

Claims

[1] [Claim 1] A method for receiving a signal, comprising an estimation step for estimating a time shift and a frequency shift that are embedded in the signal, wherein the estimation step refers to a non-commutative shift parameter space of co-dimension 2, wherein in the estimation step, the time shift and the frequency shift that are embedded in the signal are estimated with an operator including a half shift that is a shift symmetrical in time and frequency.

[2] [Claim 2] The method recited in claim 1, wherein the non-commutative shift parameter space of co-dimension 2 is a space obtained by 3-dimensionalizing a plane, which is defined by a first axis indicative of time and a second axis indicative of frequency, by attaching, to the plane, a third axis indicative of time-frequency shifts.

[3] [Claim 3] The method recited in claim 1 or 2, wherein the estimation step estimates the time shift and the frequency shifts that are embedded in the signal, with use of a time-frequency shift operator(TFSO) of type 1 representing an estimated time shift, frequency shift, and a phase term due to a half shift of the estimated time shift

[MFC1]

$$\mathcal{T}_{\hat{k}_d, \ell_\mu}^d,$$

a TFSO of type 2 representing time shift, an estimated frequency shift, and a phase term due to a half shift of the estimated frequency shift

[MFC2]

$$\mathcal{T}_{\hat{\ell}_D, -k_\sigma}^{f,d},$$

a TFSO of type 3 representing an observable time shift to be estimated, an observable frequency shift to be estimated, and a phase term due to a half shift of the time shift to be estimated

[MFC3]

$$\mathcal{T}_{k_d, \ell_D}^d$$

or a frequency dual of the TFSO of type 3

[MFC4]

$$\mathcal{T}_{\ell_D, -k_d}^{f,d},$$

and a TFSO of type 4 representing the estimated time shift, the estimated frequency shift, and the phase term due to the half shift of the estimated time shift

[MFC5]

$$\mathcal{T}_{\hat{k}_d, \hat{\ell}_D}^d$$

or a frequency dual of the TFSO of type 4

[MFC6]

$$\mathcal{T}_{\hat{\ell}_D, -\hat{k}_d}^{f,d}$$

[4] [Claim 4] The method recited in claim 3, wherein the estimation step estimates the time shift and the frequency shift that are embedded in the signal, with use of a time-domain-cross-correlation function(TD-CCF) of type 1, represented in terms of the TFSOs of type 1, of type 3, and of type 4, and a frequency-domain-cross-correlation function(FD-CCF) of type 2, represented in terms of the TFSOs of type 2, of type 3, and of type 4.

[5] [Claim 5] The method recited claim 4, wherein the TD-CCF of type 1 and the FD-CCF of type 2 contain a phase distortion(PD) due to a non-commutative shift operation between modulation and demodulation by a carrier f_c and a time shift t_d

[MFC7]

$$e^{i2\pi t_d f_c}$$

or a discretized version of the PD

[MFC8]

$$W^{k_d l_c},$$

and a PD due to the phase term e^{ik_c} of the attenuation factor Ae^{ik_c} .

[6] [Claim 6] The method recited in claim 4 or 5, wherein the estimation step includes two alternative updating steps: (1) updating the estimated frequency shift with reference to the TD-CCF of type 1 and (2) updating the estimated time shift with reference to the FD-CCF of type 2.

[7] [Claim 7] The method recited in any one claim among claims 1 to 6, wherein the estimation step estimates the time shift and the frequency shift that are embedded in the signal, with use of maximum-likelihood estimate(MLE)s of frequency shift for detecting N' time-domain(TD)-templates and MLEs of time shift for detecting N frequency-domain(FD)-templates.

[8] [Claim 8] A receiving apparatus for receiving a signal, comprising an estimation part for estimating a time shift and a frequency shift that are embedded in the signal, with reference to a non-commutative shift parameter space of co-dimension 2, wherein the estimation part estimates the time shift and the frequency shift that are embedded in the signal with use of an operator including a half shift that is a shift symmetrical in time and frequency.

[9] [Claim 9] A method for transmitting a signal, comprising a shift step for time-frequency shifting the signal to be transmitted, with reference to a non-commutative shift parameter space of co-dimension 2, wherein in the shift step, a time and a frequency of the signal to be transmitted are shifted by a half shift that is a shift symmetrical in time and frequency.

[10] [Claim 10] The method recited in claim 9, wherein the shift step generates the signal to be transmitted by phase-shift-keying(PSK)-modulating a chip pulse wave in the time domain(TD) by the TD-phase code(PC) of period N and PSK-modulating the TD-PSK modulated TD-pulse wave by the FD-PC of period N' to generate a multicarrier version of the TD-PSK modulated TD-pulse wave.

[11] [Claim 11] A transmitter apparatus for transmitting a signal, comprising a time-frequency shift part for time-frequency shifting the signal to be transmitted, with reference to a non-commutative shift parameter space of co-dimension 2, wherein the time-frequency shift part time-frequency shifts the signal to be transmitted by a half shift that is a shift symmetrical in time and frequency.

[12] [Claim 12] A transmitter-receiver system, comprising:

a transmitter apparatus; and

a receiver apparatus,

the transmitter apparatus including a time-frequency shift part for time-frequency shifting a signal to be transmitted, with reference to a non-commutative shift parameter space of co-dimension 2, wherein the time-frequency shift part time-frequency shifts the signal to be transmitted by a half shift that is a shift symmetrical in time and frequency,

the receiver apparatus including an estimation part for estimating a time shift and a frequency shift that are embedded in the signal to be transmitted, with reference to the non-commutative shift parameter space of co-dimension 2, wherein the estimation part estimates the time shift and the frequency shift that are embedded in the signal with use of an operator including a half shift that is a shift symmetrical in time and frequency.

[13] [Claim 13] A method for receiving an image signal, comprising an estimation step for estimating a space shift and a spatial frequency shift (SSFS) that are embedded in the image signal, with reference to a non-commutative shift parameter space of co-dimension 2, wherein in the estimation step, the space shift and the spatial frequency shift that are embedded in the image signal are estimated with an operator including a half shift that is a shift symmetrical in space and spatial frequency, and

wherein each of the space shift and the spatial frequency shift has dimension ≥ 2 .

[14] [Claim 14] The method recited in claim 13, wherein the estimation step estimates the SSFSs, with reference to 2-D symmetrical SSF operator(SSFSO)s

[MFC9]

$$\mathcal{T}_{\mathbf{a}_i, \mathbf{b}_i}^{(2), d}$$

or a frequency dual of the 2-D symmetrical SSFSOs

[MFC10]

$$\mathcal{T}_{\mathbf{b}_i, -\mathbf{a}_i}^{(2), f, d}$$

[15] [Claim 15] A method for transmitting an image signal, comprising a shift step for space-spatial frequency shifting the image signal to be transmitted, with reference to a non-commutative shift parameter space, wherein in the shift step, a space and a spatial frequency of the signal to be transmitted are shifted by a half shift that is a shift symmetrical in space and spatial frequency, and wherein each of the space shift and the spatial frequency shift has dimension ≥ 2 .

[16] [Claim 16] The method recited in claim 15, wherein the shift step space-spatial frequency shifts the image signal to be transmitted, with reference to 2-D symmetrical SSFSOs

[MFC9]

$$\mathcal{T}_{\mathbf{a}_i, \mathbf{b}_i}^{(2), d}$$

and a frequency dual of the 2-D symmetrical SSFSOs

[MFC10]

$$\mathcal{T}_{\mathbf{b}_i, -\mathbf{a}_i}^{(2), f, d}$$