(12) United States Patent
Mesecher et al.

(10) **Patent No.: US 9,270,327 B2**

(45) **Date of Patent: Feb. 23, 2016**

(54) **INTERFERENCE CANCELLATION IN A SPREAD SPECTRUM COMMUNICATION SYSTEM**

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(73) Assignee: **InterDigital Technology Corporation**, Wilmington, DE (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/710,162**

(22) Filed: **May 12, 2015**

(65) **Prior Publication Data**

US 2015/0244417 A1 Aug. 27, 2015

Related U.S. Application Data

(63) Continuation of application No. 13/117,233, filed on May 27, 2011, now Pat. No. 9,036,680, which is a continuation of application No. 12/480,337, filed on Jun. 8, 2009, now Pat. No. 7,953,139, which is a

(Continued)

(51) **Int. Cl.**

H04B 1/00 (2006.01)

H04B 1/7103 (2011.01)

(Continued)

(52) **U.S. Cl.**

CPC ***H04B 1/7103*** (2013.01); ***H04B 1/7097*** (2013.01); ***H04B 1/712*** (2013.01);

(Continued)

(58) **Field of Classification Search**

CPC .. H04B 1/7103; H04B 7/0678; H04B 7/0634; H04B 2201/70701

USPC 375/144

See application file for complete search history.

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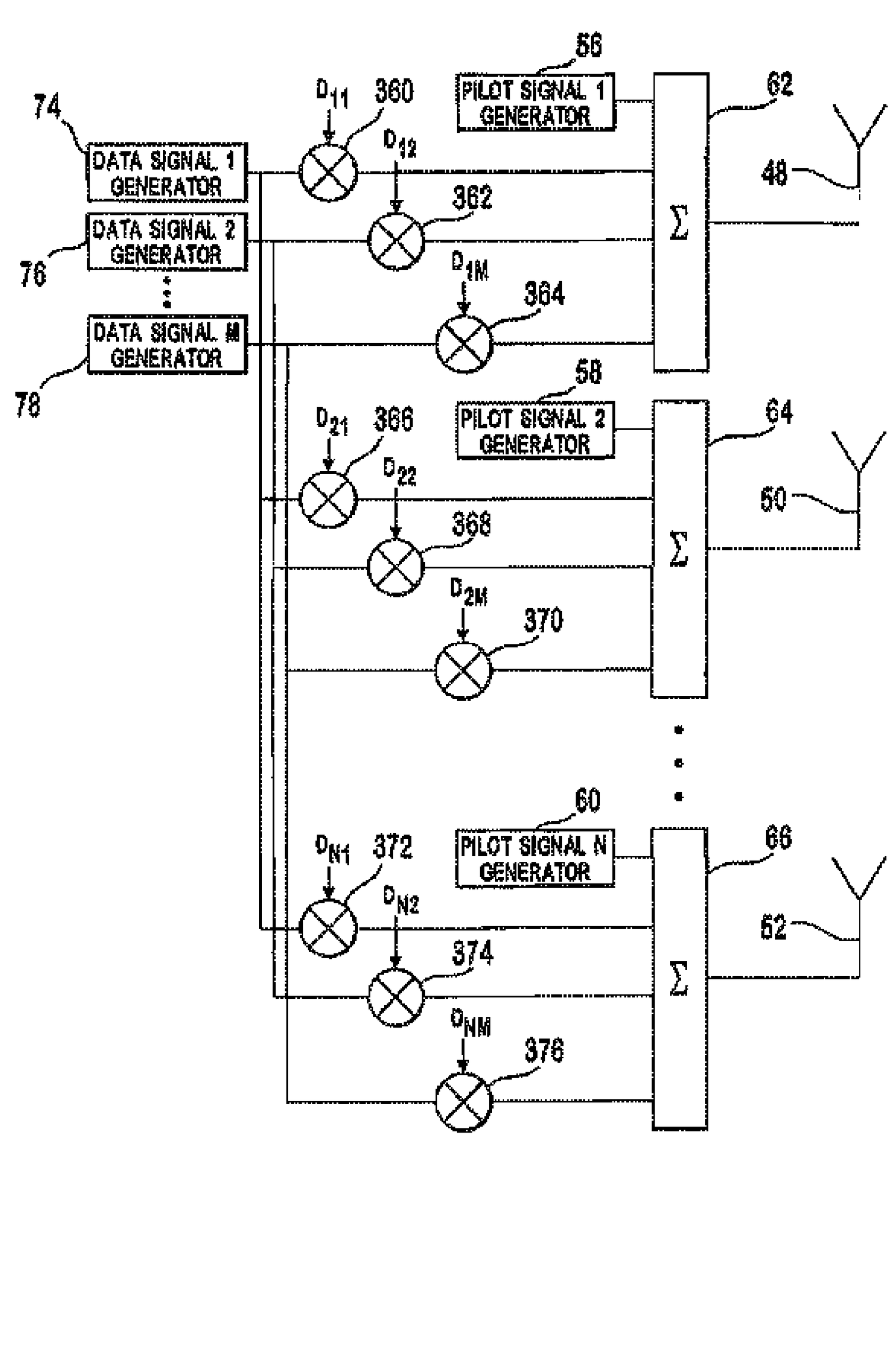
Primary Examiner — Tanmay Shah

