US 20190386856A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2019/0386856 A1

Nakajima (43) Pub. Date: Dec. 19, 2019

(54) COMMUNICATION APPARATUS AND RECEIVED SIGNAL PROCESSING METHOD

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(21) Appl. No.: **16/488,873**

(22) PCT Filed: **Mar. 6, 2017**

(86) PCT No.: **PCT/JP2017/008851**

§ 371 (c)(1),
(2) Date: **Aug. 26, 2019**

Publication Classification

(51) **Int. Cl.**
H04L 25/03 (2006.01)
H04L 27/26 (2006.01)

(52) **U.S. Cl.**
CPC ***H04L 25/03159*** (2013.01); *H04L 2025/03541* (2013.01); ***H04L 27/2605*** (2013.01)

(57) **ABSTRACT**

A wireless communication apparatus includes components below. An equalization unit performs equalization processing on a part of a received signal corresponding to a first range and a part of the received signal corresponding to a second range. The first range includes detection target data. The second range is outside the first range. A replica generation unit decomposes the second range, on which equalization processing has been performed, into a plurality of signal components, and reproduces the part of the received signal corresponding to the second range for each of the signal components to generate a replica of an interference component. An interference cancellation unit cancels the interference component from the part of the received signal corresponding to the first range by using the replica. A data extraction unit extracts the detection target data from the received signal.

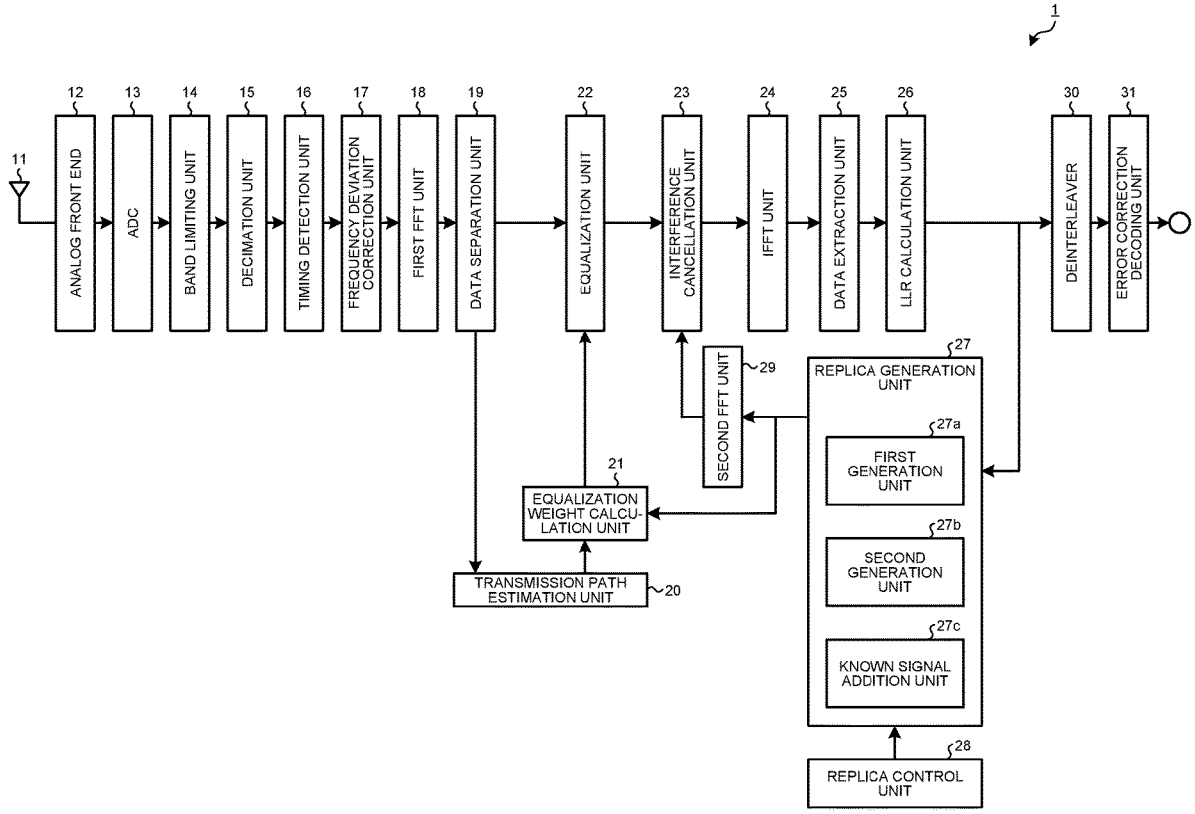


FIG.1

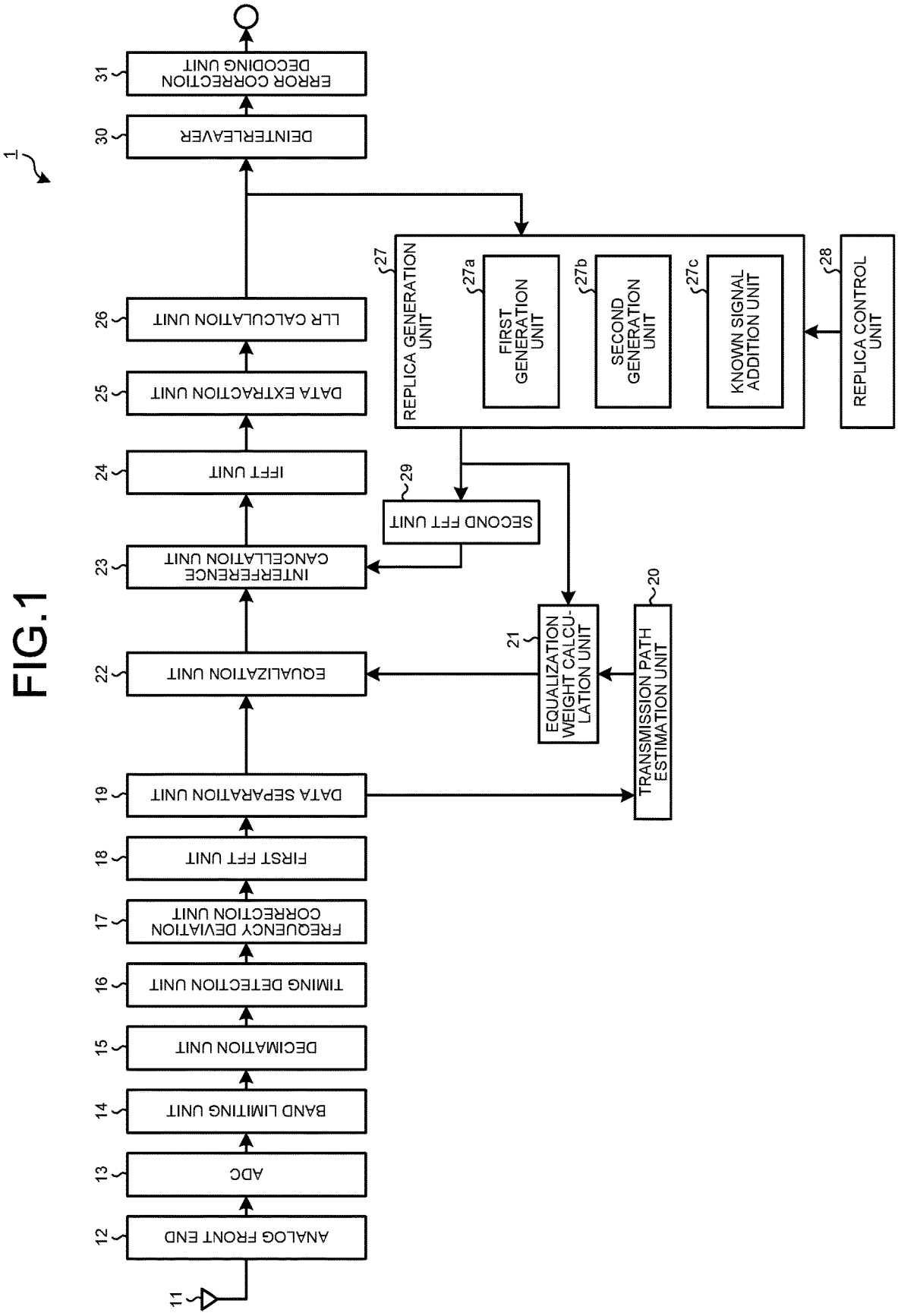

1
11
ANTENNA
12
ANALOG FRONT END
13
ADC
14
BAND LIMITING UNIT
15
DECIMATION UNIT
16
TIMING DETECTION UNIT
17
FREQUENCY DEVIATION CORRECTION UNIT
18
FIRST FFT UNIT
19
DATA SEPARATION UNIT
20
TRANSMISSION PATH ESTIMATION UNIT
21
EQUALIZATION WEIGHT CALCULATION UNIT
22
EQUALIZATION UNIT
23
INTERFERENCE CANCELLATION UNIT
24
IFFT UNIT
25
DATA EXTRACTION UNIT
26
LLR CALCULATION UNIT
27
REPLICA GENERATION UNIT
27a
FIRST GENERATION UNIT
27b
SECOND GENERATION UNIT
27c
KNOWN SIGNAL ADDITION UNIT
28
REPLICA CONTROL UNIT
29
SECOND FFT UNIT
30
DEINTERLEAVER
31
ERROR CORRECTION DECODING UNIT

FIG.2

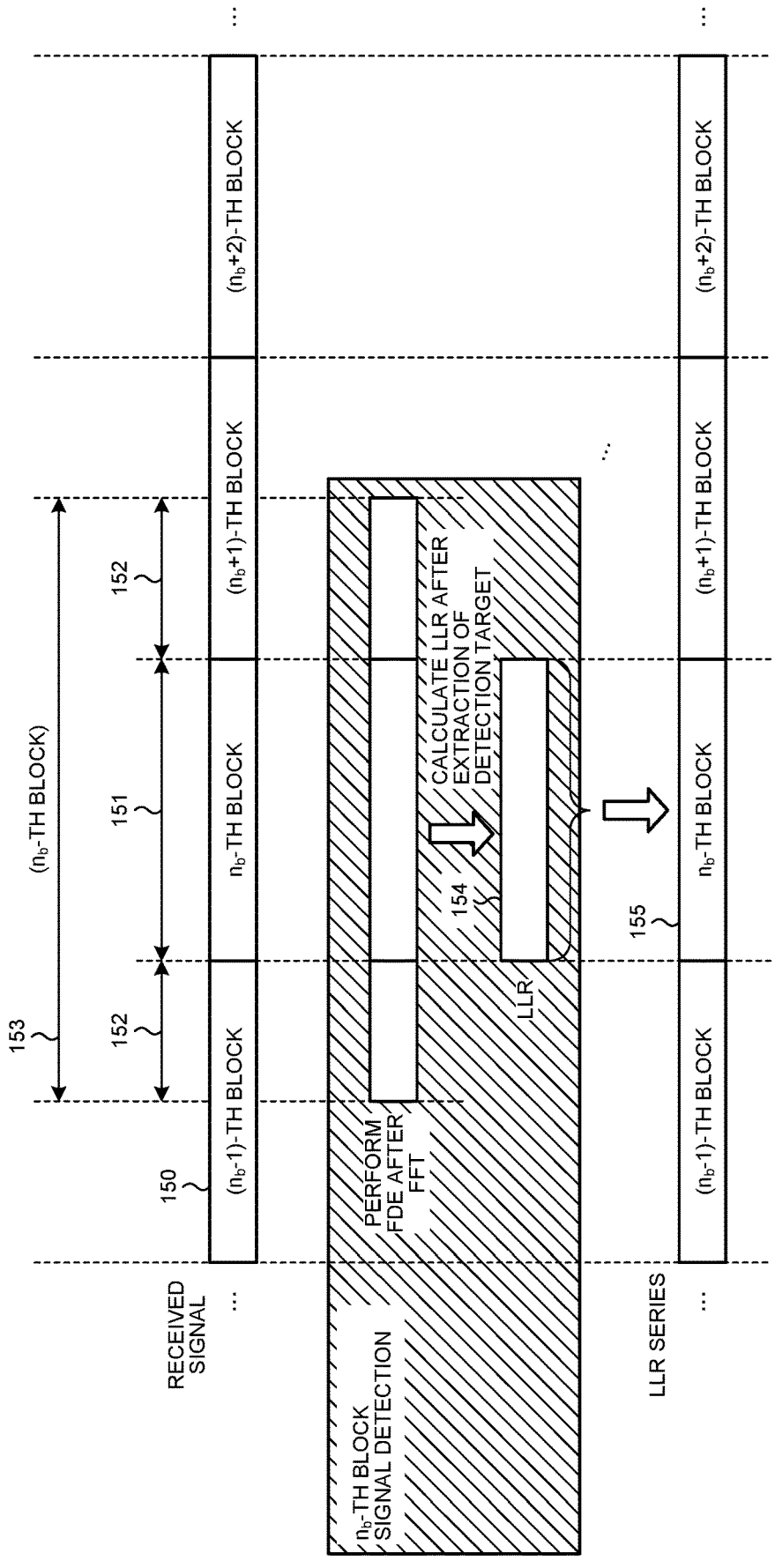

RECEIVED SIGNAL
LLR SERIES
(n_b-1)-TH BLOCK
n_b-TH BLOCK
(n_b+1)-TH BLOCK
(n_b+2)-TH BLOCK
$(n_b$-TH BLOCK)
n_b-TH BLOCK SIGNAL DETECTION
PERFORM FDE AFTER FFT
CALCULATE LLR AFTER EXTRACTION OF DETECTION TARGET
LLR
150
151
152
153
154
155

FIG.3

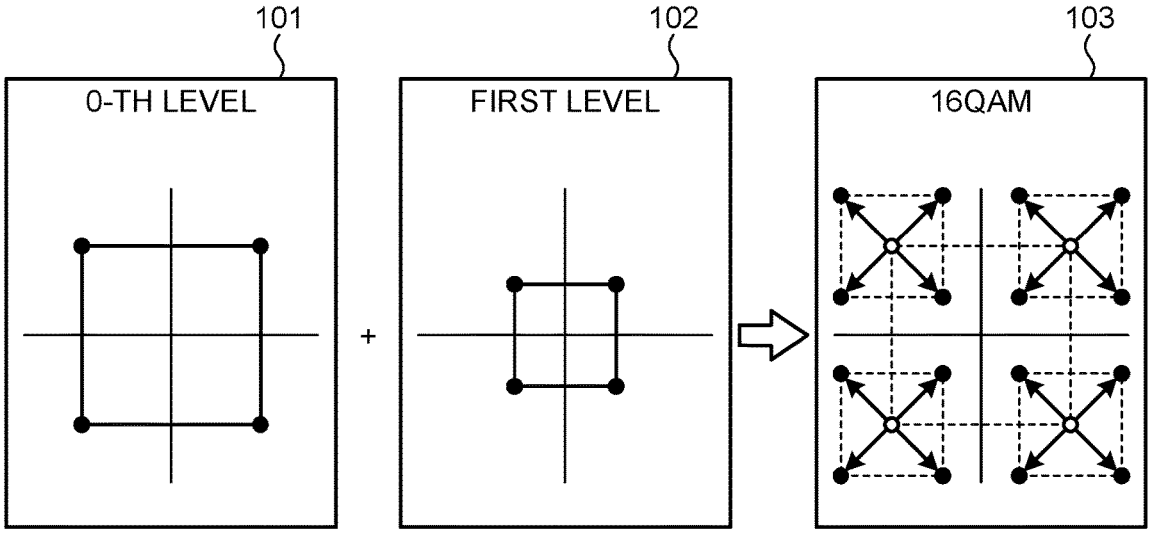

101
0-TH LEVEL
+
102
FIRST LEVEL
103
16QAM

FIG.4

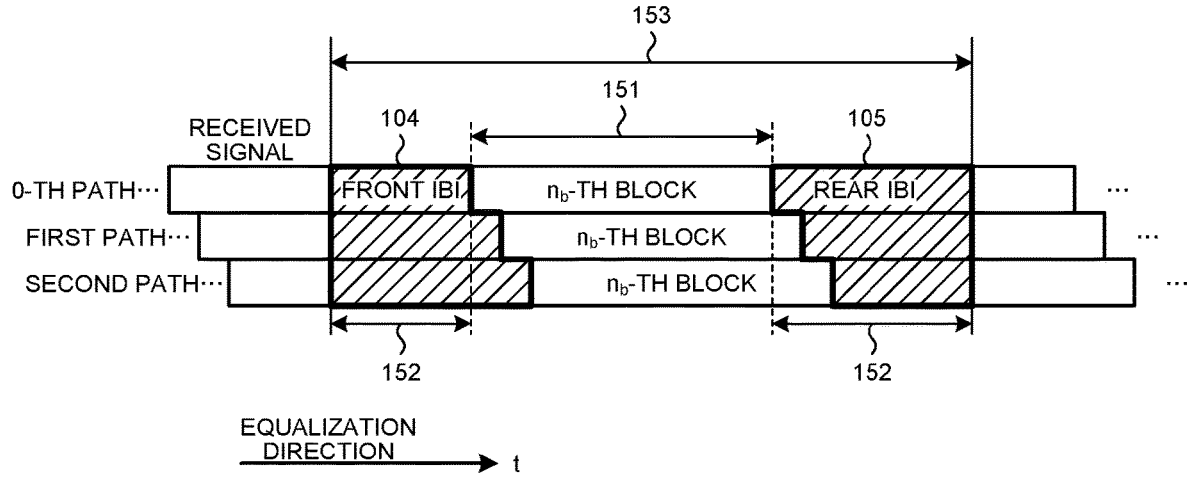

153
151
RECEIVED SIGNAL
104
105
0-TH PATH···
FRONT IBI
n_b-TH BLOCK
REAR IBI
FIRST PATH···
n_b-TH BLOCK
SECOND PATH···
n_b-TH BLOCK
152
152
EQUALIZATION DIRECTION
t

