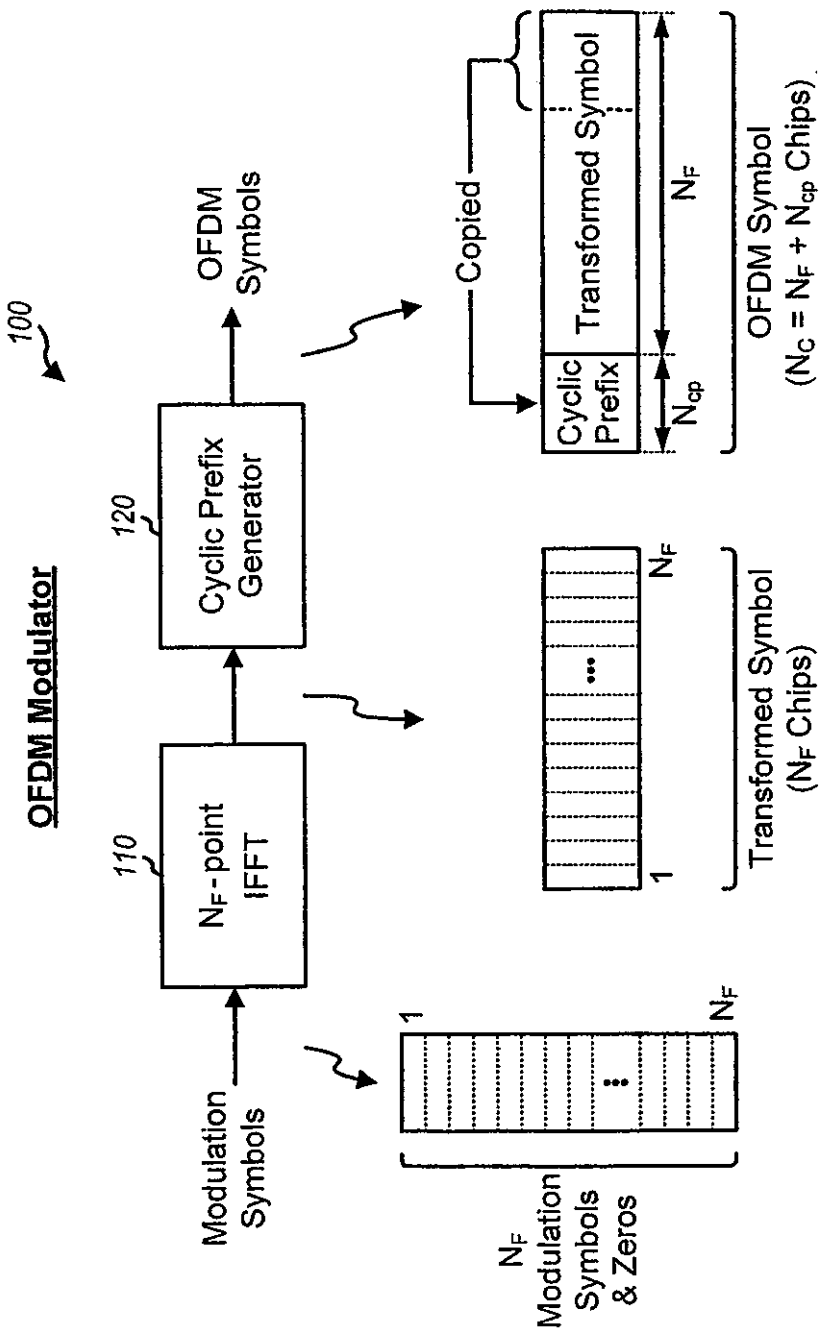

OFDM Modulator
100
110
N_F-point IFFT
120
Cyclic Prefix Generator
OFDM Symbols
Modulation Symbols
N_F Modulation Symbols & Zeros
Transformed Symbol (N_F Chips)
Copied
Cyclic Prefix
N_{cp}
Transformed Symbol
N_F
OFDM Symbol ($N_C = N_F + N_{cp}$ Chips)

FIG. 1

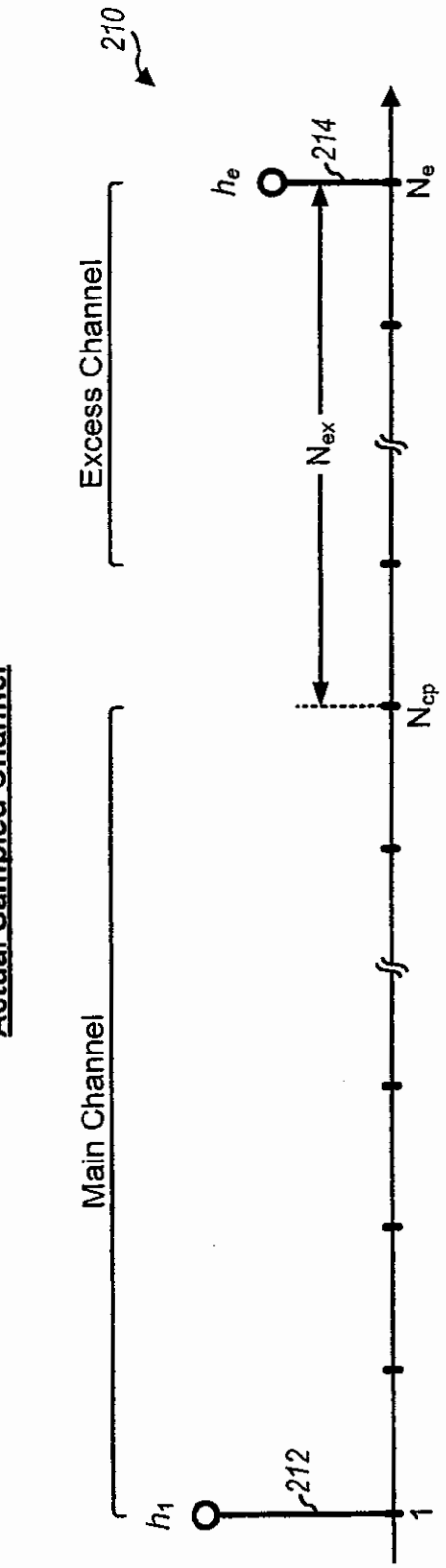

Actual Sampled Channel
210
Excess Channel
Main Channel
h_e
214
N_e
N_{ex}
N_{cp}
h_1
212
1