(74) *Attorney, Agent, or Firm* — Volpe and Koenig, P.C.

(57) **ABSTRACT**

A method and apparatus used to transmit and receive weighted data transmissions over a plurality of antennas using a plurality of different pilot signals. Different pilot signals are produced and a different pilot signal of the plurality of pilot signals is transmitted on each of a plurality of antennas. Each of the pilot signals is derived from a pseudo noise (PN) sequence and a bit sequence of the PN sequence for each of the pilot signals is different. A plurality of data streams are produced in which each of the data streams has data bits combined with bits of a PN sequence. The data streams are weighted in response to weight information received from a receiving device and the plurality of weighted data streams are transmitted using the plurality of antennas.

5 Claims, 22 Drawing Sheets



Related U.S. Application Data

continuation of application No. 11/301,666, filed on Dec. 13, 2005, now Pat. No. 7,545,846, which is a continuation of application No. 10/923,950, filed on Aug. 23, 2004, now Pat. No. 6,985,515, which is a continuation of application No. 10/423,230, filed on Apr. 25, 2003, now Pat. No. 6,782,040, which is a continuation of application No. 09/892,369, filed on Jun. 27, 2001, now Pat. No. 6,574,271, which is a continuation of application No. 09/659,858, filed on Sep. 11, 2000, now Pat. No. 6,278,726, which is a continuation-in-part of application No. 09/602,963, filed on Jun. 23, 2000, now Pat. No. 6,373,877, which is a continuation of application No. 09/394,452, filed on Sep. 10, 1999, now Pat. No. 6,115,406.

(51) **Int. Cl.**

H04B 1/7097	(2011.01)
H04B 1/712	(2011.01)
H04B 7/06	(2006.01)
H04J 13/00	(2011.01)
H04B 7/08	(2006.01)

(52) **U.S. Cl.**

CPC ***H04B 7/0613*** (2013.01); ***H04B 7/0615*** (2013.01); ***H04B 7/0619*** (2013.01); ***H04B 7/0634*** (2013.01); ***H04B 7/0678*** (2013.01); ***H04B 7/0854*** (2013.01); ***H04B 7/0857*** (2013.01); ***H04J 13/0003*** (2013.01); *H04B 7/0845* (2013.01); *H04B 7/0891* (2013.01); *H04B 2201/70701* (2013.01)