FIG.5

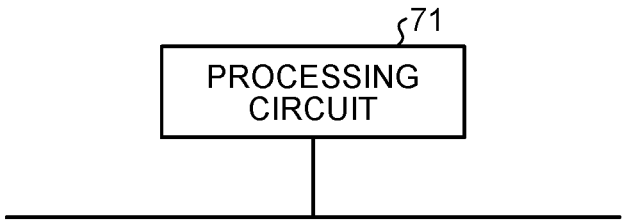


FIG.6

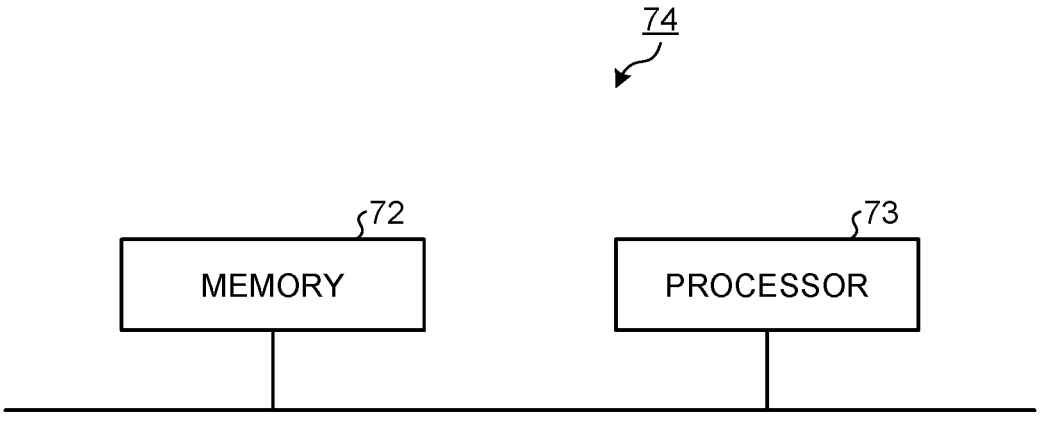


FIG.7

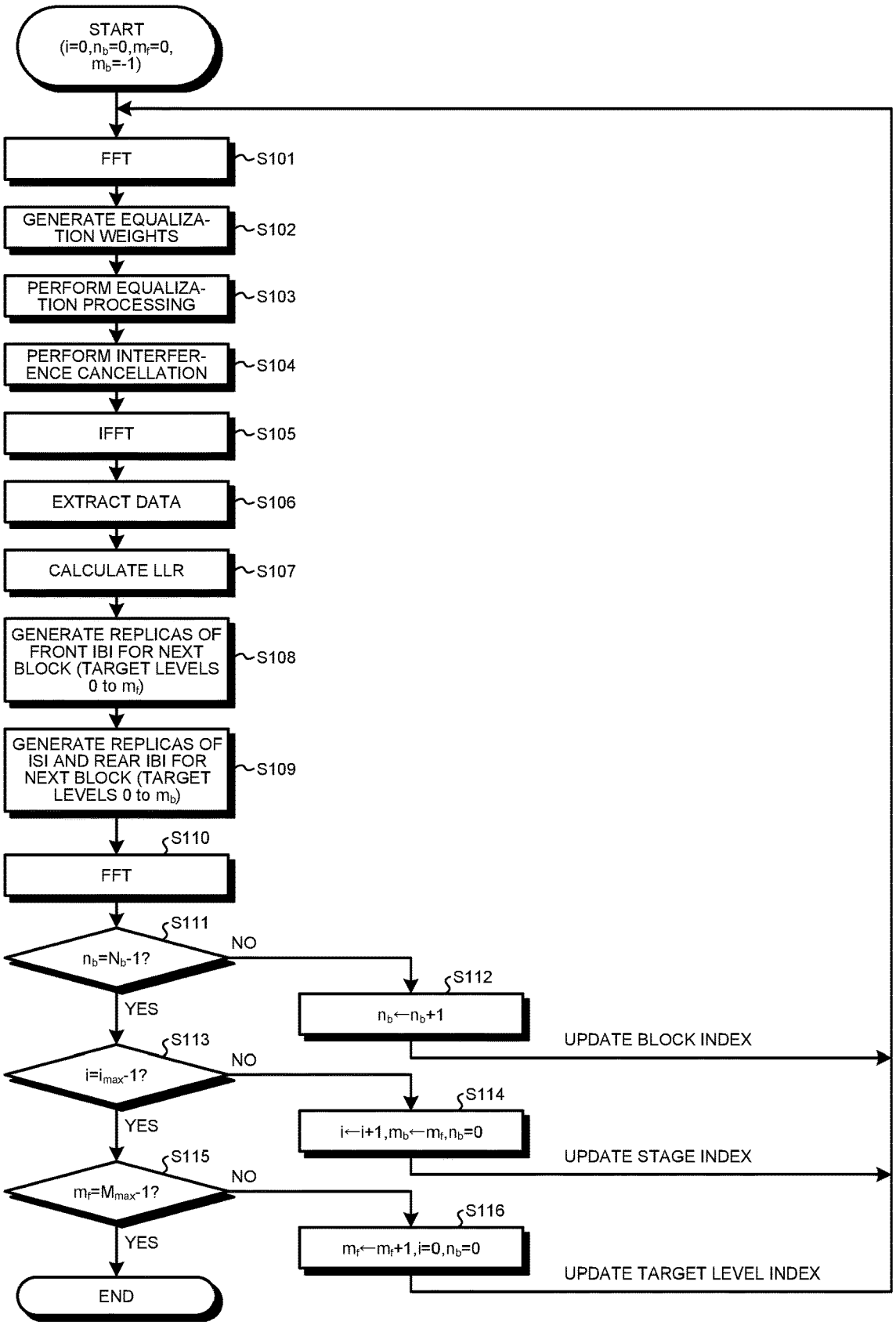

START (i=0,n_b=0,m_f=0, m_b=-1)
FFT
S101
GENERATE EQUALIZATION WEIGHTS
S102
PERFORM EQUALIZATION PROCESSING
S103
PERFORM INTERFERENCE CANCELLATION
S104
IFFT
S105
EXTRACT DATA
S106
CALCULATE LLR
S107
GENERATE REPLICAS OF FRONT IBI FOR NEXT BLOCK (TARGET LEVELS 0 to m_f)
S108
GENERATE REPLICAS OF ISI AND REAR IBI FOR NEXT BLOCK (TARGET LEVELS 0 to m_b)
S109
S110
FFT
S111
n_b=N_b-1?
NO
S112
n_b←n_b+1
UPDATE BLOCK INDEX
YES
S113
i=i_{max}-1?
NO
S114
i←i+1,m_b←m_f,n_b=0
UPDATE STAGE INDEX
YES
S115
m_f=M_{max}-1?
NO
S116
m_f←m_f+1,i=0,n_b=0
UPDATE TARGET LEVEL INDEX
YES
END

FIG.8

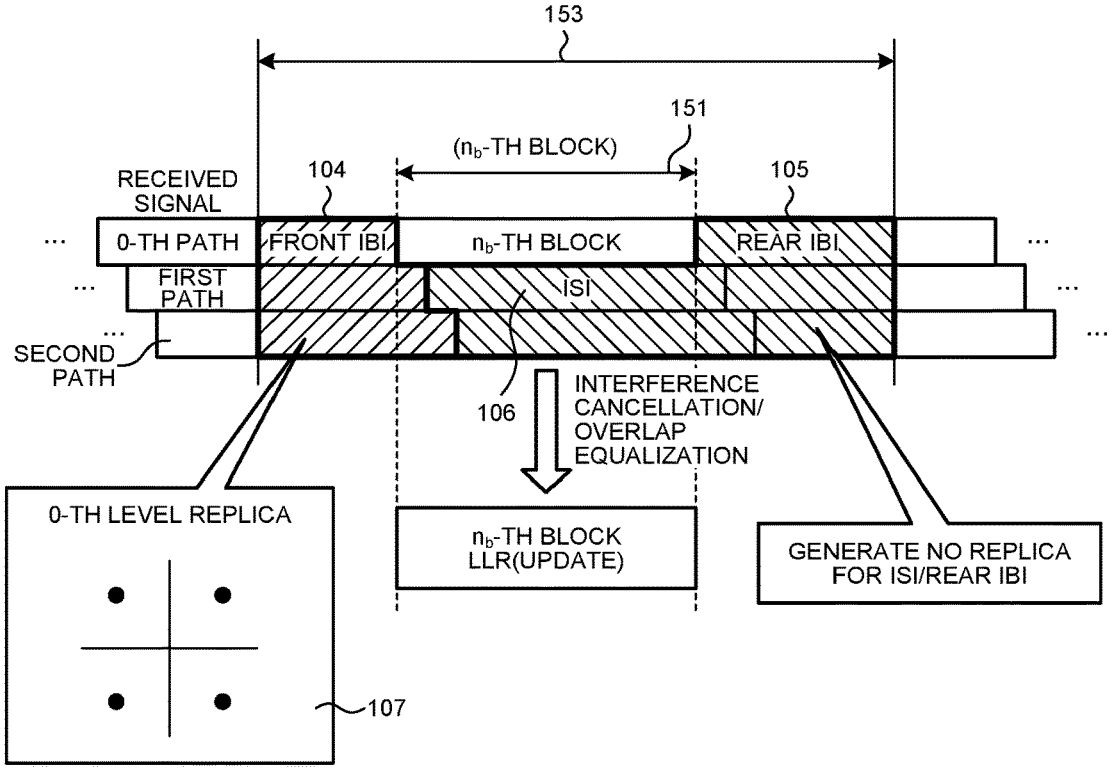

153
151
(n_b-TH BLOCK)
104
105
RECEIVED SIGNAL
0-TH PATH
FRONT IBI
n_b-TH BLOCK
REAR IBI
FIRST PATH
ISI
SECOND PATH
106
INTERFERENCE CANCELLATION/ OVERLAP EQUALIZATION
0-TH LEVEL REPLICA
n_b-TH BLOCK LLR(UPDATE)
GENERATE NO REPLICA FOR ISI/REAR IBI
107

FIG.9

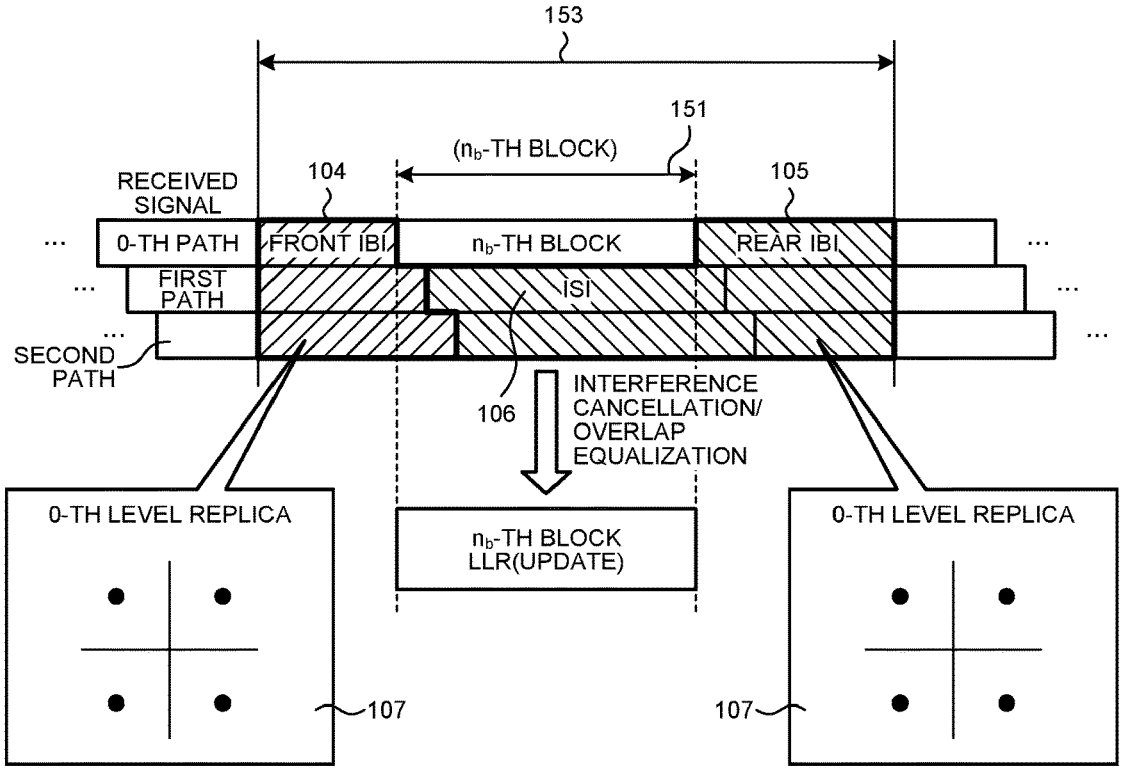

153
151
(n_b-TH BLOCK)
104
105
RECEIVED SIGNAL
0-TH PATH
FRONT IBI
n_b-TH BLOCK
REAR IBI
FIRST PATH
ISI
SECOND PATH
106
INTERFERENCE CANCELLATION/ OVERLAP EQUALIZATION
0-TH LEVEL REPLICA
n_b-TH BLOCK LLR(UPDATE)
0-TH LEVEL REPLICA
107
107