FIG. 2A

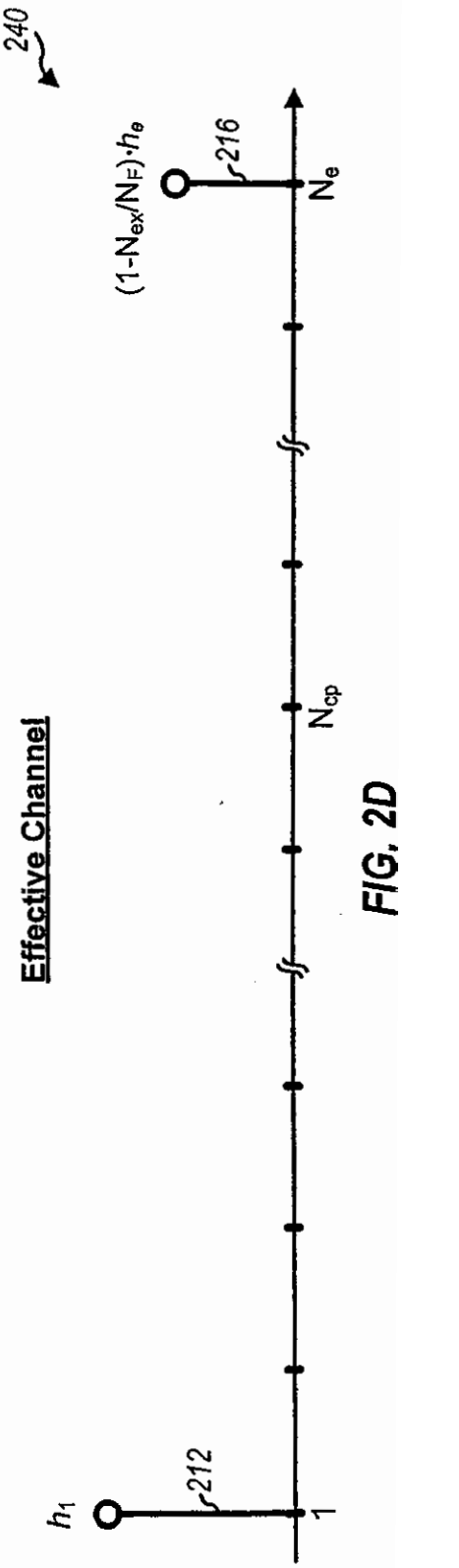

240
Effective Channel
$(1-N_{ex}/N_F)\cdot h_e$
216
N_e
N_{cp}
h_1
212
1

FIG. 2D

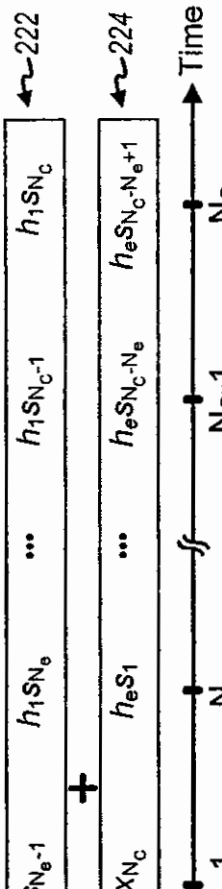

220
222
224
Tap h_1
Tap h_e
h_1s_1 h_1s_2 h_1s_3 ... $h_1s_{N_e-1}$ $h_1s_{N_e}$ ... $h_1s_{N_C-1}$ $h_1s_{N_C}$
$h_eX_{N_C-N_e+2}$ $h_eX_{N_C-N_e+3}$ $h_eX_{N_C-N_e+4}$ ... $h_eX_{N_C}$ h_es_1 ... $h_es_{N_C-N_e}$ $h_es_{N_C-N_e+1}$
1 2 3 N_e-1 N_e N_C-1 N_C
Time
Chip Period

FIG. 2B

222
226
228
230
Circular Convolution
ISI
ICI & Channel Attenuation
h_1s_1 h_1s_2 h_1s_3 ... $h_1s_{N_e-1}$ $h_1s_{N_e}$ ... $h_1s_{N_C-1}$ $h_1s_{N_C}$
$h_eS_{N_C-N_e+2}$ $h_eS_{N_C-N_e+3}$ $h_eS_{N_C-N_e+4}$ ... $h_eS_{N_C}$ h_es_1 ... $h_es_{N_C-N_e}$ $h_es_{N_C-N_e+1}$
$h_eX_{N_C-N_e+2}$ $h_eX_{N_C-N_e+3}$ $h_eX_{N_C-N_e+4}$ ... $h_eX_{N_C}$ 0 ... 0 0
$h_eS_{N_C-N_e+2}$ $h_eS_{N_C-N_e+3}$ $h_eS_{N_C-N_e+4}$ ... $h_eS_{N_C}$ 0 ... 0 0
1 2 3 N_e-1 N_e N_C-1 N_C
Time
Chip Period

FIG. 2C

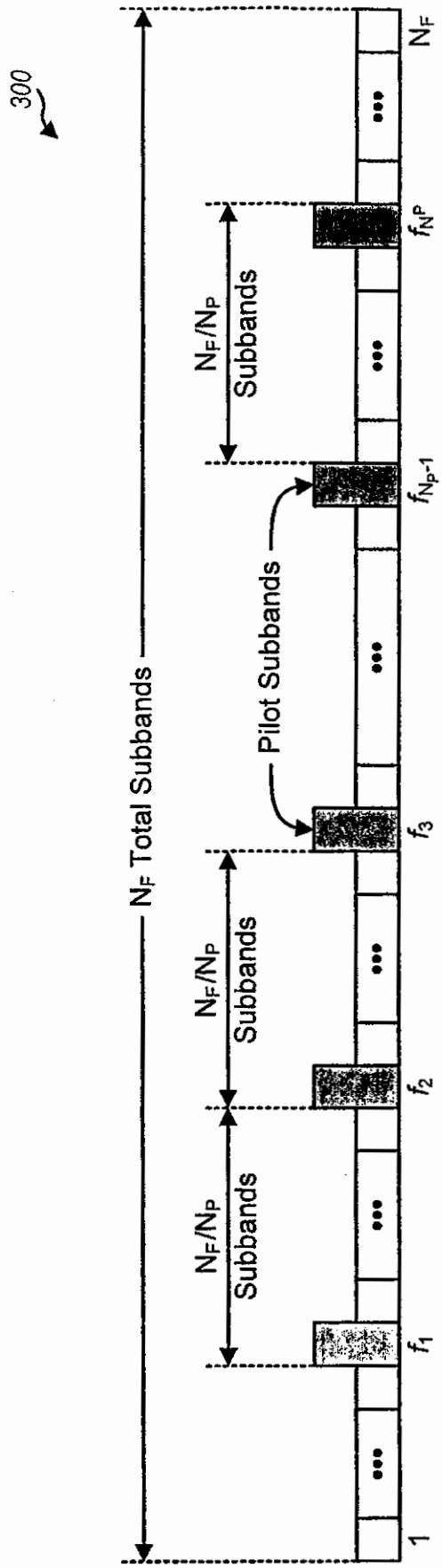

300
N_F Total Subbands
N_F/N_P Subbands
N_F/N_P Subbands
N_F/N_P Subbands
Pilot Subbands
1
f_1
f_2
f_3
f_{Np-1}
f_{NP}
N_F

FIG. 3

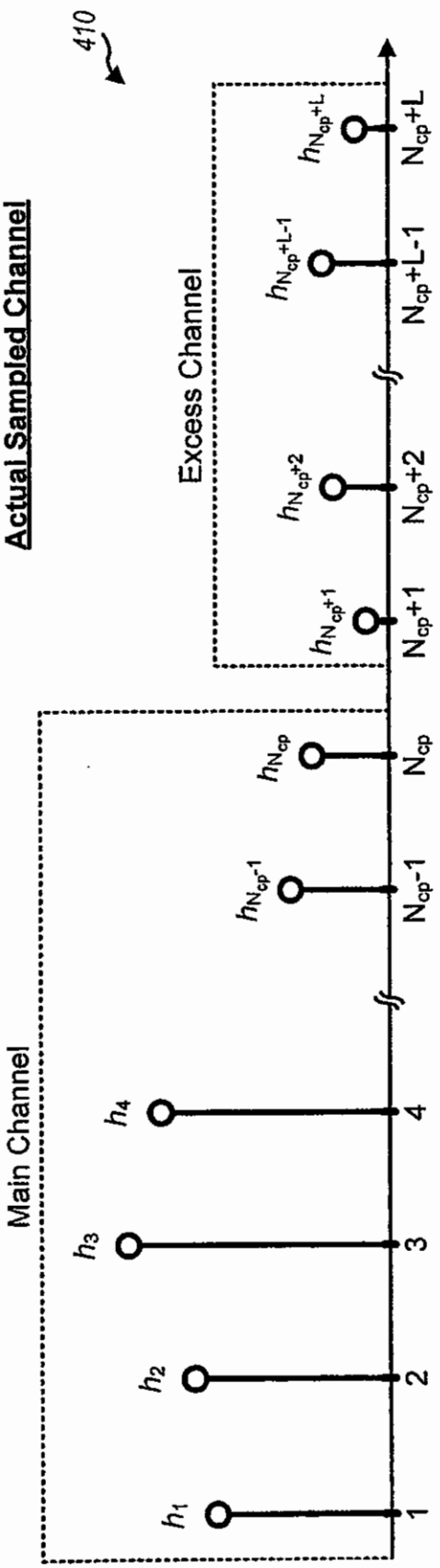

410
Actual Sampled Channel
Main Channel
Excess Channel
h_1
h_2
h_3
h_4
$h_{N_{cp}-1}$
$h_{N_{cp}}$
$h_{N_{cp}+1}$
$h_{N_{cp}+2}$
$h_{N_{cp}+L-1}$
$h_{N_{cp}+L}$
1
2
3
4
$N_{cp}-1$
N_{cp}
$N_{cp}+1$
$N_{cp}+2$
$N_{cp}+L-1$
$N_{cp}+L$
Tap Index