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WO	96/21295		7/1996
WO	97/13386		4/1997
WO	99/04537		1/1999
WO	99/12283		3/1999
WO	99/23767		5/1999
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WO	02/067444		8/2002
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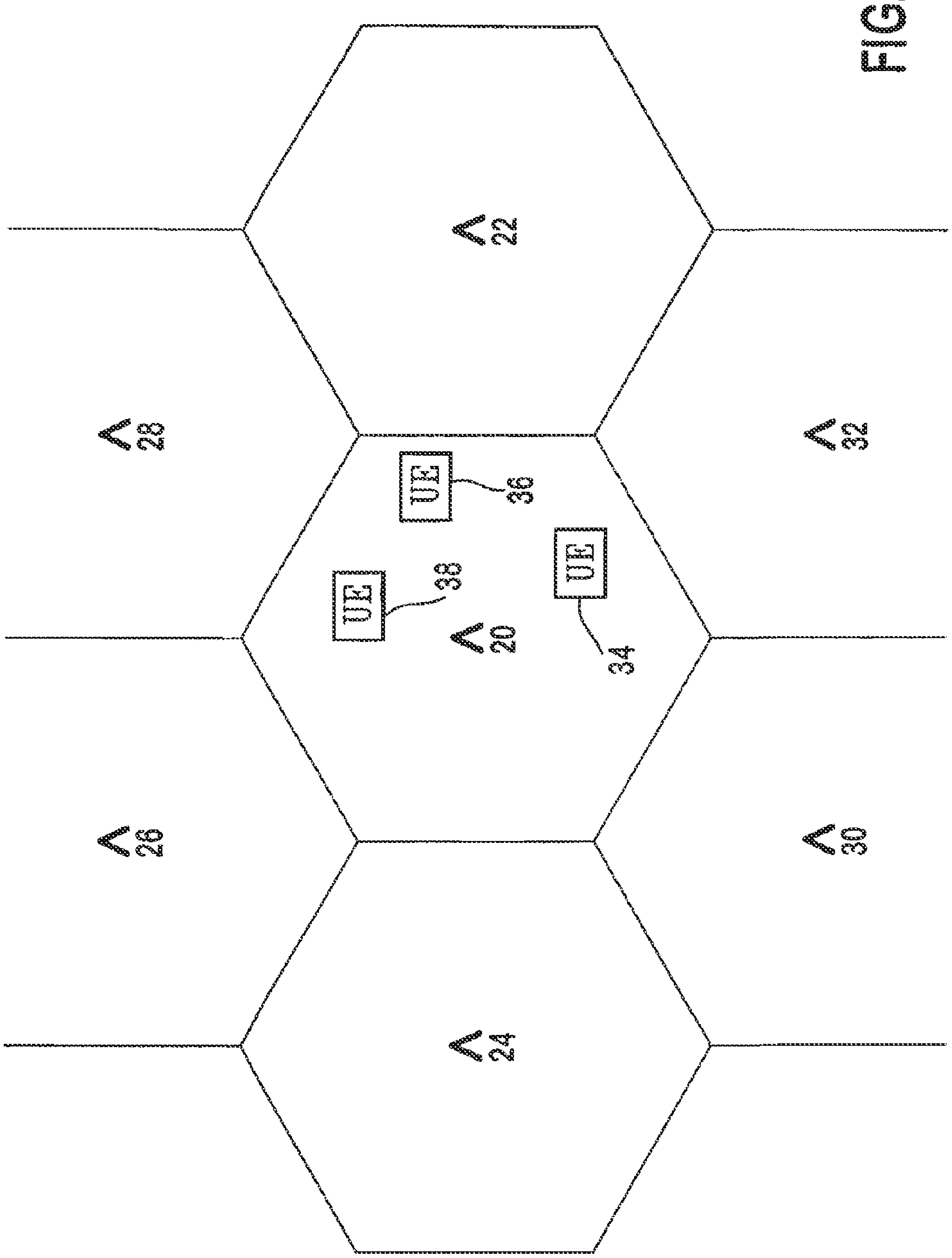
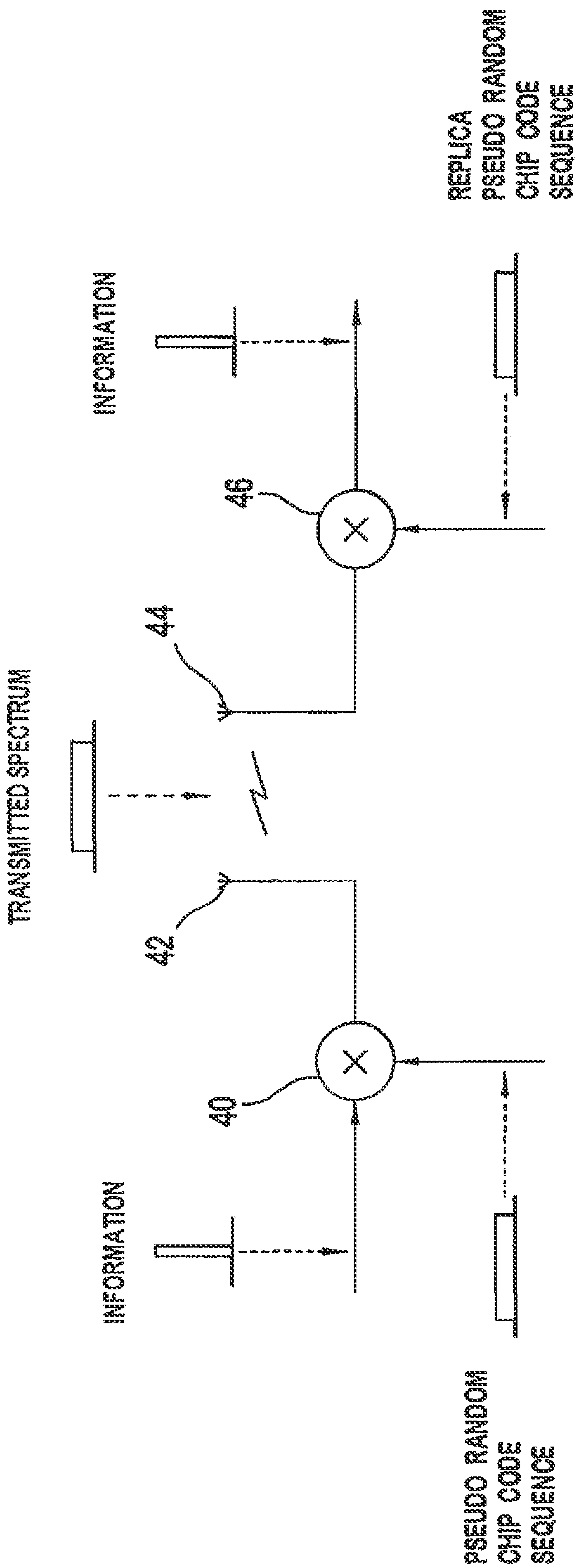