FIG.10

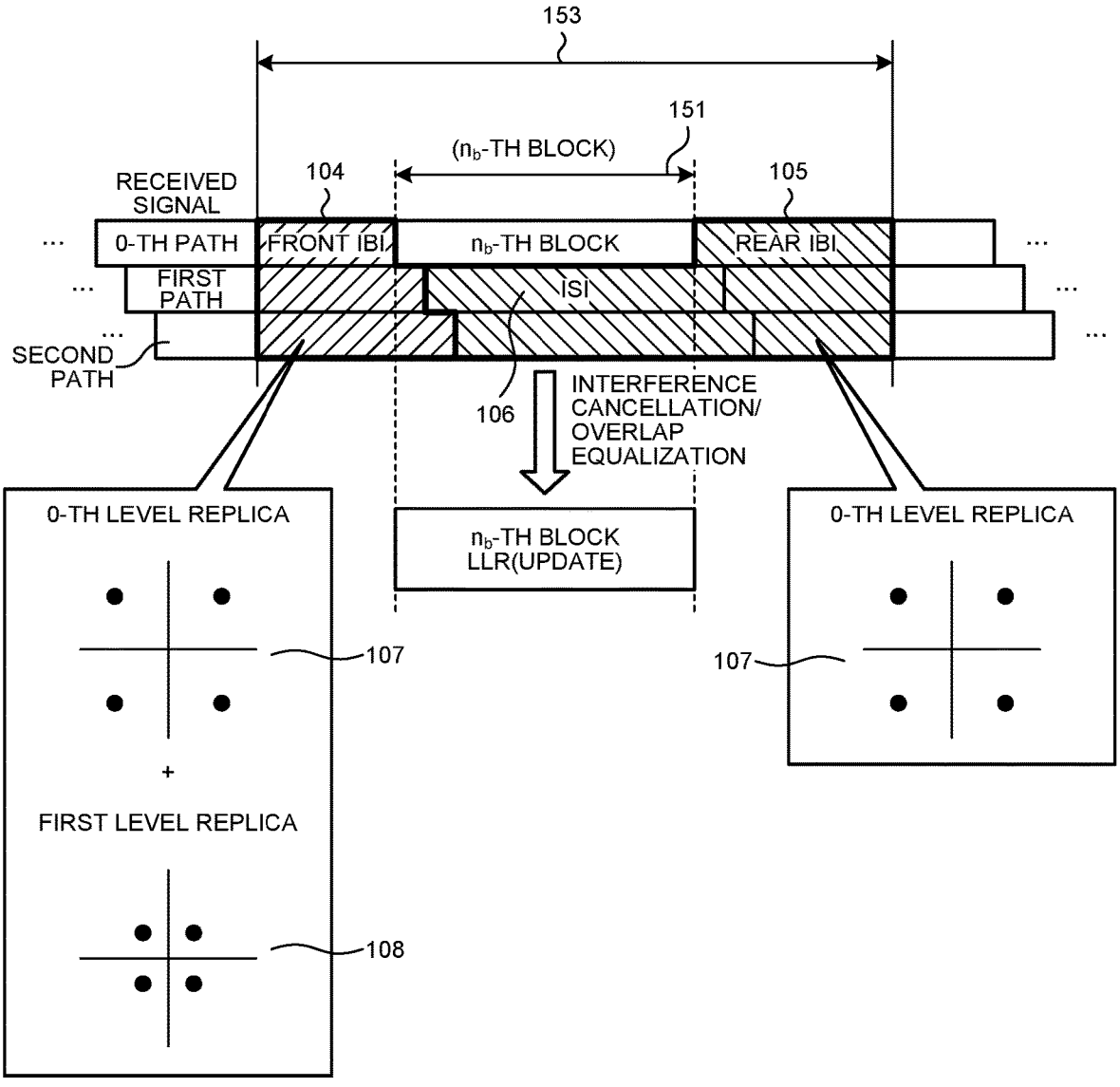

153
151
(n_b-TH BLOCK)
104
105
RECEIVED SIGNAL
0-TH PATH
FRONT IBI
n_b-TH BLOCK
REAR IBI
FIRST PATH
ISI
SECOND PATH
106
INTERFERENCE CANCELLATION/ OVERLAP EQUALIZATION
0-TH LEVEL REPLICA
n_b-TH BLOCK LLR(UPDATE)
0-TH LEVEL REPLICA
107
107
+
FIRST LEVEL REPLICA
108

FIG.11

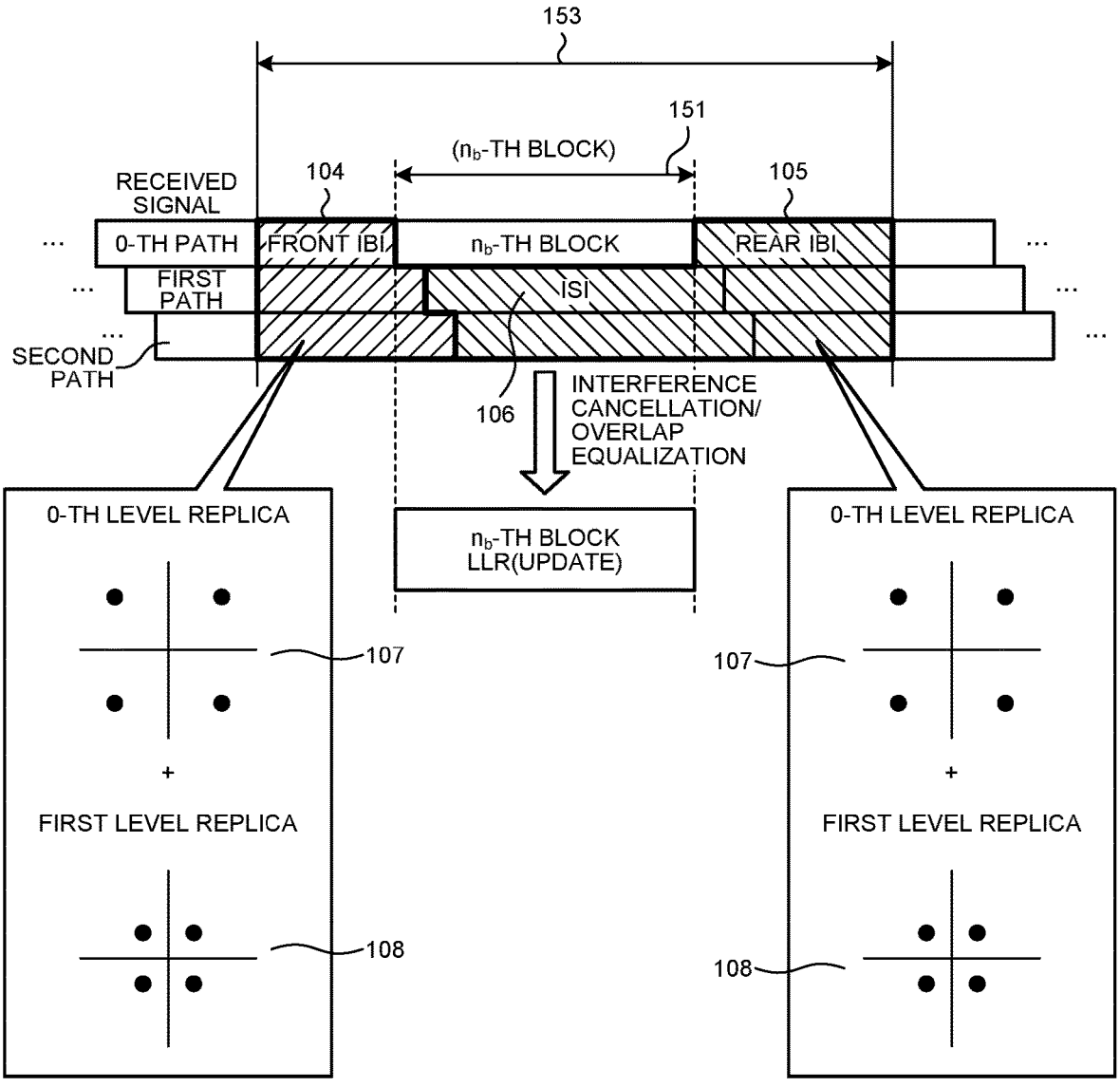

153
151
(n_b-TH BLOCK)
104
105
RECEIVED SIGNAL
0-TH PATH
FRONT IBI
n_b-TH BLOCK
REAR IBI
FIRST PATH
ISI
SECOND PATH
106
INTERFERENCE CANCELLATION/ OVERLAP EQUALIZATION
0-TH LEVEL REPLICA
n_b-TH BLOCK LLR(UPDATE)
0-TH LEVEL REPLICA
107
107
+
+
FIRST LEVEL REPLICA
FIRST LEVEL REPLICA
108
108

FIG.12

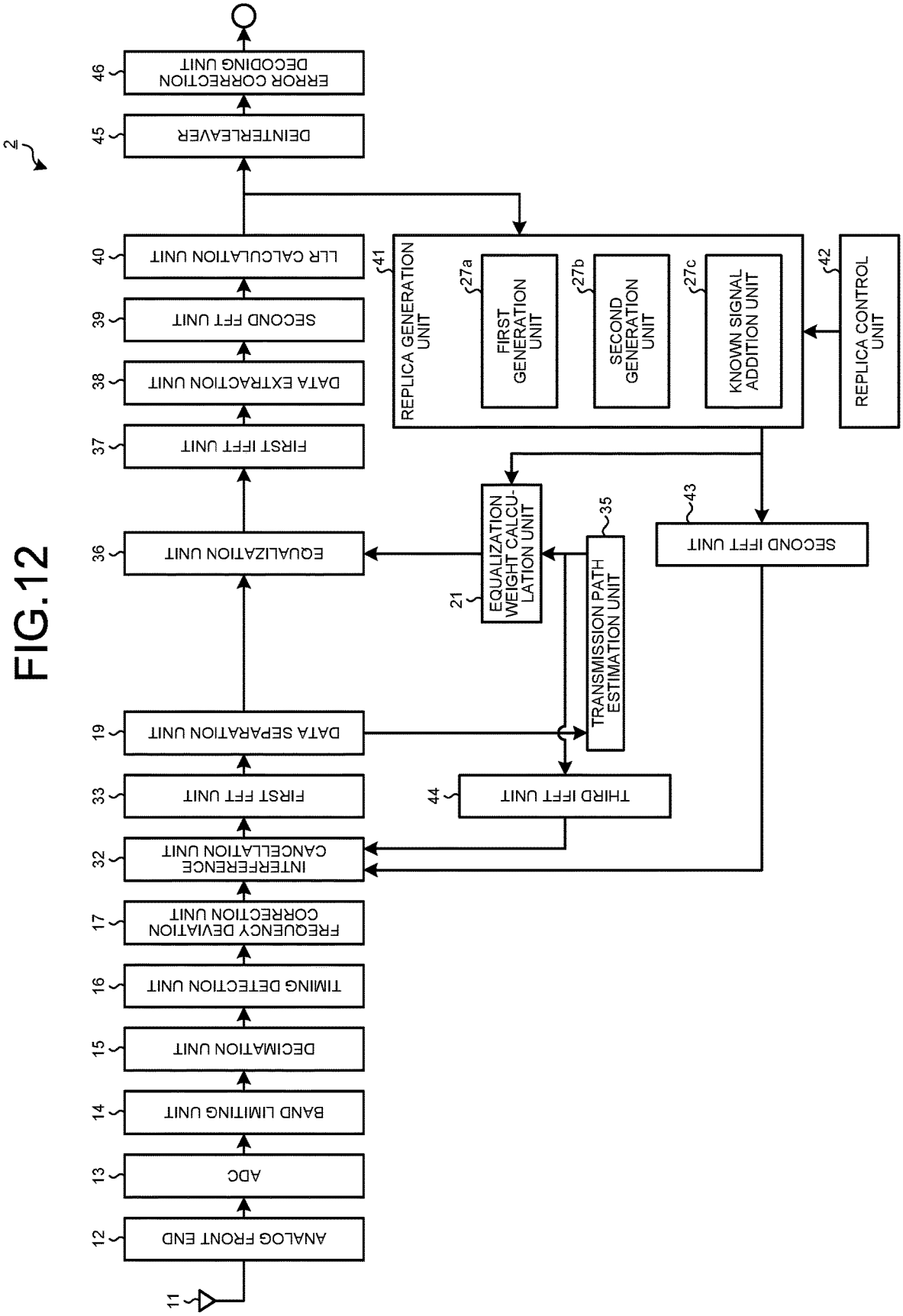

2
11
ANTENNA
12
ANALOG FRONT END
13
ADC
14
BAND LIMITING UNIT
15
DECIMATION UNIT
16
TIMING DETECTION UNIT
17
FREQUENCY DEVIATION CORRECTION UNIT
32
INTERFERENCE CANCELLATION UNIT
33
FIRST FFT UNIT
19
DATA SEPARATION UNIT
36
EQUALIZATION UNIT
37
FIRST IFFT UNIT
38
DATA EXTRACTION UNIT
39
SECOND FFT UNIT
40
LLR CALCULATION UNIT
45
DEINTERLEAVER
46
ERROR CORRECTION DECODING UNIT
21
EQUALIZATION WEIGHT CALCULATION UNIT
35
TRANSMISSION PATH ESTIMATION UNIT
44
THIRD IFFT UNIT
43
SECOND IFFT UNIT
41
REPLICA GENERATION UNIT
27a
FIRST GENERATION UNIT
27b
SECOND GENERATION UNIT
27c
KNOWN SIGNAL ADDITION UNIT
42
REPLICA CONTROL UNIT

FIG.13

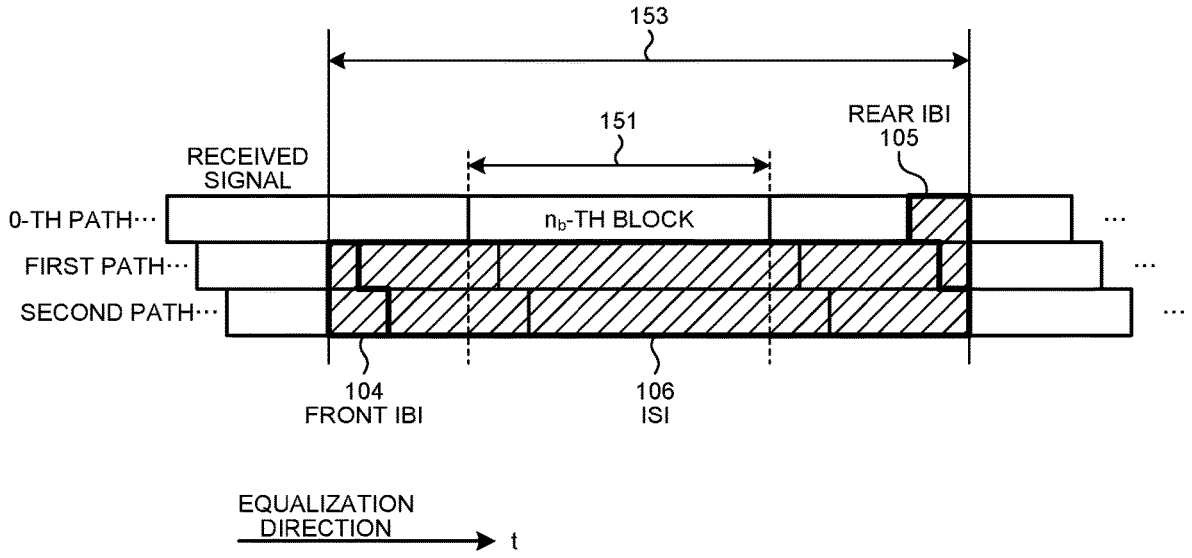

153
151
REAR IBI
105
RECEIVED
SIGNAL
0-TH PATH···
n_b-TH BLOCK
FIRST PATH···
SECOND PATH···
104
FRONT IBI
106
ISI
EQUALIZATION
DIRECTION
t