FIG. 4A

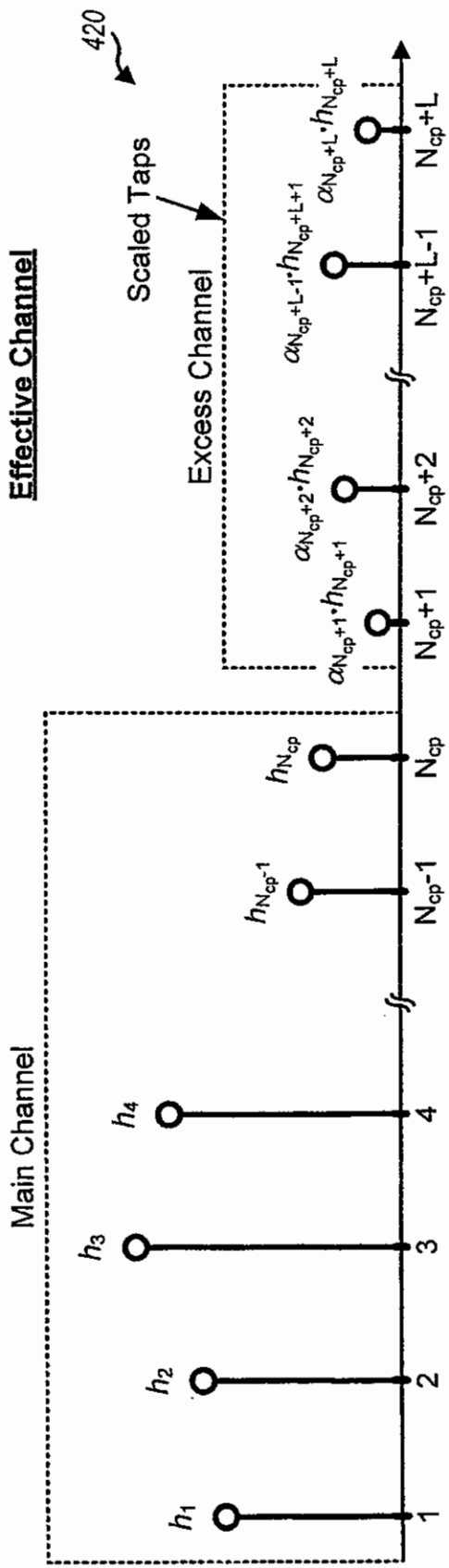

420
Effective Channel
Scaled Taps
Main Channel
Excess Channel
h_1
h_2
h_3
h_4
$h_{N_{cp}-1}$
$h_{N_{cp}}$
$\alpha_{N_{cp}+1} \cdot h_{N_{cp}+1}$
$\alpha_{N_{cp}+2} \cdot h_{N_{cp}+2}$
$\alpha_{N_{cp}+L-1} \cdot h_{N_{cp}+L-1}$
$\alpha_{N_{cp}+L} \cdot h_{N_{cp}+L}$
1
2
3
4
$N_{cp}-1$
N_{cp}
$N_{cp}+1$
$N_{cp}+2$
$N_{cp}+L-1$
$N_{cp}+L$
Tap Index

FIG. 4B

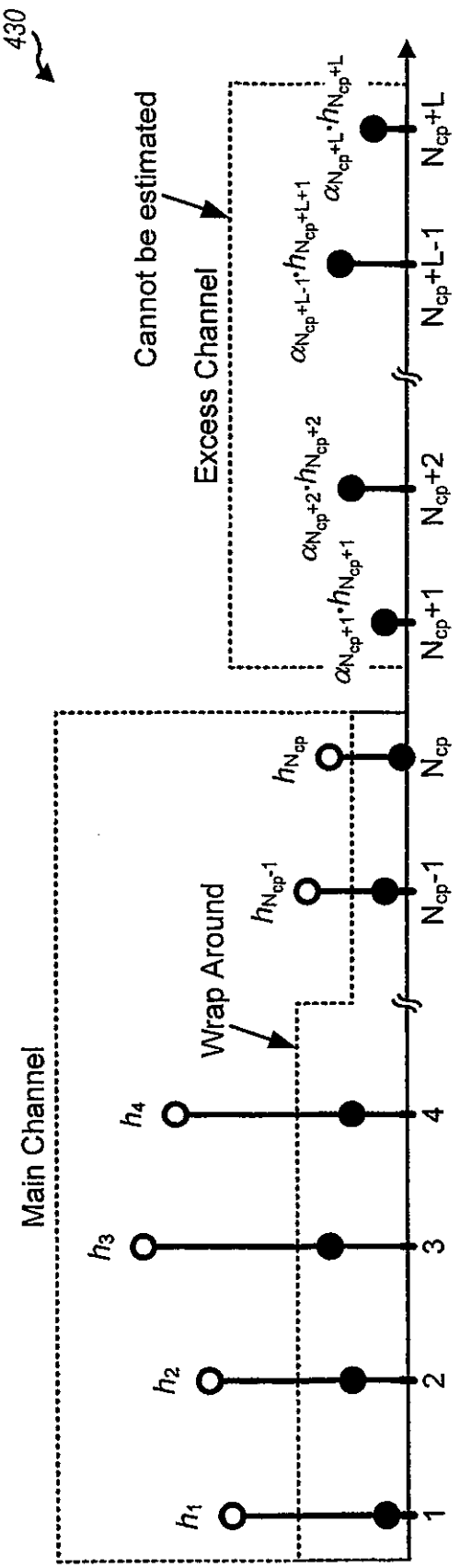

430
Estimated Channel - Critical Sampling
Main Channel
Wrap Around
Cannot be estimated
Excess Channel
h_1
h_2
h_3
h_4
$h_{N_{cp}-1}$
$h_{N_{cp}}$
$\alpha_{N_{cp}+1} \cdot h_{N_{cp}+1}$
$\alpha_{N_{cp}+2} \cdot h_{N_{cp}+2}$
$\alpha_{N_{cp}+L-1} \cdot h_{N_{cp}+L-1}$
$\alpha_{N_{cp}+L} \cdot h_{N_{cp}+L}$
1
2
3
4
$N_{cp}-1$
N_{cp}
$N_{cp}+1$
$N_{cp}+2$
$N_{cp}+L-1$
$N_{cp}+L$
Tap Index