FIG. 1



PRIOR ART

FIG. 2

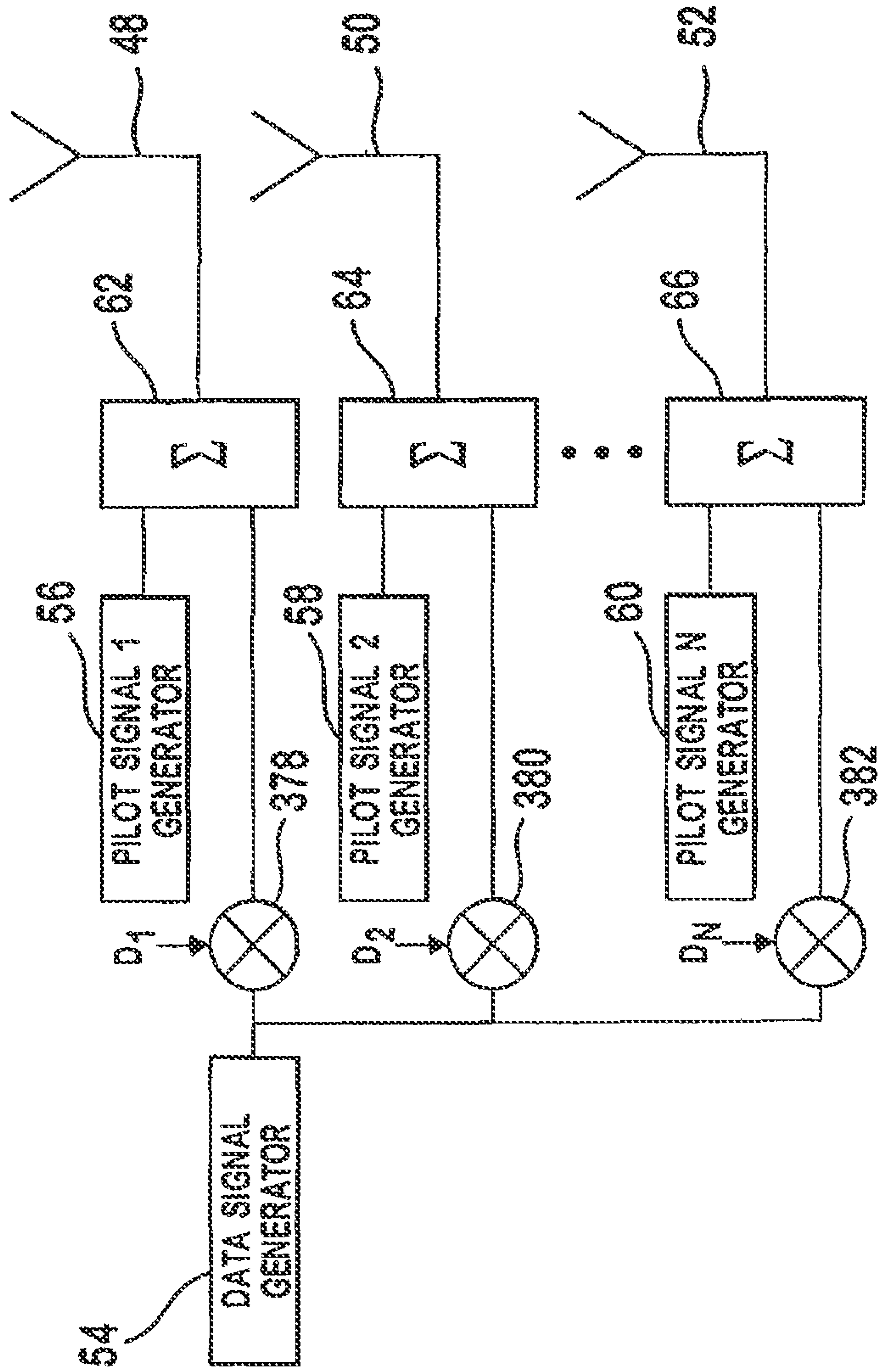

48
50
52
62
64
66
Σ
Σ
Σ
56
PILOT SIGNAL 1 GENERATOR
58
PILOT SIGNAL 2 GENERATOR
60
PILOT SIGNAL N GENERATOR
D_1
D_2
D_N
378
380
382
54
DATA SIGNAL GENERATOR