FIG.14

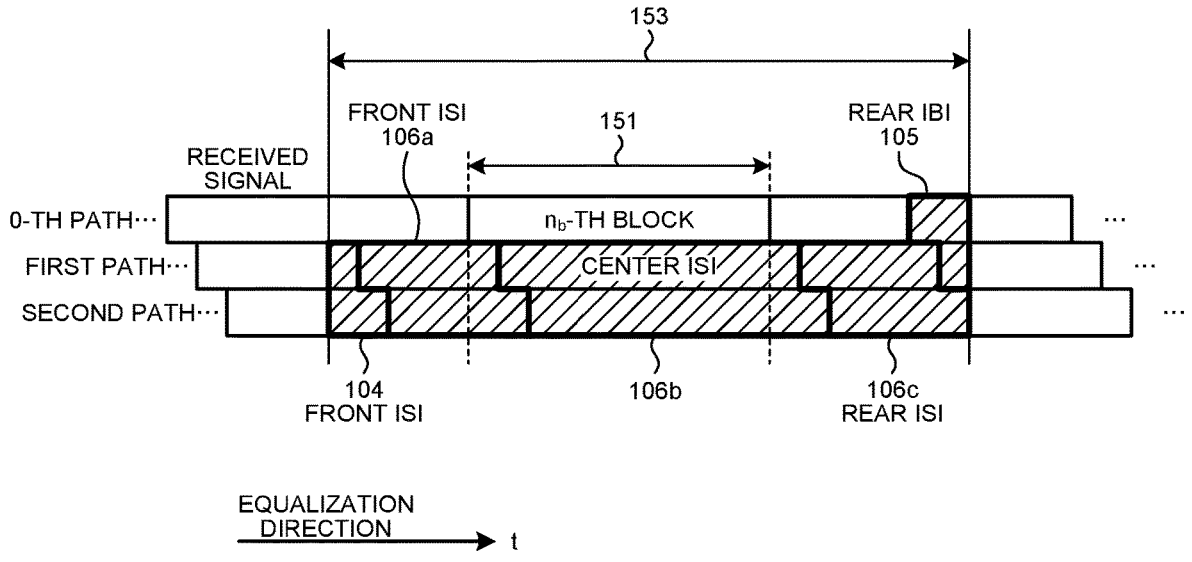

153
FRONT ISI
106a
151
REAR IBI
105
RECEIVED
SIGNAL
0-TH PATH···
n_b-TH BLOCK
FIRST PATH···
CENTER ISI
SECOND PATH···
104
FRONT ISI
106b
106c
REAR ISI
EQUALIZATION
DIRECTION
t

FIG.15

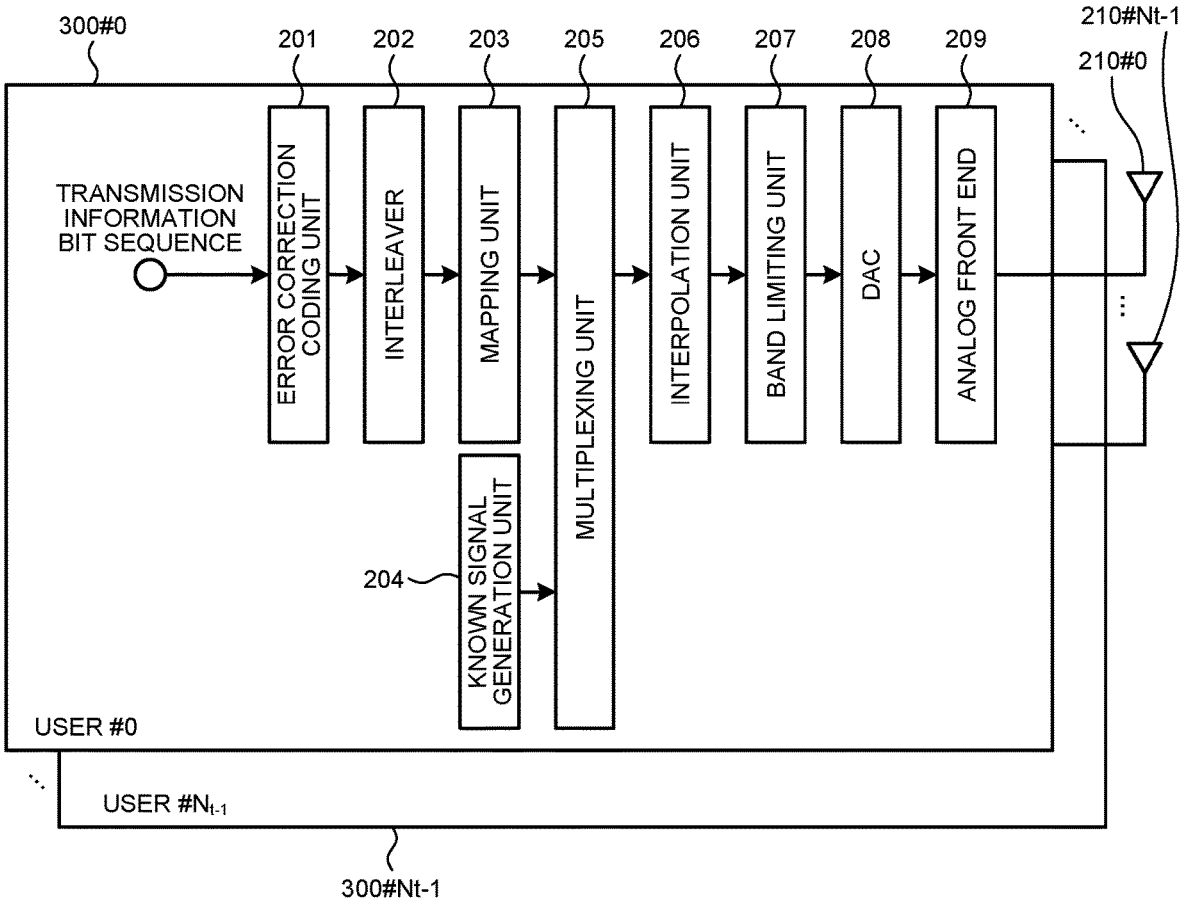

300#0
201
202
203
205
206
207
208
209
210#Nt-1
210#0
TRANSMISSION INFORMATION BIT SEQUENCE
ERROR CORRECTION CODING UNIT
INTERLEAVER
MAPPING UNIT
MULTIPLEXING UNIT
INTERPOLATION UNIT
BAND LIMITING UNIT
DAC
ANALOG FRONT END
204
KNOWN SIGNAL GENERATION UNIT
USER #0
USER #Nt-1
300#Nt-1

FIG.16

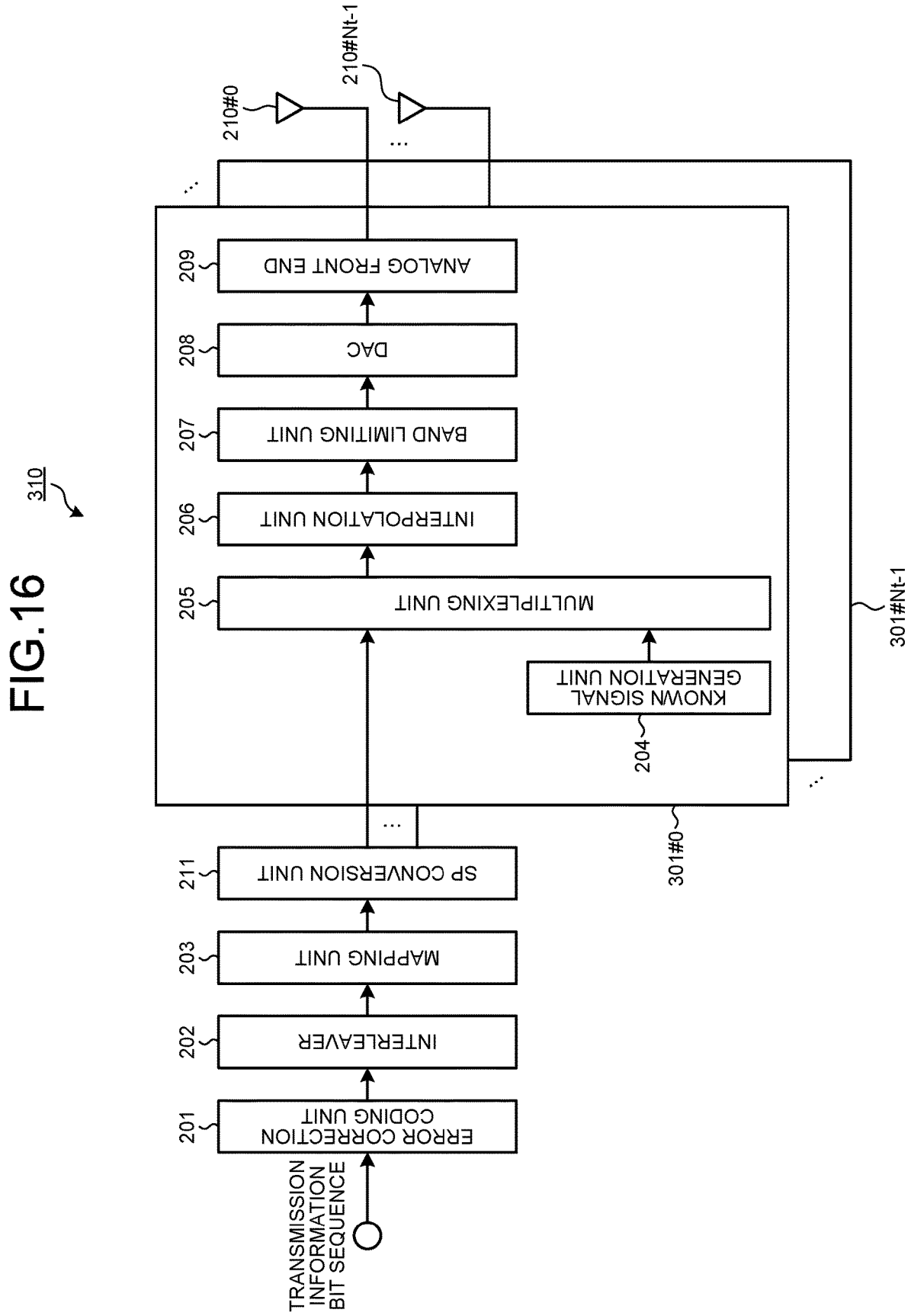

310
TRANSMISSION INFORMATION BIT SEQUENCE
201
ERROR CORRECTION CODING UNIT
202
INTERLEAVER
203
MAPPING UNIT
211
SP CONVERSION UNIT
205
MULTIPLEXING UNIT
206
INTERPOLATION UNIT
207
BAND LIMITING UNIT
208
DAC
209
ANALOG FRONT END
204
KNOWN SIGNAL GENERATION UNIT
301#0
301#Nt-1
210#0
210#Nt-1

FIG.17

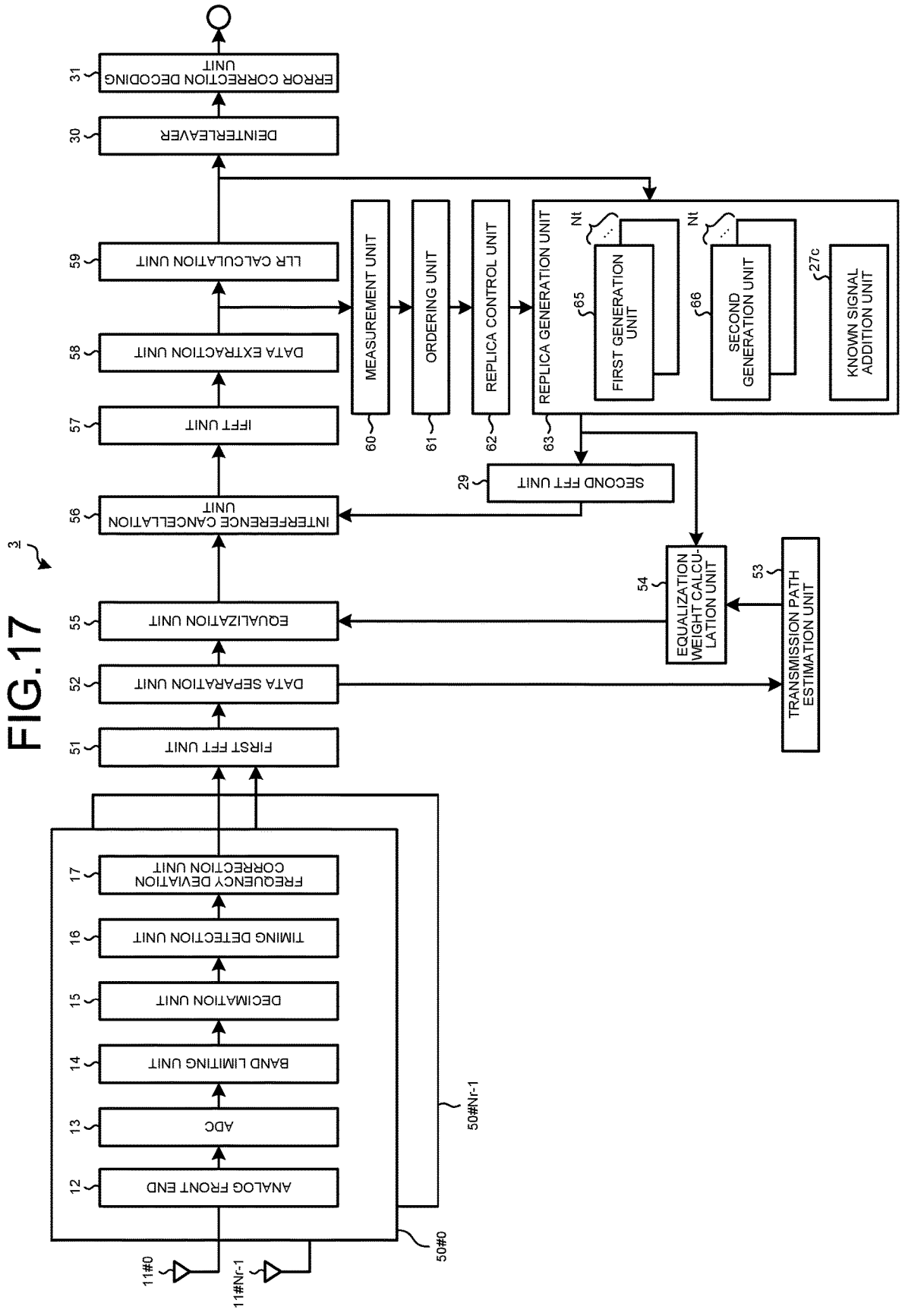

3
11#0
11#Nr-1
50#0
50#Nr-1
12 ANALOG FRONT END
13 ADC
14 BAND LIMITING UNIT
15 DECIMATION UNIT
16 TIMING DETECTION UNIT
17 FREQUENCY DEVIATION CORRECTION UNIT
51 FIRST FFT UNIT
52 DATA SEPARATION UNIT
53 TRANSMISSION PATH ESTIMATION UNIT
54 EQUALIZATION WEIGHT CALCULATION UNIT
55 EQUALIZATION UNIT
56 INTERFERENCE CANCELLATION UNIT
57 IFFT UNIT
58 DATA EXTRACTION UNIT
59 LLR CALCULATION UNIT
29 SECOND FFT UNIT
60 MEASUREMENT UNIT
61 ORDERING UNIT
62 REPLICA CONTROL UNIT
63 REPLICA GENERATION UNIT
65 FIRST GENERATION UNIT
66 SECOND GENERATION UNIT
27c KNOWN SIGNAL ADDITION UNIT
Nt
Nt
30 DEINTERLEAVER
31 ERROR CORRECTION DECODING UNIT

FIG.18

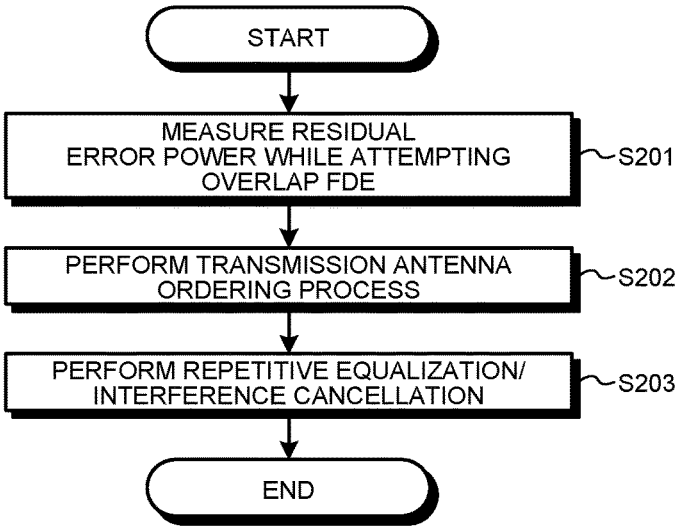

START
MEASURE RESIDUAL ERROR POWER WHILE ATTEMPTING OVERLAP FDE
S201
PERFORM TRANSMISSION ANTENNA ORDERING PROCESS
S202
PERFORM REPETITIVE EQUALIZATION/ INTERFERENCE CANCELLATION
S203
END

