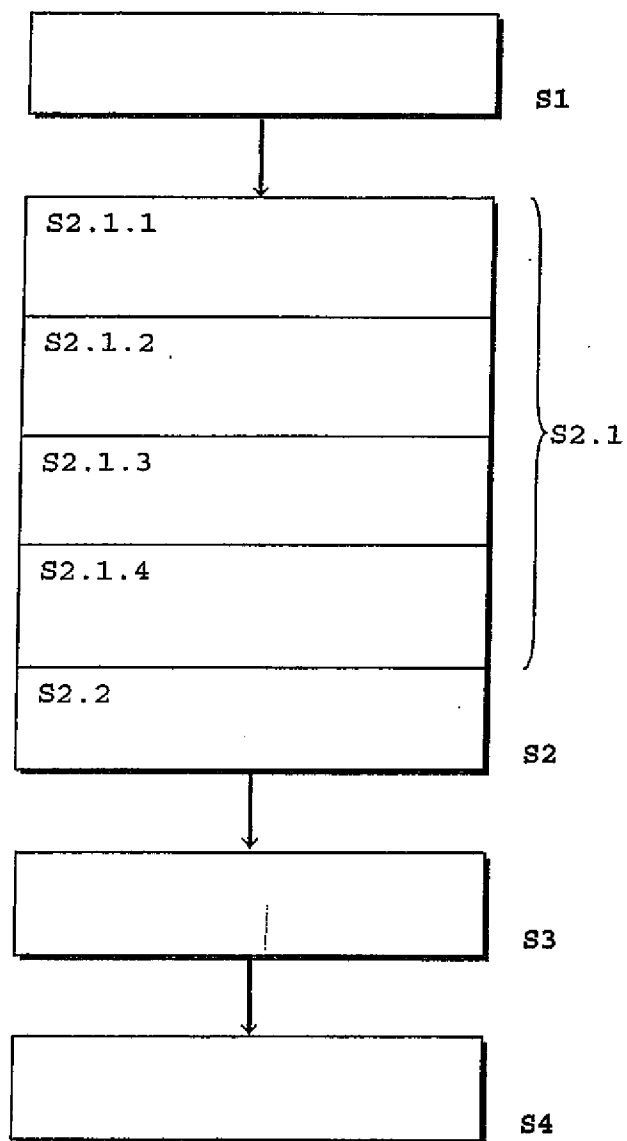
Fig. 6

tap	τ_{TAP} [ns]	σ_{TAP} [dB]
1	0	0
2	30	-1,5
3	150	-1,4
4	310	-3,6
5	370	-0,6
6	710	-9,1
7	1090	-7
8	1730	-12
9	2510	-16,9

Fig. 7

8x2 case	R_{mich}																			
	1.0000	0.0100	0.9883	0.0000	0.9542	0.0000	0.8829	0.0100	-0.3300	0.0000	-0.2365	0.0000	-0.2365	0.0000	-0.2362	0.0000	-0.2362	0.0000	-0.2362	0.0000
0.0000	1.0000	0.0000	0.9883	0.0000	0.9542	0.0000	0.8829	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.9883	0.0000	1.0000	0.0000	0.9883	0.0000	0.9542	0.0000	0.8829	-0.2365	0.0000	0.2365	0.0000	0.2365	0.0000	0.2365	0.0000	0.2365	0.0000	0.2365	0.0000
0.0000	0.9883	0.0000	1.0000	0.0000	0.9883	0.0000	0.9542	0.0000	0.0000	0.2365	0.0000	0.2365	0.0000	0.2365	0.0000	0.2365	0.0000	0.2365	0.0000	0.0000
0.9542	0.0000	0.9883	0.0000	1.0000	0.0000	1.0000	0.8829	0.0000	0.2362	0.0000	-0.2362	0.0000	-0.2362	0.0000	-0.2362	0.0000	-0.2362	0.0000	-0.2362	0.0000
0.0000	0.9542	0.0000	0.9883	0.0000	1.0000	0.0000	0.8829	0.0000	0.0000	0.2362	0.0000	0.2362	0.0000	0.2362	0.0000	0.2362	0.0000	0.2362	0.0000	0.0000
0.8829	0.0000	0.0100	0.8542	0.0000	0.8829	0.0000	1.0000	0.0000	-0.2362	0.0000	0.2362	0.0000	0.2362	0.0000	0.2362	0.0000	0.2362	0.0000	0.2362	0.0000
0.0000	0.8829	0.0000	0.8542	0.0000	0.8829	0.0000	1.0000	0.0000	0.0000	0.2362	0.0000	0.2362	0.0000	0.2362	0.0000	0.2362	0.0000	0.2362	0.0000	0.0000
-0.3300	0.0000	0.0000	-0.2365	0.0000	-0.2362	0.0000	-0.2362	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	-0.3300	0.0000	-0.2365	0.0000	-0.2362	0.0000	-0.2362	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.2365	0.0000	0.2365	0.0000	0.2365	0.0000	0.2365	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
-0.2365	0.0000	0.0000	-0.2365	0.0000	-0.2362	0.0000	-0.2362	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.2365	0.0000	0.2365	0.0000	0.2365	0.0000	0.2365	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
-0.2362	0.0000	-0.2365	0.0000	-0.2365	0.0000	-0.2365	0.0000	-0.2362	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.2362	0.0000	0.2365	0.0000	0.2365	0.0000	0.2365	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
-0.2300	0.0000	0.0000	-0.2362	0.0000	-0.2365	0.0000	-0.2365	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.2300	0.0000	0.2362	0.0000	0.2365	0.0000	0.2365	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000

Fig. 8



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/061484

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B17/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04B H04W

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 440 165 A (RACAL INSTR WIRELESS SOLUTIONS [GB]) 23 January 2008 (2008-01-23) abstract page 3, lines 5-25 page 4, line 21 - page 5, line 20 page 6, lines 21-23	1-18
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Date of the actual completion of the international search

11 October 2013

Date of mailing of the international search report

18/10/2013

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/061484

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2013/061484

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