FIG. 4C

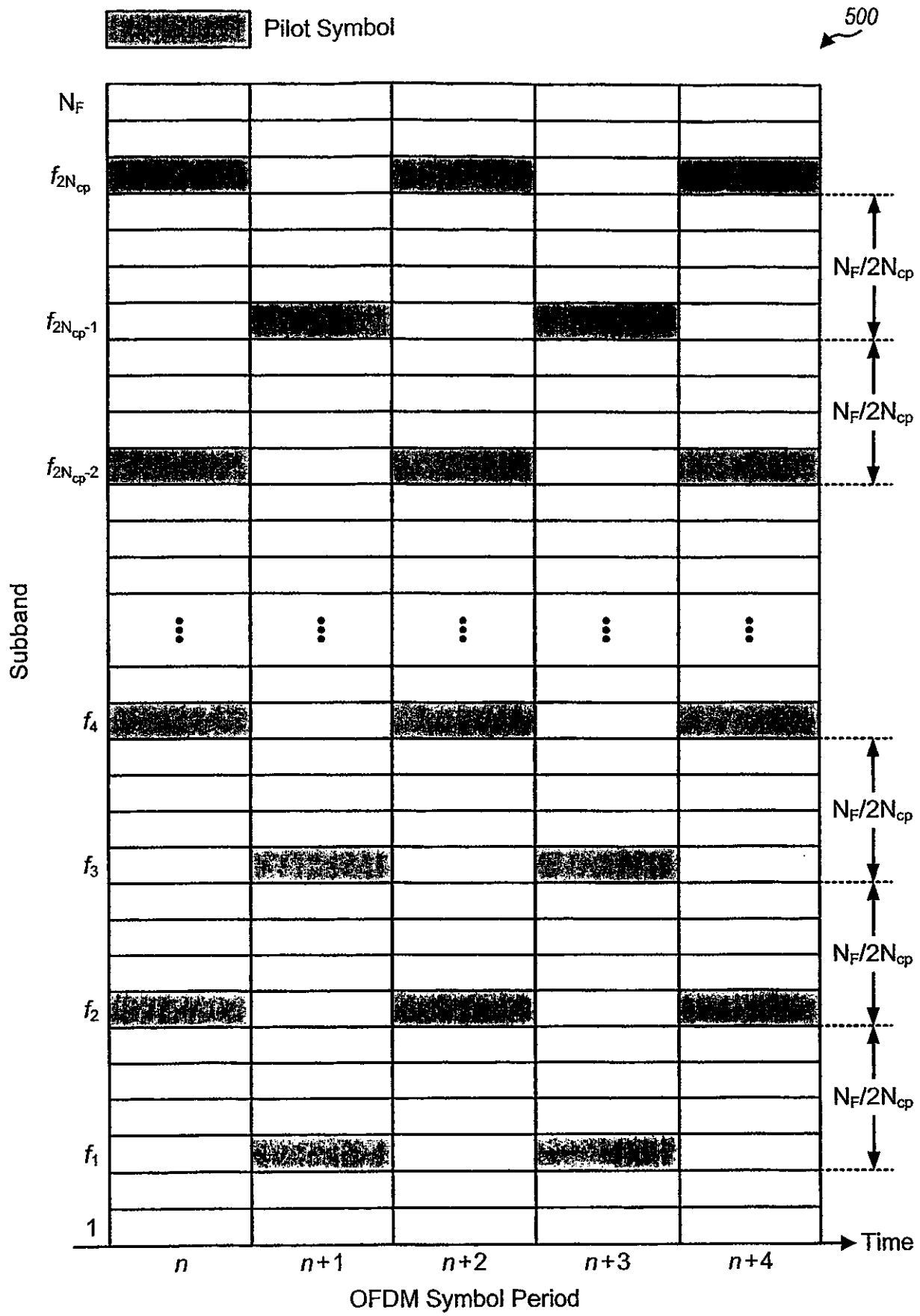

Pilot Symbol
500
N_F
$f_{2N_{cp}}$
$f_{2N_{cp}-1}$
$f_{2N_{cp}-2}$
f_4
f_3
f_2
f_1
1
Subband
$N_F/2N_{cp}$
$N_F/2N_{cp}$
$N_F/2N_{cp}$
$N_F/2N_{cp}$
$N_F/2N_{cp}$
Time
n
n+1
n+2
n+3
n+4
OFDM Symbol Period

FIG. 5

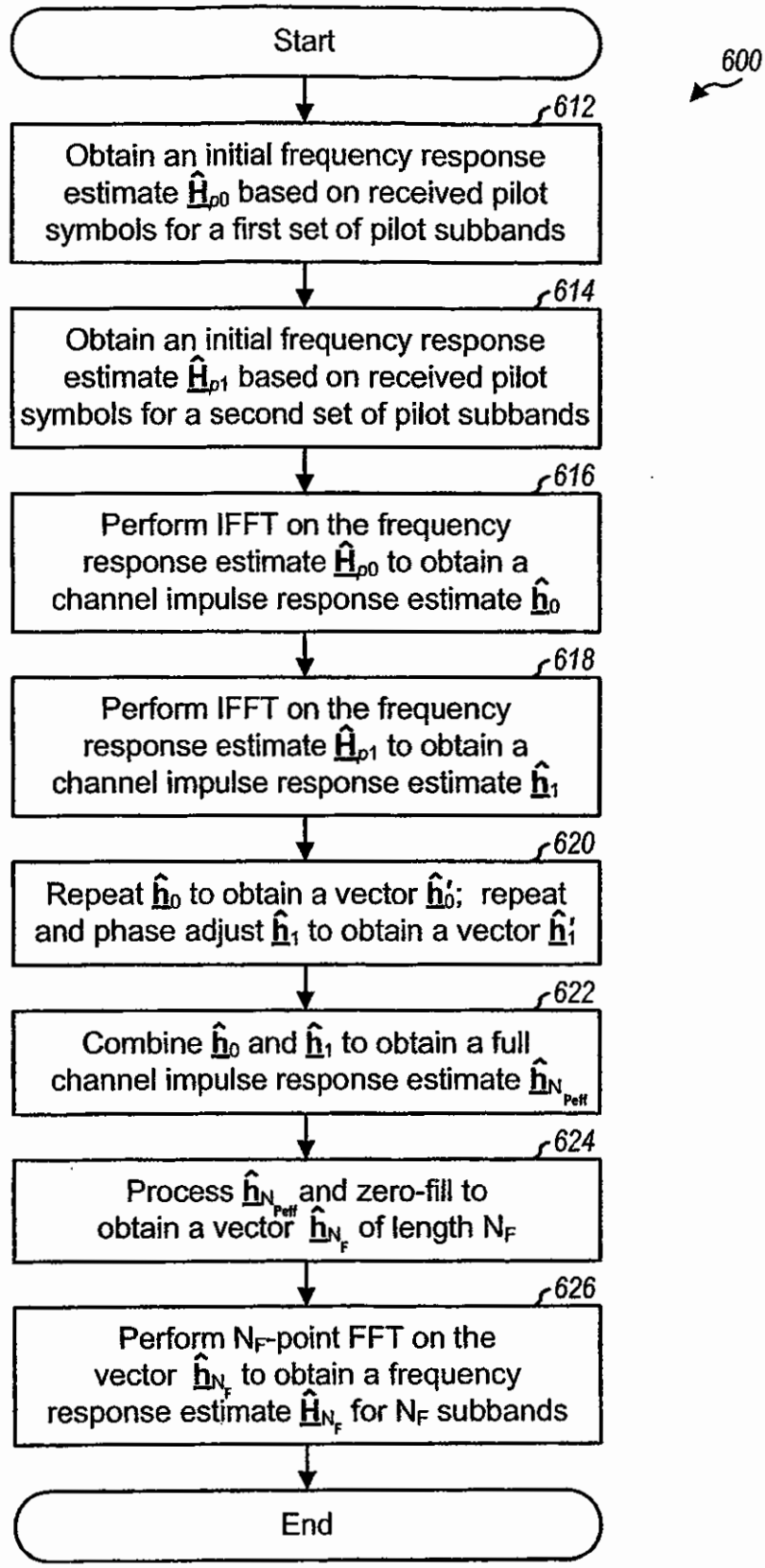

Start
600
612
Obtain an initial frequency response estimate $\hat{\underline{H}}_{p0}$ based on received pilot symbols for a first set of pilot subbands
614
Obtain an initial frequency response estimate $\hat{\underline{H}}_{p1}$ based on received pilot symbols for a second set of pilot subbands
616
Perform IFFT on the frequency response estimate $\hat{\underline{H}}_{p0}$ to obtain a channel impulse response estimate $\hat{\underline{h}}_0$
618
Perform IFFT on the frequency response estimate $\hat{\underline{H}}_{p1}$ to obtain a channel impulse response estimate $\hat{\underline{h}}_1$
620
Repeat $\hat{\underline{h}}_0$ to obtain a vector $\hat{\underline{h}}_0'$; repeat and phase adjust $\hat{\underline{h}}_1$ to obtain a vector $\hat{\underline{h}}_1'$
622
Combine $\hat{\underline{h}}_0$ and $\hat{\underline{h}}_1$ to obtain a full channel impulse response estimate $\hat{\underline{h}}_{N_{Peff}}$
624
Process $\hat{\underline{h}}_{N_{Peff}}$ and zero-fill to obtain a vector $\hat{\underline{h}}_{N_F}$ of length N_F
626
Perform N_F-point FFT on the vector $\hat{\underline{h}}_{N_F}$ to obtain a frequency response estimate $\hat{\underline{H}}_{N_F}$ for N_F subbands
End