FIG.19

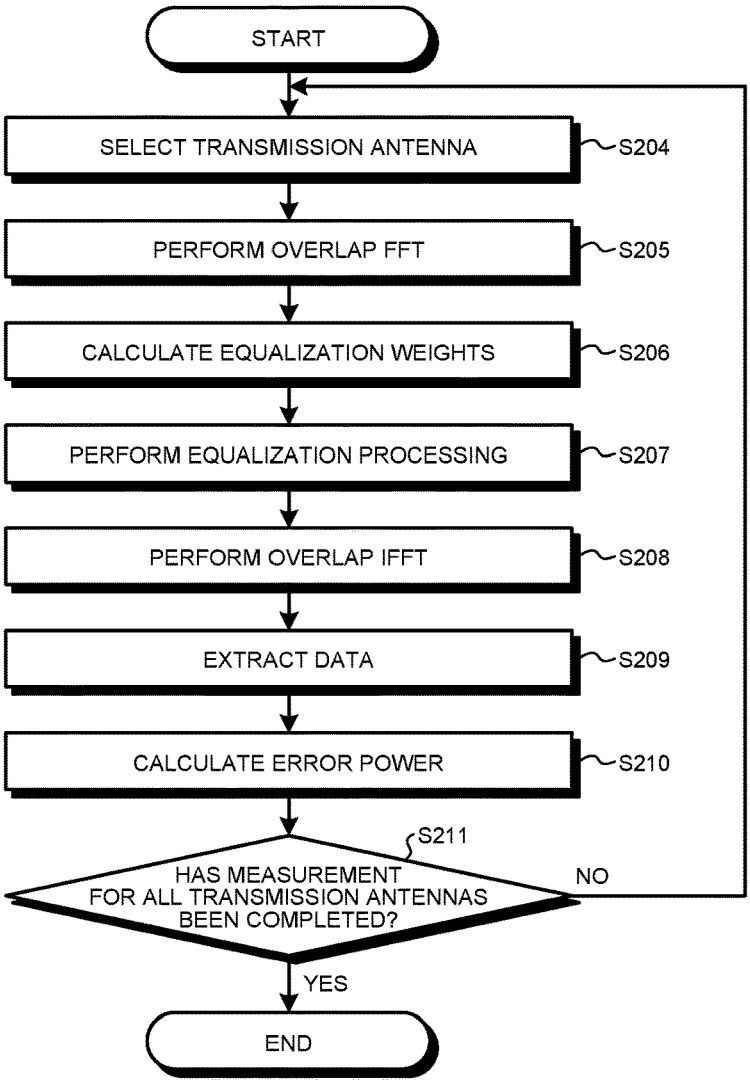
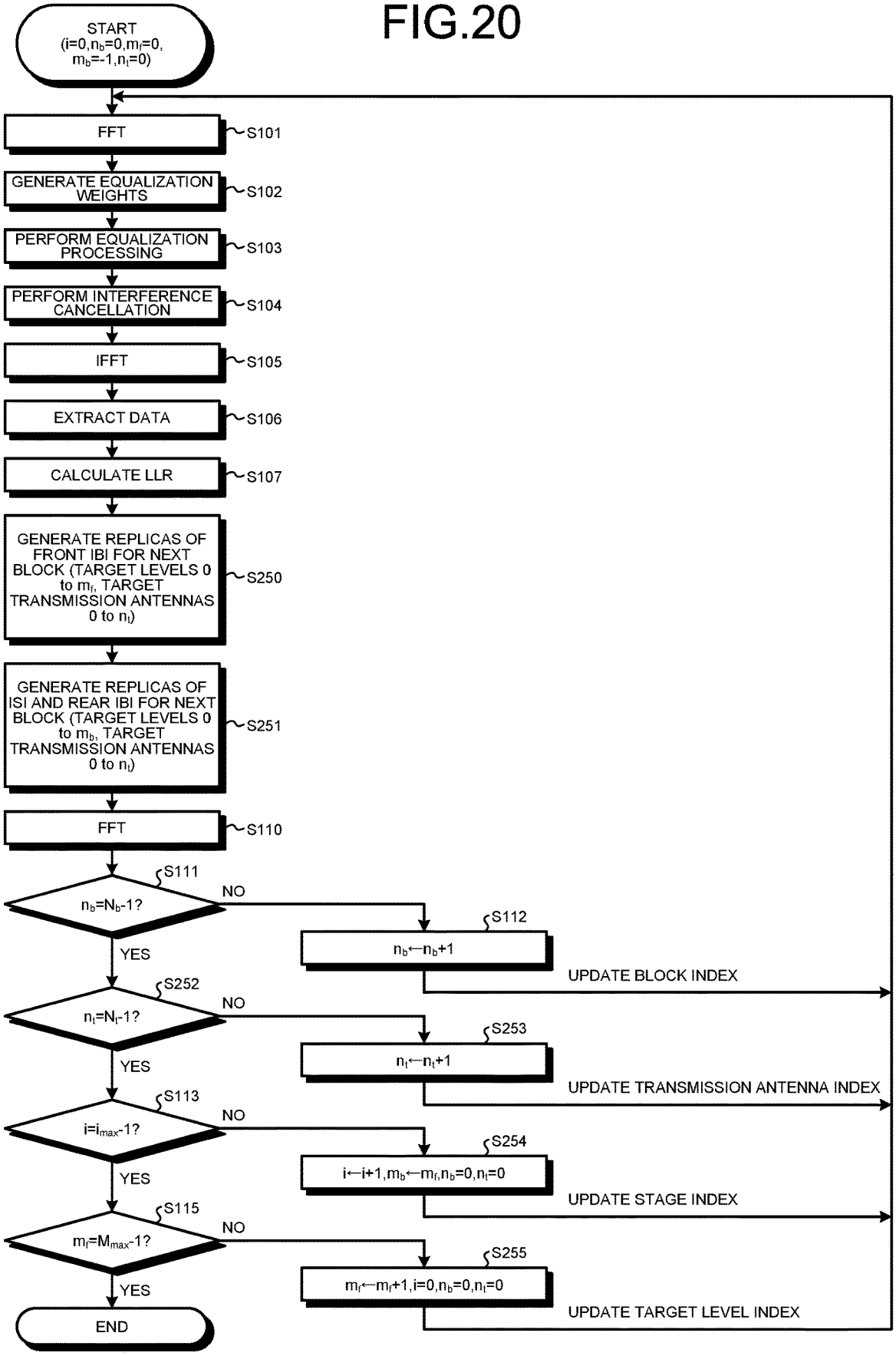

START
SELECT TRANSMISSION ANTENNA
S204
PERFORM OVERLAP FFT
S205
CALCULATE EQUALIZATION WEIGHTS
S206
PERFORM EQUALIZATION PROCESSING
S207
PERFORM OVERLAP IFFT
S208
EXTRACT DATA
S209
CALCULATE ERROR POWER
S210
S211
HAS MEASUREMENT FOR ALL TRANSMISSION ANTENNAS BEEN COMPLETED?
NO
YES
END

FIG.20


START (i=0,n_b=0,m_f=0, m_b=-1,n_t=0)
FFT
S101
GENERATE EQUALIZATION WEIGHTS
S102
PERFORM EQUALIZATION PROCESSING
S103
PERFORM INTERFERENCE CANCELLATION
S104
IFFT
S105
EXTRACT DATA
S106
CALCULATE LLR
S107
GENERATE REPLICAS OF FRONT IBI FOR NEXT BLOCK (TARGET LEVELS 0 to m_f, TARGET TRANSMISSION ANTENNAS 0 to n_t)
S250
GENERATE REPLICAS OF ISI AND REAR IBI FOR NEXT BLOCK (TARGET LEVELS 0 to m_b, TARGET TRANSMISSION ANTENNAS 0 to n_t)
S251
FFT
S110
S111
n_b=N_b-1?
NO
S112
n_b←n_b+1
UPDATE BLOCK INDEX
YES
S252
n_t=N_t-1?
NO
S253
n_t←n_t+1
UPDATE TRANSMISSION ANTENNA INDEX
YES
S113
i=i_{max}-1?
NO
S254
i←i+1,m_b←m_f,n_b=0,n_t=0
UPDATE STAGE INDEX
YES
S115
m_f=M_{max}-1?
NO
S255
m_f←m_f+1,i=0,n_b=0,n_t=0
UPDATE TARGET LEVEL INDEX
YES
END

COMMUNICATION APPARATUS AND RECEIVED SIGNAL PROCESSING METHOD

FIELD

[0001] The present invention relates to a communication apparatus and a received signal processing method, for performing single carrier or multicarrier transmission in which a cyclic prefix (CP) is not used or a delay amount in a delay wave exceeds a CP length.

BACKGROUND

[0002] In digital wireless communication, a process of equalizing a received signal is performed on a receiving side so as to prevent inter symbol interference (ISI) caused by the spread of delay waves. When equalization processing is performed in a frequency domain, there is used a technique for adding, as a guard interval called CP, a copy of data at the end of each of divided data pieces of a predetermined length, to the top of each of the divided data pieces. Addition of the CP enables prevention of interference from adjacent blocks when a received signal is converted into a signal in the frequency domain. However, a CP length needs to be larger than a multipath delay amount. Thus, the CP length needs to be increased so as to avoid the influence of a large multipath delay. Accordingly, there is a problem of a decrease in transmission efficiency due to an increase in the CP length.

[0003] There is known a method of block transmission using no CP called overlap frequency domain equalization (FDE). According to this method, in order to improve transmission efficiency, a section including a detection target block is converted into the frequency domain, and equalized in the frequency domain. Then, the detection target block is extracted after the section is converted into a time domain. In the overlap frequency domain equalization, interference components of inter block interference (IBI) and inter symbol interference remain in a received signal after equalization in the frequency domain. Therefore, reception performance tends to be lower than that in block transmission using a CP.

[0004] Patent Literature 1 discloses a method for reducing interference components included in a received signal in block transmission using no CP. In this method, replicas of the interference components are generated by use of the received signal on which equalization processing has been performed. Then, the remaining interference components are canceled by use of the generated replicas. Cancellation of the interference components is repeated by use of the overlap frequency domain equalization and the replicas. As a result, the interference components included in the received signal are reduced and a decrease in reception performance is prevented.

CITATION LIST

Patent Literature

[0005] Patent Literature 1: Japanese Patent Application Laid-open No. 2012-70196

SUMMARY

Technical Problem

[0006] However, in the technique described in Patent Literature 1 above, the replica is generated in frame units. Thus, accuracy in generating the replica is low. Therefore, the technique described in Patent Literature 1 has a problem in that the interference components still remaining in the received signal cannot be reduced in some cases.

[0007] The present invention has been made in view of the above. An object of the present invention is to provide a communication apparatus capable of increasing accuracy in generating a replica of an interference component to prevent a decrease in reception performance in single carrier or multicarrier transmission in which a CP is not used or a delay amount in a delay wave exceeds a CP length.

Solution to Problem

[0008] In order to solve the problems described above and to achieve the object, a communication apparatus according to the present invention includes: an equalization unit that performs equalization processing on a part of a received signal corresponding to a first range and a part of the received signal corresponding to a second range, the first range including detection target data, the second range being outside the first range; a replica generation unit that generates a replica of an interference component for the part of the received signal corresponding to the first range by using the part of the received signal corresponding to the second range on which the equalization processing has been performed; an interference cancellation unit that cancels the interference component from the part of the received signal corresponding to the first range by using the generated replica; and a data extraction unit that extracts the detection target data from the received signal. The replica generation unit is characterized by decomposing the part of the received signal corresponding to the second range into a plurality of signal components, and reproducing the part of the received signal corresponding to the second range for each of the signal components to generate the replica.

Advantageous Effects of Invention

[0009] The communication apparatus according to the present invention can achieve an effect of generating a replica of inter block interference with higher accuracy to prevent a decrease in reception performance in single carrier or multicarrier transmission in which a CP is not used or a delay amount in a delay wave exceeds a CP length.

BRIEF DESCRIPTION OF DRAWINGS

[0010] FIG. **1** is a diagram illustrating an example of a reception configuration of a wireless communication apparatus according to a first embodiment of the present invention.

[0011] FIG. **2** is a diagram illustrating the concept of overlap frequency domain equalization to be performed by the wireless communication apparatus illustrated in FIG. **1**.

[0012] FIG. **3** is a diagram illustrating an example of signal components to be used by a replica generation unit illustrated in FIG. **1**, for generating a replica.

[0013] FIG. **4** is a diagram illustrating definitions of interference components to be canceled from a received signal, by the wireless communication apparatus illustrated in FIG. **1**.

[0014] FIG. **5** is a diagram illustrating an example of implementing the function of the wireless communication apparatus illustrated in FIG. **1** by use of a processing circuit that is dedicated hardware.

[0015] FIG. **6** is a diagram illustrating an example of implementing the function of the wireless communication apparatus illustrated in FIG. **1** by use of a processing circuit that is a control circuit.

[0016] FIG. **7** is a flowchart for describing a receiving operation of the wireless communication apparatus illustrated in FIG. **1**.

[0017] FIG. **8** is a diagram illustrating a first example of a replica to be used in an interference cancellation process to be performed by the wireless communication apparatus illustrated in FIG. **1**.

[0018] FIG. **9** is a diagram illustrating a second example of the replica to be used in the interference cancellation process to be performed by the wireless communication apparatus illustrated in FIG. **1**.

[0019] FIG. **10** is a diagram illustrating a third example of the replica to be used in the interference cancellation process to be performed by the wireless communication apparatus illustrated in FIG. **1**.

[0020] FIG. **11** is a diagram illustrating a fourth example of the replica to be used in the interference cancellation process to be performed by the wireless communication apparatus illustrated in FIG. **1**.

[0021] FIG. **12** is a diagram illustrating a wireless communication apparatus according to a variation of the first embodiment of the present invention.

[0022] FIG. **13** is a diagram illustrating a first variation of the definitions of the interference components to be canceled from the received signal, by the wireless communication apparatus illustrated in FIG. **1**.

[0023] FIG. **14** is a diagram illustrating a second variation of the definitions of the interference components to be canceled from the received signal, by the wireless communication apparatus illustrated in FIG. **1**.

[0024] FIG. **15** is a diagram illustrating a configuration for multiple users to transmit signals in a wireless communication system according to a second embodiment of the present invention.

[0025] FIG. **16** is a diagram illustrating a configuration for transmitting signals by spatial multiplexing in the wireless communication system according to the second embodiment of the present invention.

[0026] FIG. **17** is a diagram illustrating the configuration of a wireless communication apparatus according to the second embodiment of the present invention.

[0027] FIG. **18** is a flowchart illustrating the overall operation of the wireless communication apparatus illustrated in FIG. **17**.

[0028] FIG. **19** is a flowchart illustrating a detailed operation of step **S201** in FIG. **18**.

[0029] FIG. **20** is a flowchart illustrating a detailed operation of step **S203** in FIG. **18**.

DESCRIPTION OF EMBODIMENTS

[0030] Hereinafter, communication apparatuses and received signal processing methods according to embodiments of the present invention will be described in detail based on the drawings. It should be noted that the present invention is not limited to the embodiments.

First Embodiment

[0031] FIG. **1** is a diagram illustrating an example of a reception configuration of a wireless communication apparatus according to a first embodiment of the present invention. A wireless communication apparatus **1** illustrated in FIG. **1** includes an antenna **11**, an analog front end **12**, an analog-to-digital converter (ADC) **13**, a band limiting unit **14**, a decimation unit **15**, a timing detection unit **16**, a frequency deviation correction unit **17**, and a first fast Fourier transform (FFT) unit **18**. The wireless communication apparatus **1** further includes a data separation unit **19**, a transmission path estimation unit **20**, an equalization weight calculation unit **21**, an equalization unit **22**, an interference cancellation unit **23**, an inverse FFT (IFFT) unit **24**, a data extraction unit **25**, and a log likelihood ratio (LLR) calculation unit **26**. The wireless communication apparatus **1** further includes a replica generation unit **27**, a replica control unit **28**, a second FFT unit **29**, a deinterleaver **30**, and an error correction decoding unit **31**. The replica generation unit **27** includes a first generation unit **27***a*, a second generation unit **27***b*, and a known signal addition unit **27***c*.

[0032] The antenna **11** receives a wireless signal from a transmitting-side wireless communication apparatus. The wireless signal received by the antenna **11** includes a known signal such as a known preamble added on the transmitting side. The antenna **11** inputs the received signal to the analog front end **12**. The analog front end **12** down-converts the signal input from the antenna **11**, and inputs the down-converted signal to the ADC **13**. The ADC **13** converts the input analog signal into a digital signal, and inputs the digital signal to the band limiting unit **14**. The band limiting unit **14** limits the band of the input digital signal, and inputs the digital signal with the limited band to the decimation unit **15**. The decimation unit **15** reduces the sampling rate of the input signal, and inputs the signal subjected to reduction of the sampling rate to the timing detection unit **16**. The timing detection unit **16** detects the symbol block timing of the input signal. Specifically, the timing detection unit **16** detects the symbol block timing by performing cross-correlation processing using a known preamble and the like, and inputs the signal to the frequency deviation correction unit **17**.

[0033] The frequency deviation correction unit **17** estimates the frequency deviation of the input signal by using the known preamble and the like, and performs frequency deviation correction on the data area of the input signal by using the estimated frequency deviation. Then, the first FFT unit **18** performs FFT processing on the input signal to convert the input signal into a signal in the frequency domain, and inputs the received signal in the frequency domain to the data separation unit **19**. The data separation unit **19** separates the input received signal into a known signal including the above-described known preamble and the like, and data. The data separation unit **19** inputs the known signal to the transmission path estimation unit **20**, and inputs a signal in the frequency domain including the data to the equalization unit **22**. The transmission path estimation unit **20** estimates a transmission path by using the input known signal. The equalization weight calculation unit **21** calculates an equalization weight for overlap frequency domain equalization for each frequency based on a transmission path estimation result and a replica to be described below, and inputs the calculated equalization weights to the equalization unit **22**. The equalization weight is a weight determined based on the least-squares-error criterion on the basis of the received signal on which interference cancellation has been performed. The equalization weight is calcu-

lated in consideration of the electric power of an interference component to be canceled after equalization processing. The equalization unit **22** performs equalization processing on a part of the received signal corresponding to a first range and a part of the received signal corresponding to a second range for each frequency by using the input equalization weights. The first range includes detection target data. The second range is outside the first range.

[0034] The interference cancellation unit **23** cancels an interference component for the part of the received signal corresponding to the first range from the received signal. The interference cancellation unit **23** cancels the interference component by using a replica generated by the replica generation unit **27** to be described below. The IFFT unit **24** performs IFFT processing on the received signal from which the interference component has been canceled, to convert the received signal into a signal in a time domain, and inputs the converted signal to the data extraction unit **25**. The data extraction unit **25** extracts the detection target data from the input received signal, and inputs the detection target data to the LLR calculation unit **26**. The data extraction unit **25** extracts the detection target data from the central part of the received signal in the time domain by using the fact that interference components are unevenly distributed at both ends of the received signal in the time domain. The LLR calculation unit **26** calculates LLRs of all the bits of each symbol, and inputs the calculated LLRs to the replica generation unit **27**.

[0035] FIG. **2** is a diagram illustrating the concept of overlap frequency domain equalization to be performed by the wireless communication apparatus **1** illustrated in FIG. **1**. Assuming that detection target data corresponds to an n_b-th block among a plurality of blocks included in a received signal **150**, the first FFT unit **18** converts a part of the received signal corresponding to a processing range **153** into a signal in the frequency domain. The processing range **153** includes a first range **151** and a second range **152**. The first range **151** is a detection target range including the detection target data. The second range **152** is a range outside the first range. Therefore, the equalization unit **22** performs equalization processing on the part of the received signal corresponding to the processing range **153**. The interference cancellation unit **23** cancels an interference component from the received signal on which equalization processing has been performed. The data extraction unit **25** extracts the detection target data from the received signal. Then, the LLR calculation unit **26** calculates an LLR **154**. Here, the n_b-th block is assumed to be the detection target data. Meanwhile, it is possible to obtain an LLR series **155** by similarly performing extraction of detection target data and calculating LLRs also for the other blocks.

[0036] The description returns to FIG. **1**. The replica generation unit **27** decomposes a part of the received signal corresponding to the second range **152** into a plurality of signal components, and reproduces the part of the received signal corresponding to the second range **152** for each signal component to generate a replica. The replica generation unit **27** generates a replica by using the signal component specified by the replica control unit **28**. The replica generated by the replica generation unit **27** is used for cancelling an interference component from the received signal in the interference cancellation unit **23**.

[0037] FIG. **3** is a diagram illustrating an example of signal components to be used by the replica generation unit **27** illustrated in FIG. **1**, for generating a replica. In the present embodiment, a received signal subjected to multi-level modulation is regarded as a plurality of hierarchized sub-symbols. In this case, the sub-symbol is an example of a signal component. For example, a 16 quadrature amplitude modulation (QAM) symbol **103** can be regarded as a quadrature phase shift keying (QPSK) symbol hierarchized into two levels different in signal power. The two levels of the QPSK symbol are referred to as a 0-th level QPSK sub-symbol **101** and a first level QPSK sub-symbol **102** in descending order of amplitude. The hierarchized sub-symbols are characterized in that the distance between signal points is shorter in an upper level, so that accuracy in determining a signal of a QPSK sub-symbol is low and accuracy in generating a replica is also low. The replica generation unit **27** can generate a replica for each sub-symbol level.

[0038] Described below is an example of a method for generating a replica of a sub-symbol, to be performed by the replica generation unit **27**. Assuming that $\lambda_{m'}(0)$ is an LLR of a 0-th bit of an m'-th level, a replica of the m'-th level sub-symbol is expressed by mathematical formula (1) below. Here, an amplitude a_m in each level is expressed by mathematical formula (2) below.

$$\hat{d}_{m'}(t) = \frac{a_{m'}}{\sqrt{2}}\left[\tanh\left\{\frac{\lambda_{n_t,m'-1}(0)}{2}\right\}\tanh\left\{\frac{\lambda_{n_t,m'}(0)}{2}\right\} + j\tanh\left\{\frac{\lambda_{n_t,m'-1}(1)}{2}\right\}\tanh\left\{\frac{\lambda_{n_t,m'}(1)}{2}\right\}\right] \quad \text{[Formula 1]}$$

$$a_m = \frac{2^{M-m-1}}{\sqrt{\sum_{m'=0}^{M-1} 2^{2m'}}} \quad \text{[Formula 2]}$$

[0039] The generated replica of the sub-symbol is used in the equalization weight calculation unit **21** and the interference cancellation unit **23**. An example of interference cancellation will be cited below. In the following description, characters may be shown in the following manner in some cases: when a character with a bar is shown, "(bar)" is put after the character; when a character with a hat is shown, "(hat)" is put after the character; and when a character with a tilde is shown, "(tilde)" is put after the character.

[0040] With regard to processing for an f-th frequency, let R(tilde) (f) be a received signal subjected to frequency domain equalization, H(bar) (f) be the equivalent channel gain of an interference component after frequency domain equalization, and D(hat) (f) be the replica of the m'-th level sub-symbol in the frequency domain. Then, the received signal R(hat) (f) subjected to cancellation of interference is expressed by mathematical formula (3) below. It should be noted that each of m_f and m_b denotes the range of target levels for replicas of reproduced sub-symbols.

$$\hat{R}(f) = \tilde{R}(f) - \overline{H}(f)\sum_{m'=0}^{m_{forb}-1}\hat{D}_{m'}(f) \quad \text{[Formula 3]}$$

[0041] FIG. **4** is a diagram illustrating definitions of interference components to be canceled from a received signal, by the wireless communication apparatus **1** illustrated in

FIG. **1**. The part of the received signal corresponding to the second range **152** includes a front IBI **104** and a rear IBI **105**. The front IBI **104** is a front signal corresponding to a past signal received prior to the first range **151** with respect to a direction on a time axis along which equalization processing proceeds. The rear IBI **105** is a rear signal corresponding to a future signal to be received later than the front signal with respect to the direction on the time axis. Interference components for a part of the received signal corresponding to the first range **151** include an interference component generated by an influence of the front IBI **104** and an interference component generated by an influence from the rear IBI **105**.

[0042] The description returns to FIG. **1**. The first generation unit **27***a* decomposes the front signal into a plurality of signal components, and reproduces the front signal for each signal component to generate a replica of the interference component. Specifically, the first generation unit **27***a* decomposes the front signal into symbols of a plurality of levels to generate a replica of the interference component for each level. The second generation unit **27***b* decomposes the rear signal or ISI into a plurality of signal components, and reproduces the rear signal or ISI for each signal component to generate a replica of the interference component. Specifically, the second generation unit **27***b* decomposes a second interference component into symbols of a plurality of levels to generate a replica for each level. As a response to a known signal multiplexed to the received signal according to a frame format, the known signal addition unit **27***c* obtains a corresponding known signal from among a plurality of known signals internally held in advance, and adds the obtained known signal to the replica. With the above-described function, the replica generation unit **27** inputs the generated replicas to the second FFT unit **29** and the equalization weight calculation unit **21**.

[0043] The second FFT unit **29** converts the input replicas into signal components in the frequency domain, and inputs the converted replicas to the interference cancellation unit **23**. The equalization unit **22**, the interference cancellation unit **23**, and the data extraction unit **25** repeatedly perform equalization processing, cancellation of interference components, and extraction of detection target data. The number of the signal components to be used by the replica generation unit **27** for reproducing the front signal is equal to or larger than the number of the signal components to be used by the replica generation unit **27** for reproducing the rear signal. The number of the signal components to be used by the replica generation unit **27** for reproducing the front signal is increased as the equalization processing, the cancellation of interference components, and the process of extracting detection target data are repeated. The data extraction unit **25** regards the extracted detection target data as a final detection result when, as a result of expansion of a replica generation range, the number of the signal components included in the replica generation range has reached a predetermined number such as the maximum number of the signal components obtained by decomposition of a first interference component. Then, the detection result is input from the LLR calculation unit **26** to the deinterleaver **30**.

[0044] The deinterleaver **30** interleaves, in blocks, the LLR series that is latest at the time point of input of the detection result and restores a permutation, and inputs a signal to the error correction decoding unit **31**. The error correction decoding unit **31** performs error correction decoding of the input signal to obtain a bit sequence.

[0045] Next, the hardware configuration of the wireless communication apparatus **1** will be described. Each constituent element of the wireless communication apparatus **1** can be implemented by hardware. The antenna **11** is an antenna for wireless communication. The other constituent elements are implemented by, for example, processing circuits. A plurality of constituent elements may be implemented by a single processing circuit. Alternatively, a single constituent element may be implemented by a plurality of processing circuits.

[0046] In addition, the processing circuit may be dedicated hardware. Alternatively, the processing circuit may be a control circuit including a memory and a central processing unit (CPU) (also referred to as a central processor, processing unit, arithmetic unit, microprocessor, microcomputer, processor, or digital signal processor (DSP)) that executes a program stored in the memory. Here, examples of the memory include a nonvolatile or volatile semiconductor memory such as a random access memory (RAM), a read only memory (ROM), a flash memory, an erasable programmable read only memory (EPROM), or an electrically erasable programmable read only memory (EEPROM), a magnetic disk, a flexible disk, an optical disk, a compact disk, a mini disk, and a digital versatile disk (DVD).

[0047] In the case where the processing circuit is implemented by dedicated hardware, the processing circuit is exemplified by a processing circuit **71** illustrated in FIG. **5**. FIG. **5** is a diagram illustrating an example of implementing the function of the wireless communication apparatus **1** illustrated in FIG. **1** by use of a processing circuit that is dedicated hardware. Examples of the processing circuit **71** include a single circuit, a composite circuit, a programmed processor, a parallel-programmed processor, an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), and a combination thereof.

[0048] In the case where the processing circuit is implemented by a control circuit including a CPU, the control circuit is exemplified by a control circuit with a configuration illustrated in FIG. **6**. FIG. **6** is a diagram illustrating an example of implementing the function of the wireless communication apparatus **1** illustrated in FIG. **1** by use of a processing circuit that is a control circuit. As illustrated in FIG. **6**, a control circuit **74** includes a memory **72** and a processor **73**. The memory **72** is a CPU. In the case where the processing circuit is implemented by the control circuit **74**, the processing circuit is implemented by the processor **73** reading and executing a program corresponding to each process of each constituent element, stored in the memory **72**. In addition, the memory **72** is also used as a temporary memory in each process performed by the processor **73**.

[0049] A part of each constituent element included in the wireless communication apparatus **1** may be implemented by dedicated hardware, and another part may be implemented by a control circuit including a CPU.

[0050] Next, a receiving operation of the wireless communication apparatus **1** will be described. FIG. **7** is a flowchart for describing the receiving operation of the wireless communication apparatus **1** illustrated in FIG. **1**. Here, in repetition of equalization processing and interference cancellation, each repetition unit is referred to as a stage. At the start of the receiving operation, values of indices are assumed as follows: a repetition stage index i=0, a first target level index m_f=0, a second target level index m_b=−1, and a detection target block index n_b=0, where the

first target level index is the maximum value of the number of levels to be reproduced in the front IBI, and the second target level index is the maximum value of the number of levels to be reproduced in the rear IBI.

[0051] The first FFT unit **18** performs FFT processing on the part of the received signal corresponding to the processing range **153** to generate a signal in the frequency domain (step S**101**). Subsequently, the equalization weight calculation unit **21** generates equalization weights based on a transmission path estimation value estimated by use of a known signal obtained from the received signal (step S**102**). The equalization unit **22** performs equalization processing on the received signal in the frequency domain by using the generated equalization weights (step S**103**). Subsequently, the interference cancellation unit **23** performs a process of canceling the interference components included in the received signal by using the replicas (step S**104**). However, because there is no generated replica at a first repetition, interference cancellation is omitted.

[0052] The IFFT unit **24** performs IFFT processing for converting the received signal in the frequency domain into a signal in the time domain (step S**105**). The data extraction unit **25** extracts detection target data of a current block (step S**106**). The LLR calculation unit **26** calculates an LLR by using the extracted detection target data (step S**107**).

[0053] The first generation unit **27***a* of the replica generation unit **27** generates a replica of the front IBI for each of 0-th to m_f-th levels for the next block, by using the calculated LLR (step S**108**). In the first repetition, because m_f=0, a replica of the front IBI for the 0-th level is generated. The second generation unit **27***b* of the replica generation unit **27** generates a replica of the rear IBI for each of 0-th to m_b-th levels for the next block, by using the calculated LLR (step S**109**). In the first repetition, there is no corresponding LLR obtained. Therefore, no replica of the rear IBI is generated. The second FFT unit **29** converts the obtained replicas into signals in the frequency domain, and inputs the signals to the interference cancellation unit **23** (step S**110**).

[0054] The equalization unit **22** determines whether the detection target block index n_b has reached the number N_b−1 of blocks in one frame (step S**111**). If the detection target block index n_b has not reached the number N_b−1 of blocks in one frame (step S**111**: No), the block index n_b is incremented and updated (step S**112**), and the process returns to step S**101** to perform processing on the next block. If the detection target block index n_b has reached the number N_b of blocks in one frame (step S**111**: Yes), that is, if processing for one frame has been completed, the equalization unit **22** determines whether the repetition stage index i has reached the maximum number i_{max}−1 of repetition stages (step S**113**). If the repetition stage index i has not reached the maximum number i_{max}−1 of repetition stages (step S**113**: No), the repetition stage index i is incremented and updated, and n_b is set such that n_b=0 so as to return to the process of a 0-th detection target block. Furthermore, the second target level index m_b is made equal to the first target level index m_f so as to equally expand the target range of reproduction of the rear IBI and the target range of reproduction of the front IBI (step S**114**). As a result, a replica of the rear IBI is generated in the subsequent process. If the repetition stage index i has reached the maximum number i_{max}−1 of repetition stages (step S**113**: Yes), the equalization unit **22** determines whether the first target level index m_f has reached M_{max}−1 (step S**115**). If the first target level index m_f has not reached M_{max}−1 (step S**115**: No), the equalization unit **22** increments and updates the first target level index m_f (step S**116**), and returns to the process of step S**101**. If the first target level index m_f has reached M_{max}−1 (step S**115**: Yes), the repetitive processing ends.