FIG. 6

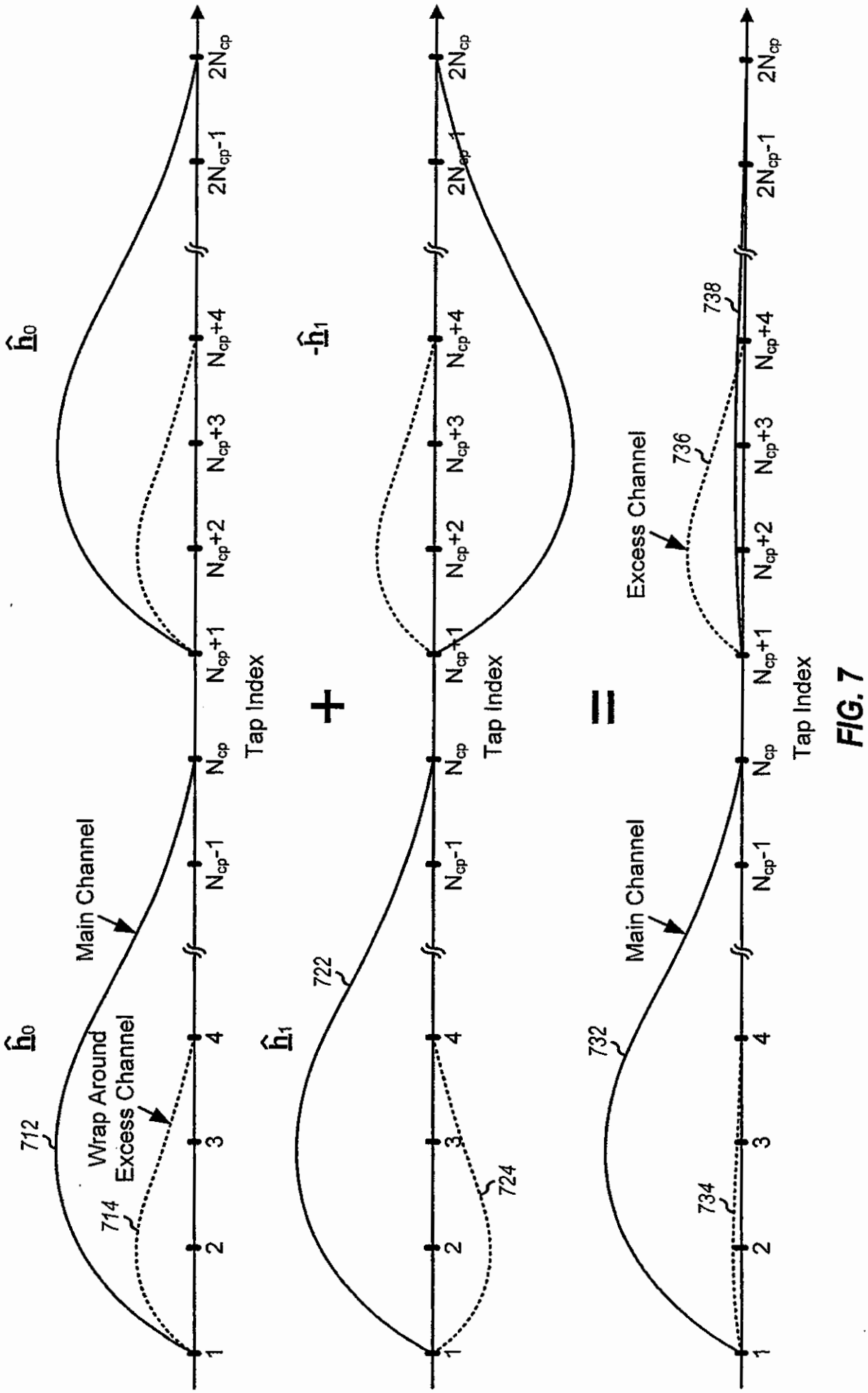

$\hat{\underline{h}}_0$
Main Channel
Wrap Around
Excess Channel
712
714
1
2
3
4
N_{cp}-1
N_{cp}
N_{cp}+1
N_{cp}+2
N_{cp}+3
N_{cp}+4
2N_{cp}-1
2N_{cp}
Tap Index
+
$-\hat{\underline{h}}_1$
722
724
=
732
734
736
738
Excess Channel

FIG. 7

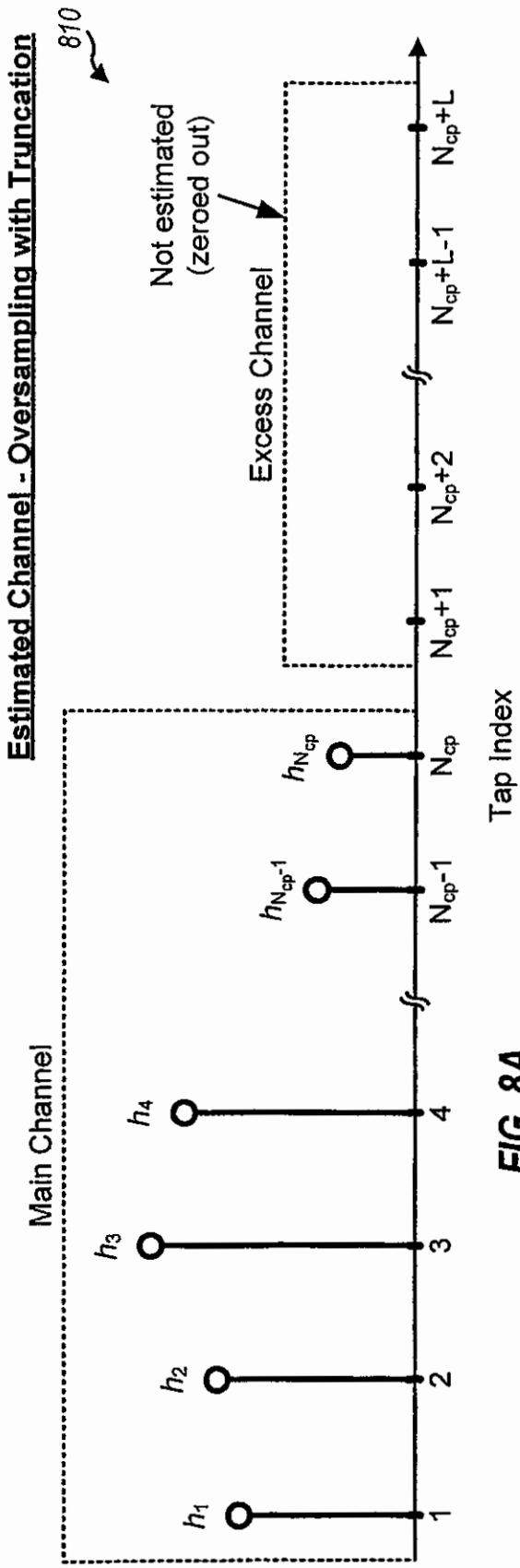

Estimated Channel - Oversampling with Truncation
810
Not estimated
(zeroed out)
Excess Channel
Main Channel
h_1
h_2
h_3
h_4
$h_{N_{cp}-1}$
$h_{N_{cp}}$
1
2
3
4
$N_{cp}-1$
N_{cp}
$N_{cp}+1$
$N_{cp}+2$
$N_{cp}+L-1$
$N_{cp}+L$
Tap Index