[0055] FIG. **8** is a diagram illustrating a first example of a replica to be used in an interference cancellation process to be performed by the wireless communication apparatus **1** illustrated in FIG. **1**. FIG. **8** illustrates an example of using 16QAM as a modulation scheme, where M_{max}=2. When performing cancellation of interference on the n_b-th detection block for the first time (in the case of m_f=0 and m_b=−1), the interference cancellation unit **23** performs cancellation of interference on the front IBI **104** corresponding to the first interference component by using a 0-th level replica **107**. Meanwhile, the interference cancellation unit **23** does not perform cancellation of interference on the rear IBI **105** and an ISI **106** corresponding to the second interference component because no replica has been generated for the rear IBI **105** and the ISI **106**.

[0056] FIG. **9** is a diagram illustrating a second example of the replica to be used in the interference cancellation process to be performed by the wireless communication apparatus **1** illustrated in FIG. **1**. When performing cancellation of interference on the n_b-th detection block for the second time (in the case of m_f=0 and m_b=0), the interference cancellation unit **23** performs cancellation of interference on the front IBI **104**, the rear IBI **105**, and the ISI **106** by using the 0-th level replica **107**.

[0057] FIG. **10** is a diagram illustrating a third example of the replica to be used in the interference cancellation process to be performed by the wireless communication apparatus **1** illustrated in FIG. **1**. When performing cancellation of interference on the n_b-th detection block for the third time (in the case of m_f=1 and m_b=0), the interference cancellation unit **23** performs cancellation of interference on the front IBI **104** by using the 0-th level replica **107** and a first level replica **108**, and performs cancellation of interference on the rear IBI **105** and the ISI **106** by using the 0-th level replica **107**.

[0058] FIG. **11** is a diagram illustrating a fourth example of the replica to be used in the interference cancellation process to be performed by the wireless communication apparatus **1** illustrated in FIG. **1**. When performing cancellation of interference on the n_b-th detection block for the fourth time (in the case of m_f=1 and m_b=1), the interference cancellation unit **23** performs cancellation of interference on the front IBI **104**, the rear IBI **105**, and the ISI **106** by using the 0-th level replica **107** and the first level replica **108**.

[0059] The first target level index m_f indicates a first range that is the range of signal components to be used by the replica generation unit **27** for reproducing the front IBI that is the first interference component. The second target level index m_b indicates a second range that is the range of signal components to be used by the replica generation unit **27** for reproducing the rear IBI that is the second interference component. The above-described operation enables the first target level index m_f to be maintained at a value equal to or larger than the second target level index m_b, so that it is possible to set the first range such that the first range is equal to or larger than the second range.

[0060] Furthermore, accuracy in generating a replica differs between sub-symbols of a plurality of levels included in one symbol. However, in the case of generating a replica in

units of one symbol, replicas for all the levels are simultaneously generated. Thus, accuracy in generating a replica decreases. Meanwhile, in the case where a replica is generated for each of the sub-symbols of the plurality of levels as signal components obtained by decomposition of an interference component as described above, generation of a replica starts from a sub-symbol of a level that is high in accuracy in replica generation, and the range of levels for which replicas are generated is expanded along with the repetitive processing. It is thus possible to increase accuracy in replica generation. As a result, the process of canceling interference is performed by use of replicas with high accuracy, so that an effect of reducing interference components is enhanced. It is thus possible to enhance reception performance.

[0061] Furthermore, according to the above operation, a replica of the front IBI **104** is generated by sequential use of an equalization result for an immediately preceding block at a current repetition stage. The equalization result of the immediately preceding block at the current repetition stage is higher in reliability than an equalization result for the same block in the previous repetition stage. Therefore, it is possible to generate a replica with higher accuracy. In addition, a replica of the rear IBI **105** is generated by use of an equalization result of the previous repetition stage. At this time, in the case where the range of levels to be used for generating the replicas of the rear IBI **105** is expanded simultaneously with the range of levels to be used for generating the replicas of the front IBI **104**, accuracy of signal detection in the previous repetition stage is lower than that in the current repetition stage. Thus, an effect of repetitive processing is limited. Therefore, in the first embodiment, the range of levels to be used for generating the replicas of the front IBI **104** is first expanded, and the range of levels to be used for generating the replicas of the rear IBI **105** is maintained as before. Then, the range of levels to be used for generating the replicas of the rear IBI **105** is expanded in the subsequent repetitive processing. This configuration enables an effect of repetitive processing to be enhanced, and also enables interference components included in the received signal to be further reduced.

[0062] It should be noted that the operation illustrated in FIG. **7** is an example, and the order of processing can be changed within the scope of the technical idea of the present invention. For example, in the above embodiment, equalization processing is performed for each frame, and a replica is updated for each block. However, the present invention is not limited to such an example, and each loop process illustrated in FIG. **7** can be changed also in the order of execution and conditions for performing the loop process. For example, in the above embodiment, interference cancellation is finally performed by use of all replicas of signal components of a plurality of levels obtained by decomposition of an interference component. However, the replicas of all the levels are not necessarily required to be generated. Therefore, "$M_{max}-1$" in step **S115** may be a value smaller than "$M_{max}-1$".

[0063] FIG. **12** is a diagram illustrating a wireless communication apparatus **2** according to a variation of the first embodiment of the present invention. The wireless communication apparatus **2** illustrated in FIG. **12** performs OFDM transmission using no CP.

[0064] The wireless communication apparatus **2** includes the antenna **11**, the analog front end **12**, the ADC **13**, the band limiting unit **14**, the decimation unit **15**, the timing detection unit **16**, and the frequency deviation correction unit **17**. The wireless communication apparatus **2** further includes an interference cancellation unit **32**, a first FFT unit **33**, the data separation unit **19**, a transmission path estimation unit **35**, the equalization weight calculation unit **21**, an equalization unit **36**, a first IFFT unit **37**, a data extraction unit **38**, a second FFT unit **39**, and an LLR calculation unit **40**. The wireless communication apparatus **2** further includes a replica generation unit **41**, a replica control unit **42**, a second IFFT unit **43**, a third IFFT unit **44**, a deinterleaver **45**, and an error correction decoding unit **46**. The replica generation unit **41** includes the first generation unit **27***a*, the second generation unit **27***b*, and the known signal addition unit **27***c*. In FIG. **12**, constituent elements similar to the constituent elements illustrated in FIG. **1** are denoted by the same reference signs, and further description will be omitted. Hereinafter, differences from the wireless communication apparatus **1** illustrated in FIG. **1** will be mainly described.

[0065] The first FFT unit **33** converts a signal in a range wider than the detection target block into a signal in the frequency domain so as to perform a process of overlap frequency domain equalization. The transmission path estimation unit **35** performs transmission path estimation, and inputs a transmission path estimation value to the equalization weight calculation unit **21** and the third IFFT unit **44**. The equalization unit **36** performs equalization processing based on calculated equalization weights. The first IFFT unit **37** performs IFFT processing on a received signal on which equalization processing has been performed, to convert the received signal into a received signal in the time domain. The data extraction unit **38** extracts detection target data from the received signal in the time domain. The second FFT unit **39** performs FFT processing with the number of points corresponding to one OFDM symbol to convert the received signal into a signal in the frequency domain again, and inputs the signal to the LLR calculation unit **40**. The LLR calculation unit **40** calculates an LLR for each subcarrier from the input signal.

[0066] Under the control of the replica control unit **42**, the replica generation unit **41** generates a replica of a specified level for each interference component. The replica generation unit **41** inputs the generated replicas to the equalization weight calculation unit **21** and the second IFFT unit **43**. The second IFFT unit **43** performs IFFT processing on the input replicas to convert the replicas into signals in the time domain, and inputs the signals obtained by conversion to the interference cancellation unit **32**. The third IFFT unit **44** performs IFFT processing on the transmission path estimation value input from the transmission path estimation unit **35** to convert the value into a signal in the time domain, and inputs the signal after conversion to the interference cancellation unit **32**. The interference cancellation unit **32** cancels the interference components of the received signal by using the received signals in the time domain and the replicas. At this time, the interference cancellation unit **32** convolves the replicas of the OFDM time waveform, and subtracts the convolved replicas from the received signal, by using an impulse response obtained from the transmission path estimation value obtained in the frequency domain. As a result, the interference cancellation unit **32** can cancel the interference components of the received signal.

[0067] As described above, according to the wireless communication apparatus **2** illustrated in FIG. **12**, it is possible to achieve an effect similar to that of the wireless communication apparatus **1** illustrated in FIG. **1** also in the OFDM transmission using no CP.

[0068] FIG. **13** is a diagram illustrating a first variation of the definitions of the interference components to be canceled from the received signal, by the wireless communication apparatus **1** illustrated in FIG. **1**. FIG. **14** is a diagram illustrating a second variation of the definitions of the interference components to be canceled from the received signal, by the wireless communication apparatus **1** illustrated in FIG. **1**. The front IBI **104** and the rear IBI **105** are defined in FIG. **4** on the assumption that a signal component of the detection target range is regarded as a signal component to be extracted. However, the present invention is not limited to such an example. Other examples are also possible as long as interference cancellation is performed in conjunction with overlap frequency domain equalization based on a predetermined criterion such as the least-squares-error criterion, on the assumption that an arbitrarily defined signal component is regarded as a signal component to be extracted. In the example of FIG. **13**, the front IBI **104**, the rear IBI **105**, and the ISI **106** are defined on the assumption that data other than the last two symbols in a processing area are regarded as a signal component to be extracted. Furthermore, in the example of FIG. **14**, the front IBI **104** and a front ISI **106***a* are defined as front interference components, and a center ISI **106***b*, a rear ISI **106***c*, and the rear IBI **105** are defined as rear interference components.

[0069] It should be noted that it is also possible to apply the technique of the present embodiment described above to the case where a delay amount in a delay wave exceeds a CP length in block transmission, by performing similar processing and extracting a data portion. In addition, the technique of the present embodiment can be applied not only to single carrier block transmission but also to single carrier transmission in which data are not blocked in transmission. Furthermore, the technique of the present embodiment can also be applied to a multi-antenna communication apparatus using a plurality of transmitting and receiving antennas, in consideration of inter-antenna interference.

Second Embodiment

[0070] Described below in a second embodiment is a wireless communication apparatus that performs a process of receiving a signal transmitted by use of two or more antennas, such as in the cases of multiuser transmission, spatial multiplexing transmission, and transmission diversity. Each of the cases of multiuser transmission and spatial multiplexing transmission is described below. Although description of the case of transmission diversity is omitted, a configuration for transmission diversity can be implemented by a similar function.

[0071] FIG. **15** is a diagram illustrating a configuration for multiple users to transmit signals in a wireless communication system according to the second embodiment of the present invention.

[0072] FIG. **15** illustrates wireless transmission apparatuses **300#0** to **300#**N_t-1 of N_t users **#0** to **#**N_t-1. When it is not necessary to distinguish between the wireless transmission apparatuses **300#0** to **300#**N_t-1, the apparatuses are each simply referred to as the wireless transmission apparatus **300**. Each of the plurality of wireless transmission apparatuses **300** includes an error correction coding unit **201**, an interleaver **202**, a mapping unit **203**, a known signal generation unit **204**, a multiplexing unit **205**, an interpolation unit **206**, a band limiting unit **207**, a digital-to-analog converter (DAC) **208**, an analog front end **209**, and a transmission antenna **210**. In the example of FIG. **15**, each wireless transmission apparatus **300** includes the single transmission antenna **210**. However, the number of the transmission antennas is not limited.

[0073] The error correction coding unit **201** performs error correction coding on a bit sequence of input transmission information, and inputs the coded bit sequence, on which error correction coding has been performed, to the interleaver **202**. The interleaver **202** performs interleaving processing on a block basis to change the order of the coded bit sequence. The interleaver **202** inputs the coded bit sequence which has been obtained to the mapping unit **203**. The mapping unit **203** performs mapping based on a multiple-value number by using the input coded bit sequence, and generates a symbol sequence by using a modulation scheme such as phase shift keying (PSK) or quadrature amplitude modulation (QAM). The known signal generation unit **204** generates a known signal sequence. The multiplexing unit **205** multiplexes the symbol sequence and the known signal sequence to generate a transmission signal, and inputs the generated transmission signal to the interpolation unit **206**.

[0074] The interpolation unit **206** performs an interpolation process for increasing the sampling frequency of the input transmission signal, and inputs the processed transmission signal to the band limiting unit **207**. The band limiting unit **207** performs a band limiting process on the input transmission signal, and inputs the processed transmission signal to the DAC **208**. The DAC **208** converts the input transmission signal from a digital signal to an analog signal, and inputs the converted transmission signal to the analog front end **209**. The analog front end **209** upconverts and amplifies the transmission signal, and transmits the transmission signal from the transmission antenna **210**.

[0075] FIG. **16** is a diagram illustrating a configuration for transmitting signals by spatial multiplexing in the wireless communication system according to the second embodiment of the present invention. Hereinafter, constituent elements similar to those of the wireless transmission apparatus **300** illustrated in FIG. **15** are denoted by the same reference signs, and further description will be omitted. Thus, differences from the wireless transmission apparatus **300** will be mainly described.

[0076] A wireless transmission apparatus **310** illustrated in FIG. **16** includes the error correction coding unit **201**, the interleaver **202**, the mapping unit **203**, a serial parallel (SP) conversion unit **211**, and a plurality of transmission processing units **301#0** to **301#**N_t-1. The wireless transmission apparatus **310** includes N_t transmission antennas **210#0** to **210#**N_t-1. In the wireless transmission apparatus **310**, the transmission processing units **301#0** to **301#**N_t-1 are provided so as to correspond to the transmission antennas **210#0** to **210#**N_t-1, respectively. Hereinafter, when it is not necessary to distinguish between the transmission processing units **301#0** to #N_t-1, the units are each simply referred to as the transmission processing unit **301**. In addition, when it is not necessary to distinguish between the transmission antennas **210#0** to #N_t-1, the antennas are each simply referred to as the transmission antenna **210**.

[0077] Each of the plurality of transmission processing units **301** includes the known signal generation unit **204**, the multiplexing unit **205**, the interpolation unit **206**, the band limiting unit **207**, the DAC **208**, the analog front end **209**, and the transmission antenna **210**.

[0078] The SP conversion unit **211** performs serial parallel conversion for converting an input serial signal into parallel signals the number of which is equal to the number N_t of the transmission antennas. The SP conversion unit **211** inputs one of the generated parallel signals to each of the transmission processing units **301**. With this configuration, a plurality of transmission signals is transmitted from the plurality of transmission antennas **210**#**0** to **210**#N_t−1. The transmission signals are transmitted to receiving-side wireless communication apparatuses via a multipath propagation channel.

[0079] FIG. **17** is a diagram illustrating the configuration of a wireless communication apparatus **3** according to the second embodiment of the present invention. The wireless communication apparatus **3** includes N_r receiving antennas **11**#**0** to **11**#N_r−1 and a plurality of reception processing units **50**#**0** to **50**#N_r−1. Each reception processing unit **50** includes the analog front end **12**, the ADC **13**, the band limiting unit **14**, the decimation unit **15**, the timing detection unit **16**, and the frequency deviation correction unit **17**. The wireless communication apparatus **3** further includes a first FFT unit **51**, a data separation unit **52**, a transmission path estimation unit **53**, an equalization weight calculation unit **54**, an equalization unit **55**, an interference cancellation unit **56**, an IFFT unit **57**, a data extraction unit **58**, and an LLR calculation unit **59**. The wireless communication apparatus **3** further includes the deinterleaver **30**, the error correction decoding unit **31**, a measurement unit **60**, an ordering unit **61**, a replica control unit **62**, a replica generation unit **63**, and the second FFT unit **29**.