FIG. 8A

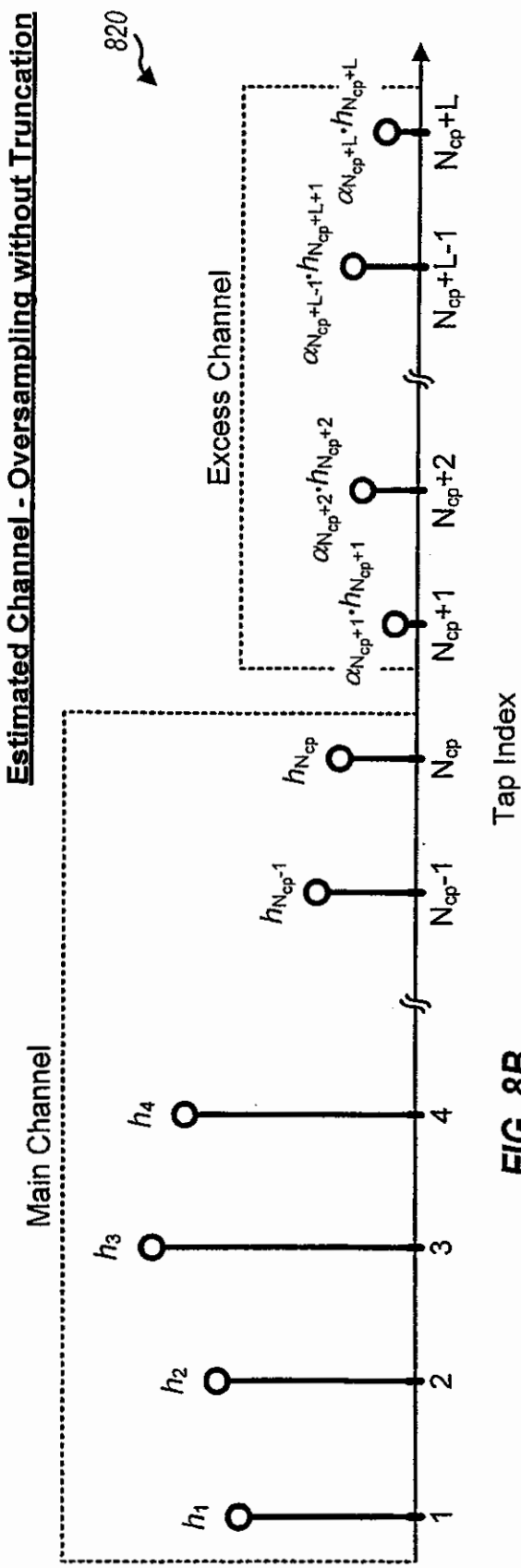

Estimated Channel - Oversampling without Truncation
820
Excess Channel
$\alpha_{N_{cp}+1} \cdot h_{N_{cp}+1}$
$\alpha_{N_{cp}+2} \cdot h_{N_{cp}+2}$
$\alpha_{N_{cp}+L-1} \cdot h_{N_{cp}+L-1}$
$\alpha_{N_{cp}+L} \cdot h_{N_{cp}+L}$
Main Channel
h_1
h_2
h_3
h_4
$h_{N_{cp}-1}$
$h_{N_{cp}}$
1
2
3
4
$N_{cp}-1$
N_{cp}
$N_{cp}+1$
$N_{cp}+2$
$N_{cp}+L-1$
$N_{cp}+L$
Tap Index

FIG. 8B

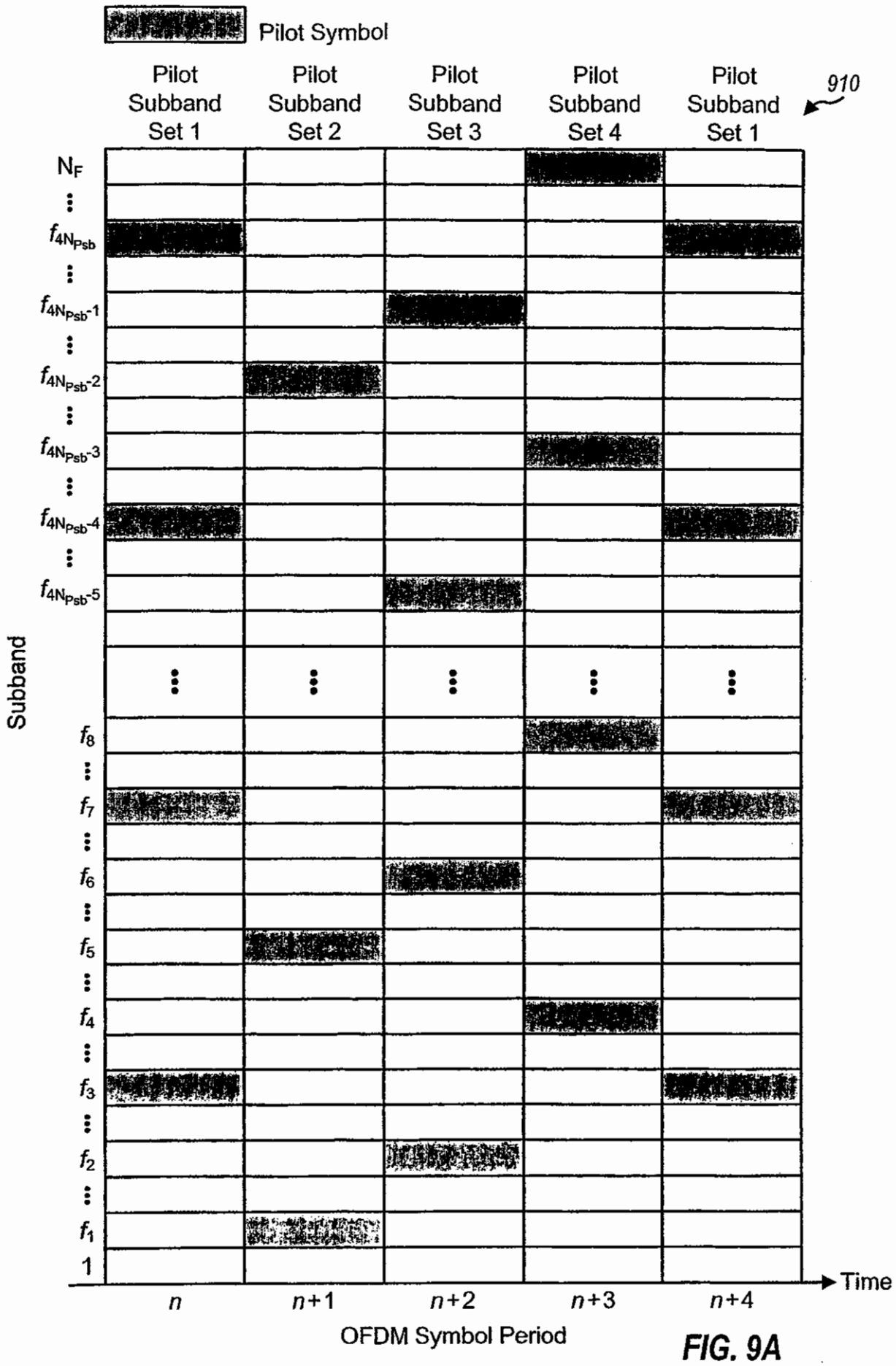

Pilot Symbol
Pilot Subband Set 1
Pilot Subband Set 2
Pilot Subband Set 3
Pilot Subband Set 4
Pilot Subband Set 1
910
Subband
N_F
$f_{4N_{Psb}}$
$f_{4N_{Psb}-1}$
$f_{4N_{Psb}-2}$
$f_{4N_{Psb}-3}$
$f_{4N_{Psb}-4}$
$f_{4N_{Psb}-5}$
f_8
f_7
f_6
f_5
f_4
f_3
f_2
f_1
1
Time
n
n+1
n+2
n+3
n+4
OFDM Symbol Period