[0080] The first FFT unit **51** performs FFT processing on received signals input from the plurality of reception processing units **50** to convert the received signals into signals in the frequency domain, and inputs the received signals subjected to conversion to the data separation unit **52**. The data separation unit **52** separates the received signals into data and known signals. Then, the data separation unit **52** inputs the received signals including the data to the equalization unit **55**, and inputs the known signals to the transmission path estimation unit **53**. The transmission path estimation unit **53** calculates transmission path estimation values, and inputs the calculated transmission path estimation values to the equalization weight calculation unit **54**. The equalization weight calculation unit **54** calculates equalization weights based on the input transmission path estimation values, and inputs the calculated equalization weights to the equalization unit **55**. The equalization unit **55** performs equalization processing on the received signals by using the input equalization weights, and inputs the received signals on which equalization processing has been performed to the interference cancellation unit **56**. The interference cancellation unit **56** uses replicas input from the second FFT unit **29** to cancel interference components included in the received signals. The interference cancellation unit **56** does not perform the process of canceling the interference components until an ordering process to be described below is completed. The interference cancellation unit **56** inputs the received signals which have been processed to the IFFT unit **57**. In the case where the process has not been performed, the interference cancellation unit **56** inputs the input received signals with no change to the IFFT unit **57**. The IFFT unit **57** performs IFFT processing for converting the input received signals into signals in the time domain, and inputs the received signals which have been processed to the data extraction unit **58**.

[0081] The data extraction unit **58** extracts detection target data from the input received signals, and inputs the detection target data to the LLR calculation unit **59**. The data extraction unit **58** also extracts known signals from the received signals, and inputs the known signals to the measurement unit **60**. The LLR calculation unit **59** calculates LLRs by using the input received signals, and outputs the LLRs to the deinterleaver **30** and the replica generation unit **63**. The measurement unit **60** measures error powers indicating the magnitudes of interference components. The measurement unit **60** measures the magnitudes of interference components included in the received signals on which equalization processing has been performed or equalization processing and cancellation of interference components have been performed. The measurement unit **60** can calculate the error powers by using, for example, the known signals. The measurement unit **60** inputs the calculated error powers to the ordering unit **61**. The ordering unit **61** determines the order of processing the received signals based on the input error powers which are values indicating the magnitudes of the interference components. The replica control unit **62** controls the order in which the replica generation unit **63** processes the received signals, based on the order determined by the ordering unit **61**. The replica control unit **62** instructs the replica generation unit **63** to generate a replica, by using at least one of a range for reproducing the interference component, a block number of a processing target in the received signal, an identifier of the transmission antenna of a transmission source of the received signal, and an identifier of a transmission source user of the received signal. The replica control unit **62** causes the replica generation unit **63** to generate a replica by specifying the range for reproducing the interference component and a target transmission antenna number.

[0082] In accordance with the instruction from the replica control unit **62**, the replica generation unit **63** generates a replica by using a signal transmitted from a transmission antenna indicated by the specified transmission antenna number. The replica generation unit **63** includes N_t first generation units **65** and N_t second generation units **66**, corresponding to the N_t transmission antennas, and the known signal addition unit **27***c*. Each of the first generation units **65** has a function similar to that of the first generation unit **27***a*. Each of the second generation units **66** has a function similar to that of the second generation unit **27***b*. The replica generation unit **63** inputs the generated replica to the second FFT unit **29** and the equalization weight calculation unit **54**.

[0083] FIG. **18** is a flowchart illustrating the overall operation of the wireless communication apparatus **3** illustrated in FIG. **17**. The wireless communication apparatus **3** measures a residual error power while attempting overlap FDE (step S**201**). Subsequently, the wireless communication apparatus **3** performs a transmission antenna ordering process (step S**202**). For example, in the case where an index value decreases as accuracy of signal detection increases, the wireless communication apparatus **3** can determine the order of process execution such that a received signal with a

smaller index value is processed earlier. After determining the processing order of the received signals, the wireless communication apparatus **3** performs repetitive equalization processing and interference cancellation processing (step S**203**).

[0084] FIG. **19** is a flowchart illustrating a detailed operation of step S**201** in FIG. **18**. The measurement unit **60** selects one of the transmission antennas **210** as a processing target (step S**204**). Then, the first FFT unit **51** performs overlap FFT processing to obtain a signal in the frequency domain (step S**205**). The equalization weight calculation unit **54** generates equalization weights based on a transmission path estimation value (step S**206**). The equalization unit **55** performs equalization processing (step S**207**). The signal on which the equalization processing has been performed is subjected to overlap IFFT processing performed by the IFFT unit **57** (step S**208**). The data extraction unit **58** extracts a known signal, and inputs the known signal to the measurement unit **60** (step S**209**). The measurement unit **60** calculates a difference between the input equalized known signal and a known signal known in advance, and accumulates the difference to calculate an error power (step S**210**). The measurement unit **60** determines whether measurement for all the transmission antennas has been completed (step S**211**). If measurement for all the transmission antennas has been completed (step S**211**: Yes), the measurement unit **60** terminates measurement of the residual error power. If measurement for all the transmission antennas has not been completed (step S**211**: No), the process returns to step S**204**.

[0085] FIG. **20** is a flowchart illustrating a detailed operation of step S**203** in FIG. **18**. It should be noted that steps similar to those in the operation illustrated in FIG. **7** are denoted by the same reference signs in FIG. **20**, and further description will be omitted. Hereinafter, differences from the operation illustrated in FIG. **7** will be mainly described.

[0086] A transmission antenna index n_t is an index of the transmission antenna **210** as a processing target, and takes a value from 0 to N_t-1. When generating a replica of the front IBI **104** for the next block, the first generation unit **65** sets, as a processing target, a received signal received by a target transmission antenna in addition to a specified level (step S**250**). When generating replicas of the ISI **106** and the rear IBI **105** for the next block, the second generation unit **66** sets, as processing targets, received signals received by target transmission antennas **0** to n_t in addition to a target level (step S**251**).

[0087] If the detection target block index n_b has reached the number N_b of blocks in one frame (step S**111**: Yes), that is, if the processing for one frame has been completed, the equalization unit **55** determines whether the transmission antenna index n_t has reached the number N_t-1 of antennas (step S**252**). If the transmission antenna index n_t has reached the number N_t-1 of antennas (step S**252**: Yes), the equalization unit **55** proceeds to the process of step S**113**. If the transmission antenna index n_t has not reached the number N_t-1 of antennas (step S**252**: No), the equalization unit **55** increments n_t (step S**253**).

[0088] In addition, if the repetition stage index i has not reached the maximum number $i_{mak}-1$ of repetition stages (step S**113**: No), the value of n_t is set such that $n_t=0$, in addition to performing the process of step S**114** (step S**254**).

[0089] If the first target level index m_f has not reached $M_{max}-1$ (step S**115**: No), the equalization unit **55** sets the value of n_t such that $n_t=0$, in addition to performing the process of step S**116** (step S**255**).

[0090] As described above, according to the second embodiment of the present invention, it is possible to cancel interference components not only for IBI and ISI in a signal transmitted from a target transmission antenna, but also for interference (including IBI) from a signal transmitted from another transmission antenna. In addition, the magnitude of an interference component included in a received signal is measured for each transmission antenna. Thus, the processing order of the received signals is determined based on the measurement results. As a result, a signal which is higher in detection accuracy is processed earlier, and a detection result thereof is used in performing the next detection process. Thus, it is also possible to improve accuracy of the next detection process.

[0091] It should be noted that the function of the measurement unit **60** described above can also be applied to the case of using one transmission antenna and one or more receiving antennas, and it is also possible to add the function of the measurement unit **60** to the configuration of the first embodiment described above. For example, after preparing two sets in which a demodulation parameter set differs between the first range and the second range and performing equalization processing based on the above-described sets, the measurement unit **60** calculates a value as an indicator of reliability, such as an error power, for each of the two sets. Then, it is also possible to select, as a final detection result, a processing result based on one of the two sets selected on the basis of the value of the indicator.

[0092] It should be noted that the interference cancellation process is performed in the frequency domain in the second embodiment described above. Meanwhile, the interference cancellation process may be performed in the time domain in the case where equivalent processing can be performed also in the time domain. Furthermore, the technique described in the second embodiment of the present invention can also be applied to OFDM transmission.

[0093] It should be noted that the hardware configuration of the wireless communication apparatus **3** according to the second embodiment described above is similar to that of the wireless communication apparatus **1** according to the first embodiment, and therefore description thereof is omitted here. The same applies to the wireless transmission apparatus **300** and the wireless transmission apparatus **310**.

[0094] The configuration illustrated in each of the above embodiments illustrates an example of the subject matter of the present invention, and it is possible to combine the configuration with another technique that is publicly known, and is also possible to make omissions and changes to part of the configuration without departing from the gist of the present invention.

[0095] For example, in the second embodiment described above, an error power calculated by use of a known signal is used as a value indicating the magnitude of an interference component remaining in a received signal. However, the present invention is not limited to such an example. For example, a value indicating the magnitude of an interference component remaining in a received signal may be calculated by use of, for example, an impulse response obtained by transmission path estimation and a norm value of equalization weights.

[0096] Furthermore, although the wireless communication system has been described in the above embodiment, the

present invention is not limited to such an example. The technique of the present invention can be applied not only to wireless transmission but also to wired transmission. When the technique of the above embodiment is applied to wired transmission, a communication apparatus includes a transmission port instead of the above-described transmission antenna, and a reception port instead of the receiving antenna.

REFERENCE SIGNS LIST

[0097] **1**, **2**, **3** wireless communication apparatus; **11** antenna; **12** analog front end; **13** ADC; **14** band limiting unit; **15** decimation unit; **16** timing detection unit; **17** frequency deviation correction unit; **18**, **33**, **51** first FFT unit; **19**, **52** data separation unit; **20**, **35**, **53** transmission path estimation unit; **21**, **54** equalization weight calculation unit; **22**, **36**, **55** equalization unit; **23**, **32**, **56** interference cancellation unit; **24**, **57** IFFT unit; **25**, **38**, **58** data extraction unit; **26**, **40**, **59** LLR calculation unit; **27**, **41**, **63** replica generation unit; **27***a*, **65** first generation unit; **27***b*, **66** second generation unit; **27***c* known signal addition unit; **28**, **42**, **62** replica control unit; **29**, **39** second FFT unit; **30**, **45** deinterleaver; **31**, **46** error correction decoding unit; **37** first IFFT unit; **43** second IFFT unit; **44** third IFFT unit; **50** reception processing unit; **60** measurement unit; **61** ordering unit; **71** processing circuit; **72** memory; **73** processor; **101** 0-th level QPSK sub-symbol; **102** first level QPSK sub-symbol; **103** 16QAM symbol; **104** front IBI; **105** rear IBI; **106** ISI; **107** 0-th level replica; **108** first level replica; **150** received signal; **151** first range; **152** second range; **153** processing range; **154** LLR; **155** LLR series; **201** error correction coding unit; **202** interleaver; **203** mapping unit; **204** known signal generation unit; **205** multiplexing unit; **206** interpolation unit; **207** band limiting unit; **208** DAC; **209** analog front end; **210** transmission antenna; **211** SP conversion unit; **300**, **310** wireless transmission apparatus.

1. A communication apparatus comprising:

processing circuitry

to perform equalization processing on a part of a received signal corresponding to a processing range including a first range and a second range, the first range including detection target data, the second range being outside the first range;

to define a plurality of replica generation ranges in the processing range, decompose the part of the received signal corresponding to each of the plurality of defined replica generation ranges into a plurality of signal components, and reproduce a part of the received signal corresponding to each of the replica generation ranges for each of the signal components to generate a replica of an interference component for a part of the received signal corresponding to the first range, for each of the replica generation ranges;

to cancel the interference component from the part of the received signal corresponding to the processing range by using a plurality of the replicas; and

to extract the detection target data from the received signal.

2. The communication apparatus according to claim **1**, wherein

the processing circuitry includes a plurality of generation circuits corresponding to two or more of the replica generation ranges,

each of the plurality of generation circuits generates the replica by using a result of equalization of a part of the received signal that corresponds to corresponding one of the replica generation ranges, and

a number of the signal components to be used by each of the plurality of generation circuits to generate the replica is determined for each of the generation circuits based on reliability of the result of equalization of the part of the received signal corresponding to the replica generation range.

3. The communication apparatus according to claim **2**, wherein

the processing circuitry repeats the equalization processing, cancellation of the interference component, and extraction of the detection target data,

each of the plurality of generation circuits independently increases the number of the signal components to be used to generate the replica, according to a number of repetitions, and

the processing circuitry regards the extracted detection target data as a detection result in a case where the number of the signal components to be used by each of the plurality of generation circuits to generate the replica has been increased to a predetermined number corresponding to each of the plurality of generation circuits.

4. The communication apparatus according to claim **3**, wherein the predetermined number in at least one of the generation circuits is a number of the signal components obtained by decomposition of the received signal.

5. The communication apparatus according to claim **1**, wherein

the processing circuitry further measures a magnitude of the interference component included in the part of the received signal corresponding to the first range on which the equalization processing has been performed or the equalization processing and cancellation of the interference component have been performed.

6. The communication apparatus according to claim **5**, wherein

the received signals are signals transmitted by use of a plurality of antennas,

the the processing circuitry measures the magnitude of the interference component for each of the antennas, and

the processing circuitry further determines an order of processing the received signals based on the measured magnitudes of the interference components.

7. The communication apparatus according to claim **1**,

the processing circuitry generates the replica, by using two or more of: a number of the signal components to be used to generate the replica, a block number of a processing target in the received signal, an identifier of a transmission antenna that is a transmission source of the received signal, and an identifier of a user as the transmission source of the received signal.

8. The communication apparatus according to claim **1**, further comprising:

one or more transmission antennas or transmission ports; and

one or more receiving antennas or reception ports,

wherein a signal is transmitted by use of a single carrier system.

9. The communication apparatus according to claim **1**, further comprising:

one or more transmission antennas or transmission ports; and

one or more receiving antennas or reception ports,

wherein a signal is transmitted by use of a single carrier block transmission system, and

the received signal is processed, the received signal having a cyclic prefix smaller than a delay wave in a transmission path or having no cyclic prefix.

10. The communication apparatus according to claim **1**, further comprising:

one or more transmission antennas or transmission ports; and

one or more receiving antennas or reception ports,

wherein a signal is transmitted by use of an orthogonal frequency division multiplex system or a multicarrier block transmission system, and the received signal is processed, the received signal having a cyclic prefix smaller than a delay wave in a transmission path or having no cyclic prefix.

11. A received signal processing method comprising:

performing equalization processing on a part of a received signal corresponding to a processing range including a first range and a second range, the first range including detection target data, the second range being outside the first range;

defining a plurality of replica generation ranges in the processing range,

decomposing the part of the received signal corresponding to each of the plurality of defined replica generation ranges into a plurality of signal components;

reproducing the part of the received signal corresponding to each of the replica generation ranges for each of the signal components to generate a replica of an interference component for the part of the received signal corresponding to the first range, for each of the replica generation ranges;

canceling the interference component from the part of the received signal corresponding to the processing range by using a plurality of the replicas; and

extracting the detection target data from the received signal.

12. The communication apparatus according to claim **1**, wherein

the processing circuitry includes a first generation circuit that corresponds to one of the replica generation ranges that is a first replica range, and a second generation circuit that corresponds to another one of the replica generation ranges that is a second replica range, the second replica range corresponding to a future range than the first replica range with respect to a direction on a time axis along which the equalization processing proceeds,

a number of the signal components to be used by the first generation circuit is greater than or equal to a number of the signal components to be used by the second generation circuit.

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