FIG. 9A

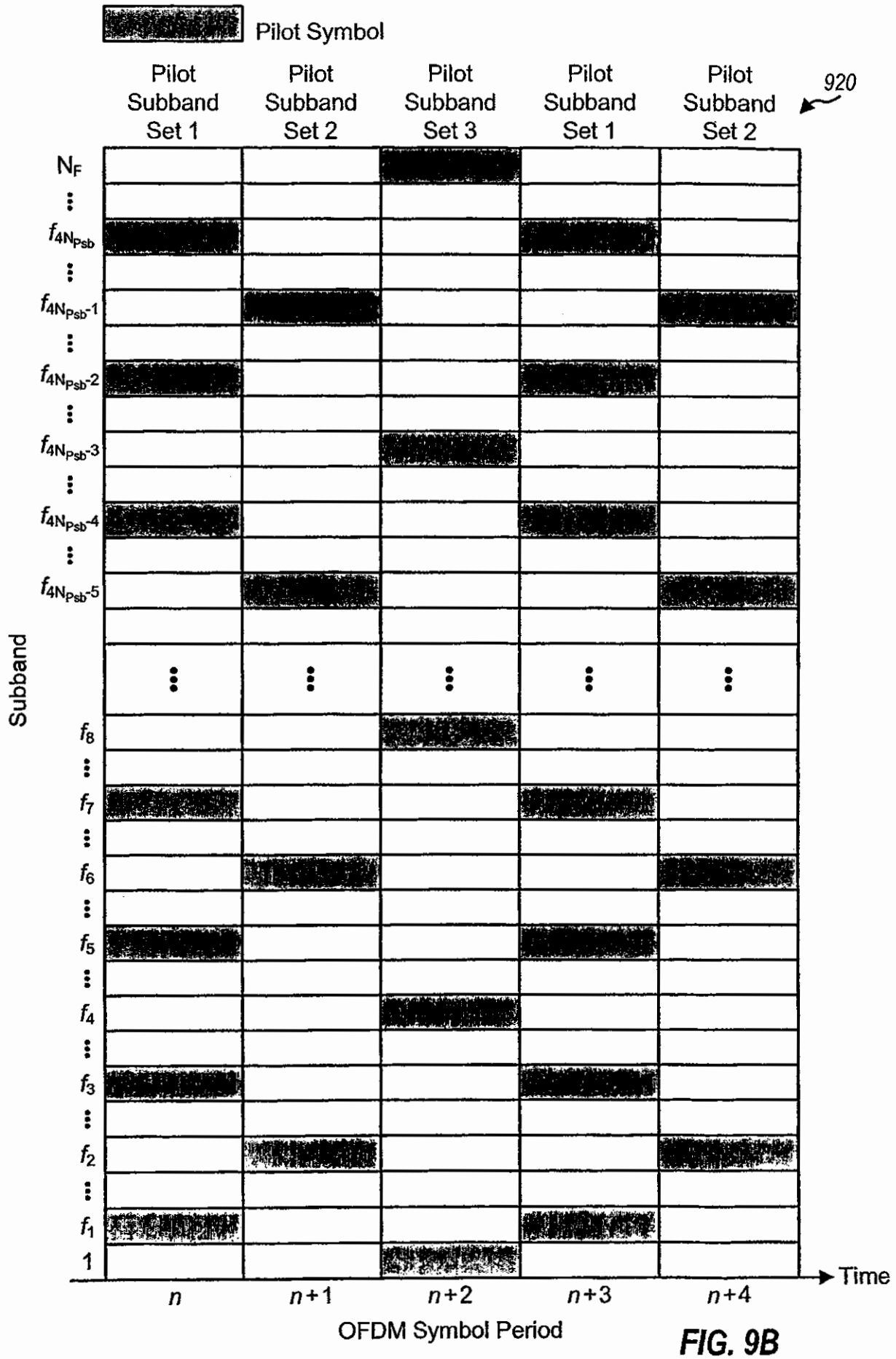

Pilot Symbol
Pilot Subband Set 1
Pilot Subband Set 2
Pilot Subband Set 3
Pilot Subband Set 1
Pilot Subband Set 2
920
N_F
$f_{4N_{Psb}}$
$f_{4N_{Psb}-1}$
$f_{4N_{Psb}-2}$
$f_{4N_{Psb}-3}$
$f_{4N_{Psb}-4}$
$f_{4N_{Psb}-5}$
f_8
f_7
f_6
f_5
f_4
f_3
f_2
f_1
1
Subband
Time
n
n+1
n+2
n+3
n+4
OFDM Symbol Period

FIG. 9B

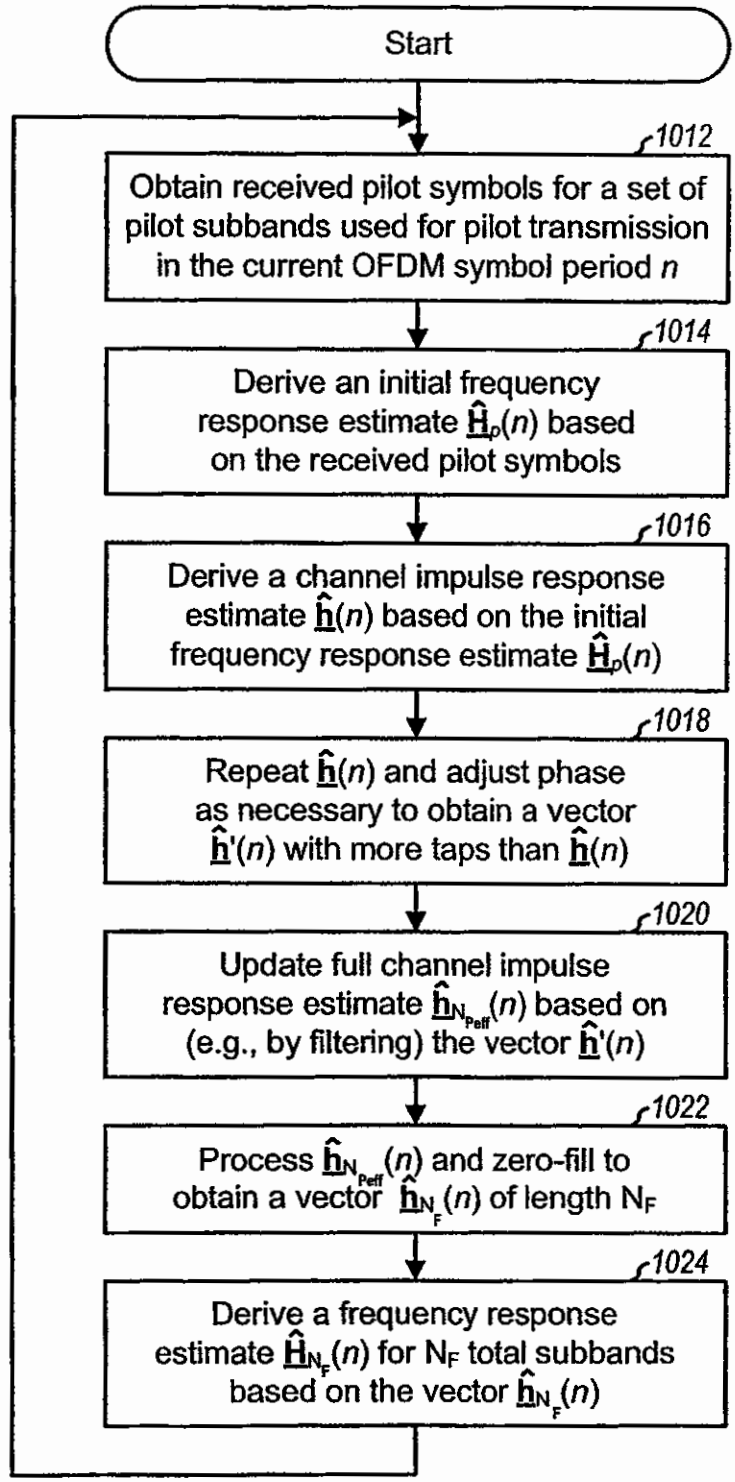

Start
1000
1012
Obtain received pilot symbols for a set of pilot subbands used for pilot transmission in the current OFDM symbol period n
1014
Derive an initial frequency response estimate $\underline{\hat{H}}_p(n)$ based on the received pilot symbols
1016
Derive a channel impulse response estimate $\underline{\hat{h}}(n)$ based on the initial frequency response estimate $\underline{\hat{H}}_p(n)$
1018
Repeat $\underline{\hat{h}}(n)$ and adjust phase as necessary to obtain a vector $\underline{\hat{h}}'(n)$ with more taps than $\underline{\hat{h}}(n)$
1020
Update full channel impulse response estimate $\underline{\hat{h}}_{N_{Peff}}(n)$ based on (e.g., by filtering) the vector $\underline{\hat{h}}'(n)$
1022
Process $\underline{\hat{h}}_{N_{Peff}}(n)$ and zero-fill to obtain a vector $\underline{\hat{h}}_{N_F}(n)$ of length N_F
1024
Derive a frequency response estimate $\underline{\hat{H}}_{N_F}(n)$ for N_F total subbands based on the vector $\underline{\hat{h}}_{N_F}(n)$

FIG. 10

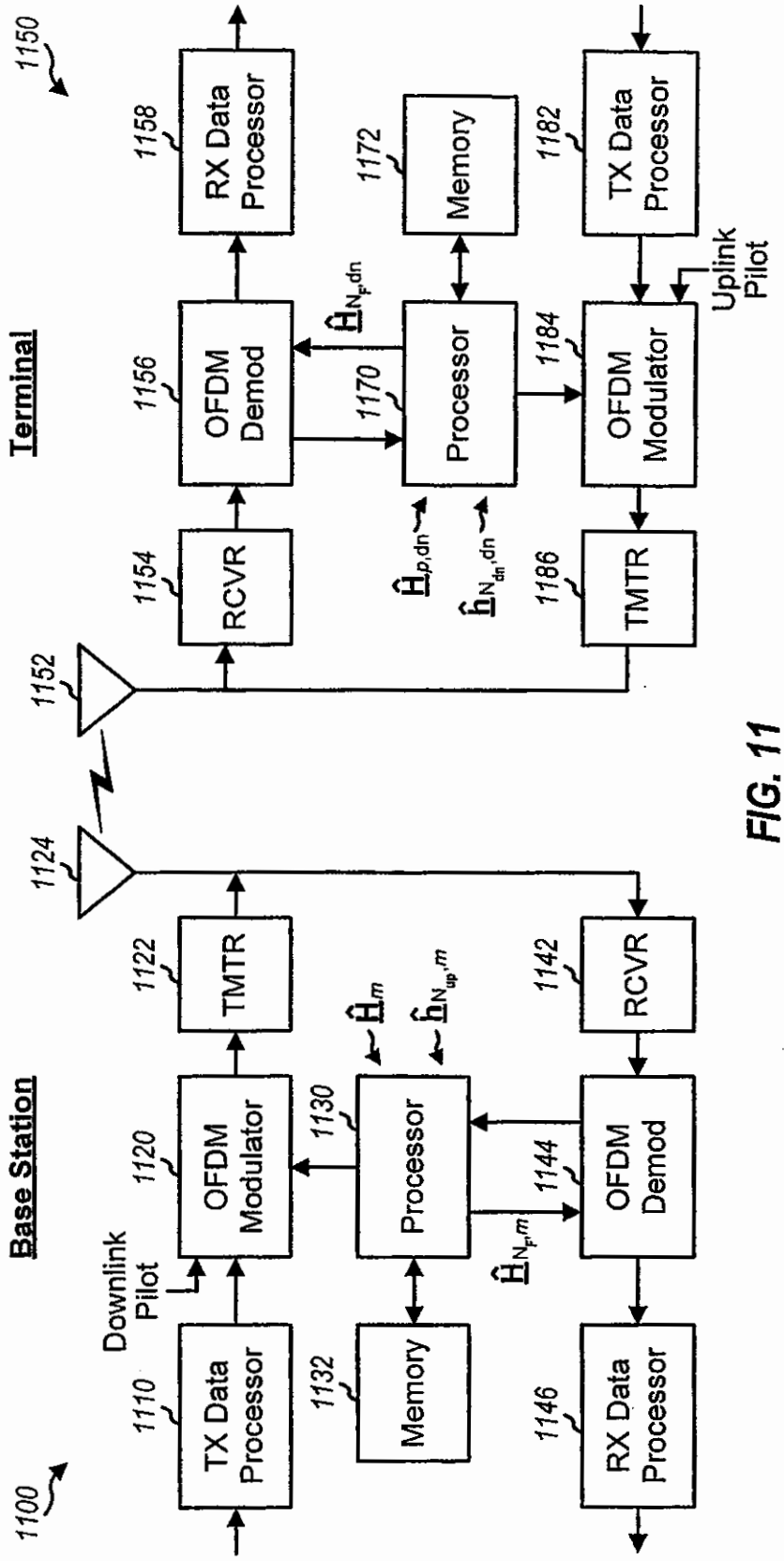

1100
Base Station
1110
TX Data Processor
Downlink Pilot
1120
OFDM Modulator
1122
TMTR
1124
1130
Processor
1132
Memory
1140
1142
RCVR
1144
OFDM Demod
1146
RX Data Processor
1150
Terminal
1152
1154
RCVR
1156
OFDM Demod
1158
RX Data Processor
1170
Processor
1172
Memory
1182
TX Data Processor
1184
OFDM Modulator
1186
TMTR
Uplink Pilot

FIG. 11

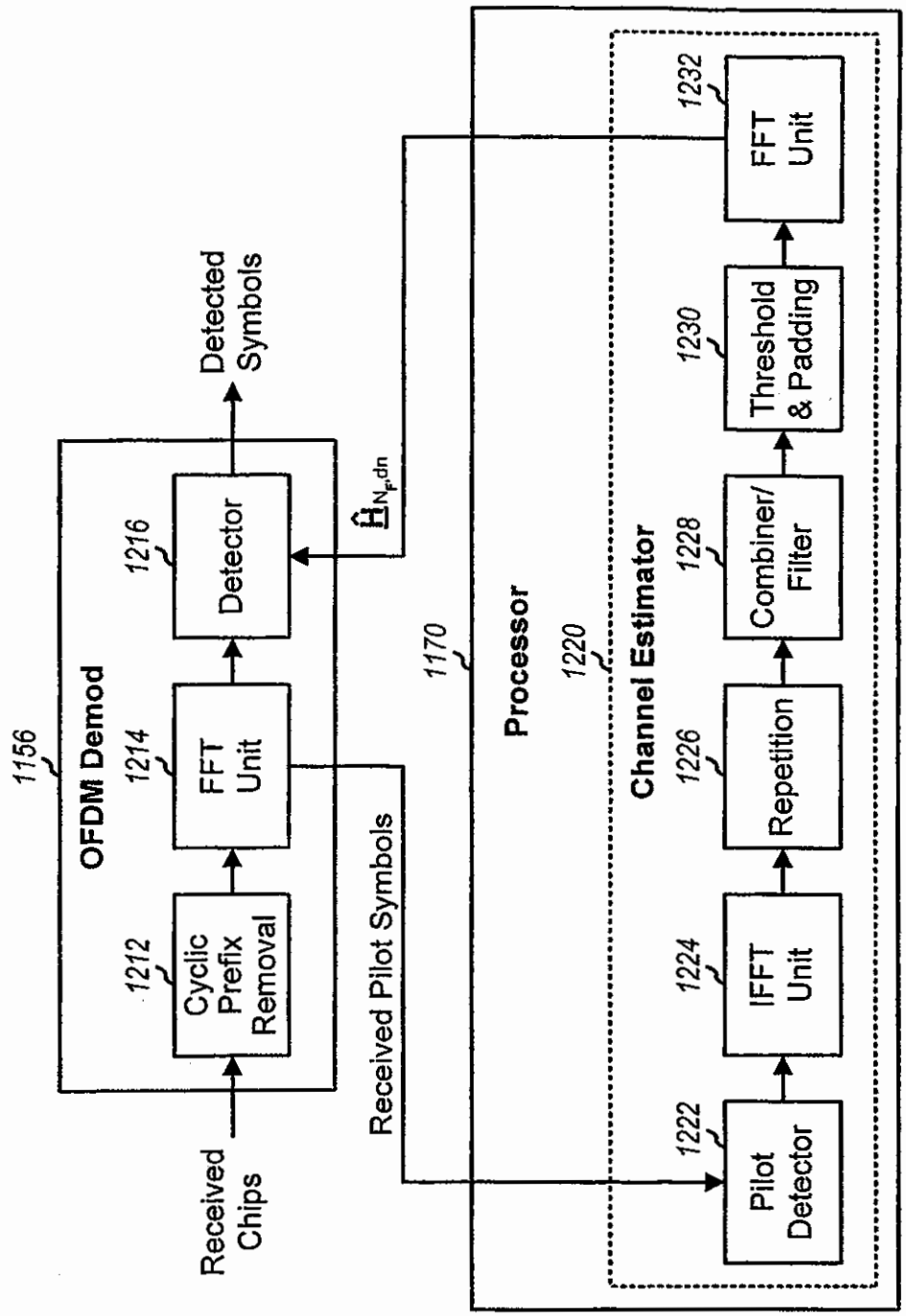

Received Chips
Detected Symbols
OFDM Demod
1156
Cyclic Prefix Removal
1212
FFT Unit
1214
Detector
1216
Received Pilot Symbols
Processor
1170
Channel Estimator
1220
Pilot Detector
1222
IFFT Unit
1224
Repetition
1226
Combiner/ Filter
1228
Threshold & Padding
1230
FFT Unit
1232

FIG. 12