FIG. 3

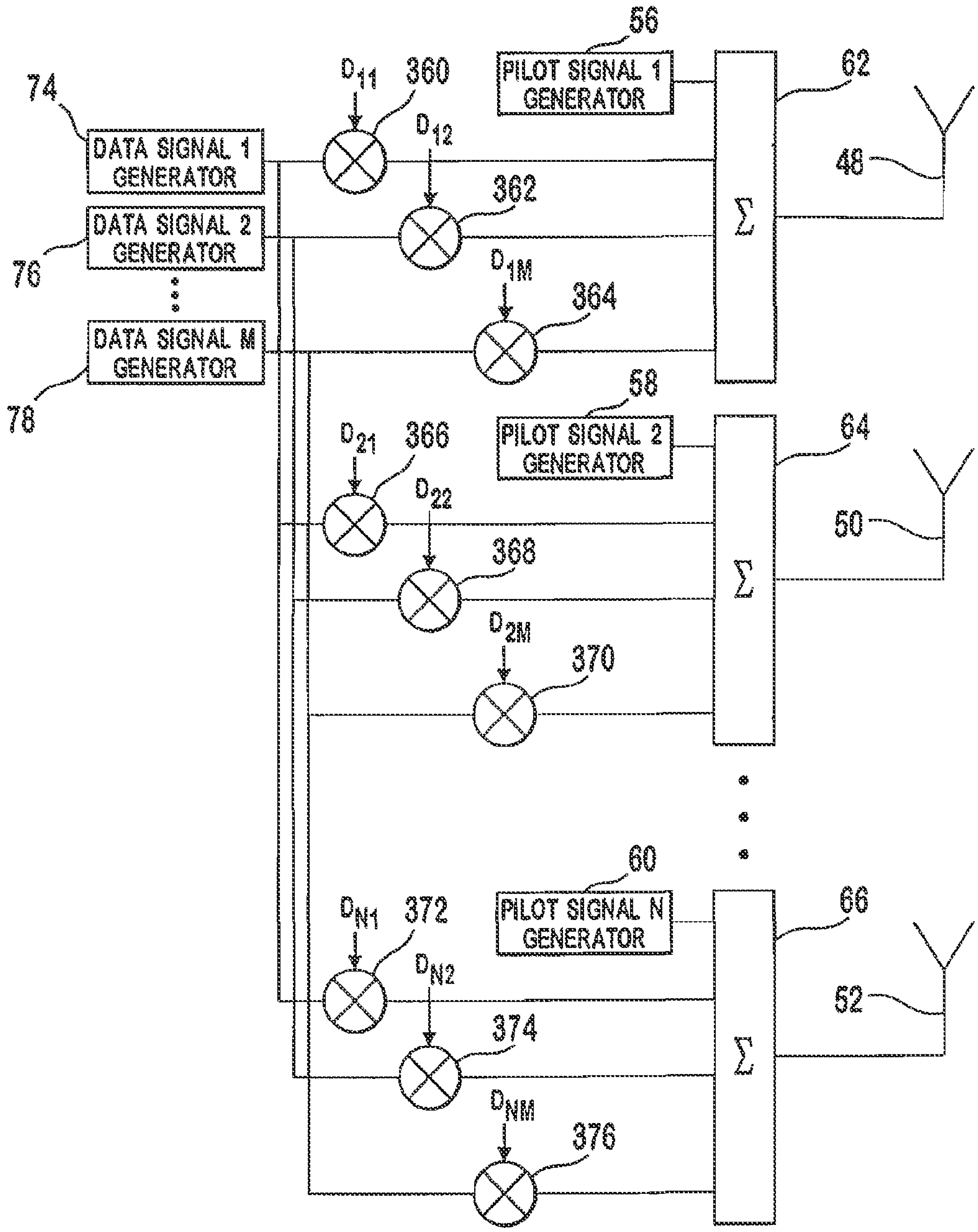
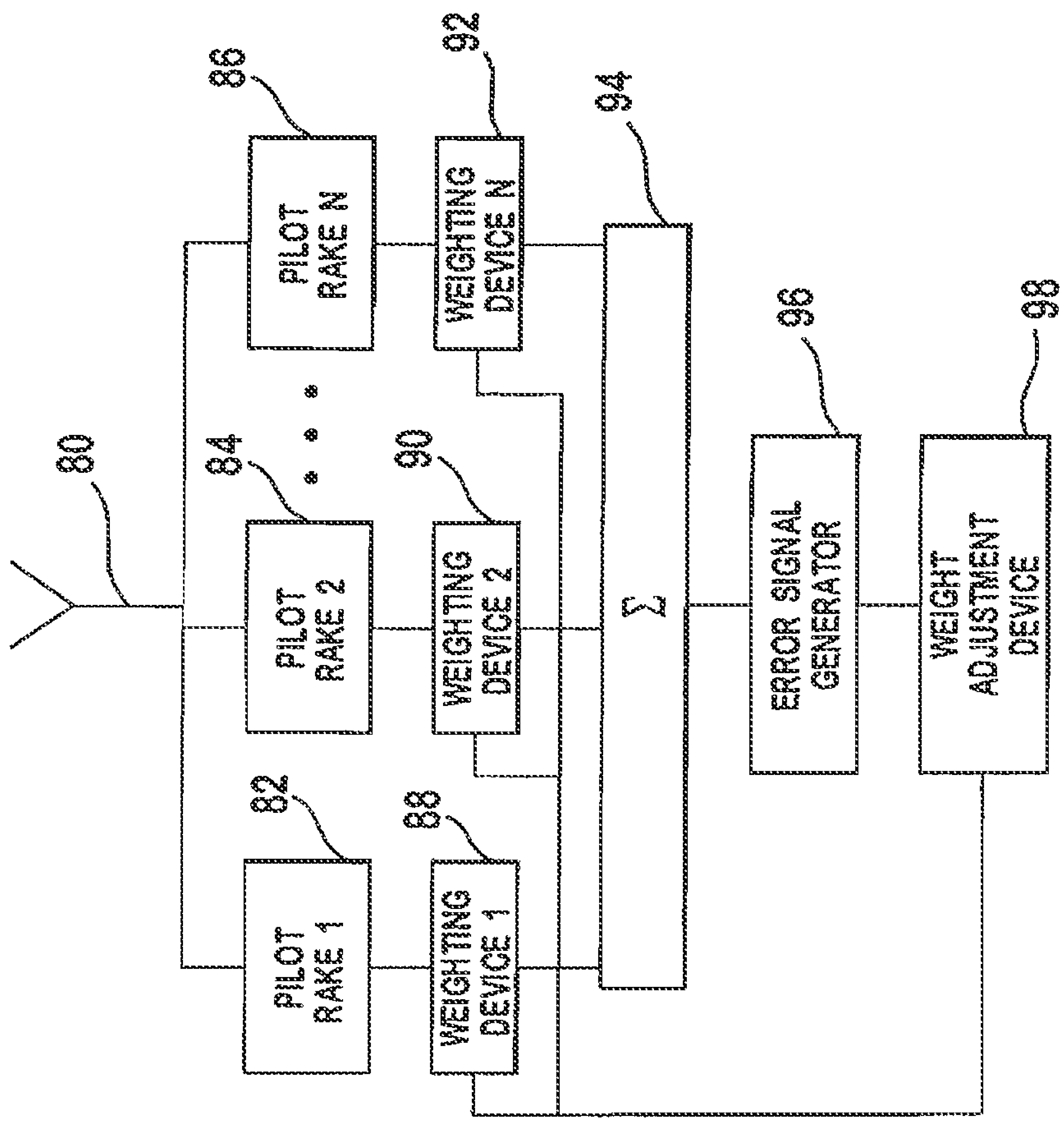
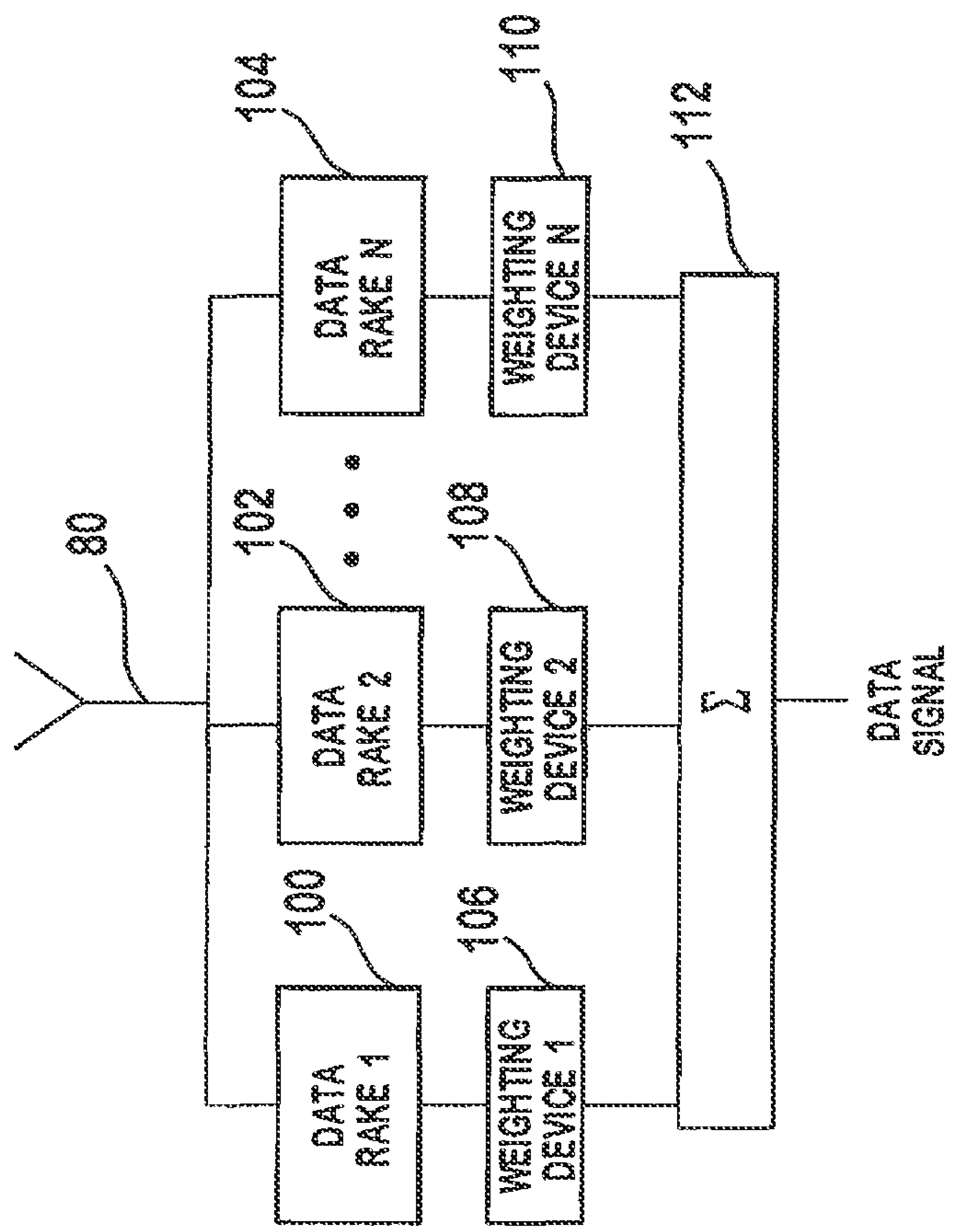

74
DATA SIGNAL 1 GENERATOR
DATA SIGNAL 2 GENERATOR
76
DATA SIGNAL M GENERATOR
78
D11
360
D12
362
D1M
364
56
PILOT SIGNAL 1 GENERATOR
62
48
Σ
58
PILOT SIGNAL 2 GENERATOR
64
50
D21
366
D22
368
D2M
370
60
PILOT SIGNAL N GENERATOR
66
52
DN1
372
DN2
374
DNM
376

FIG. 4

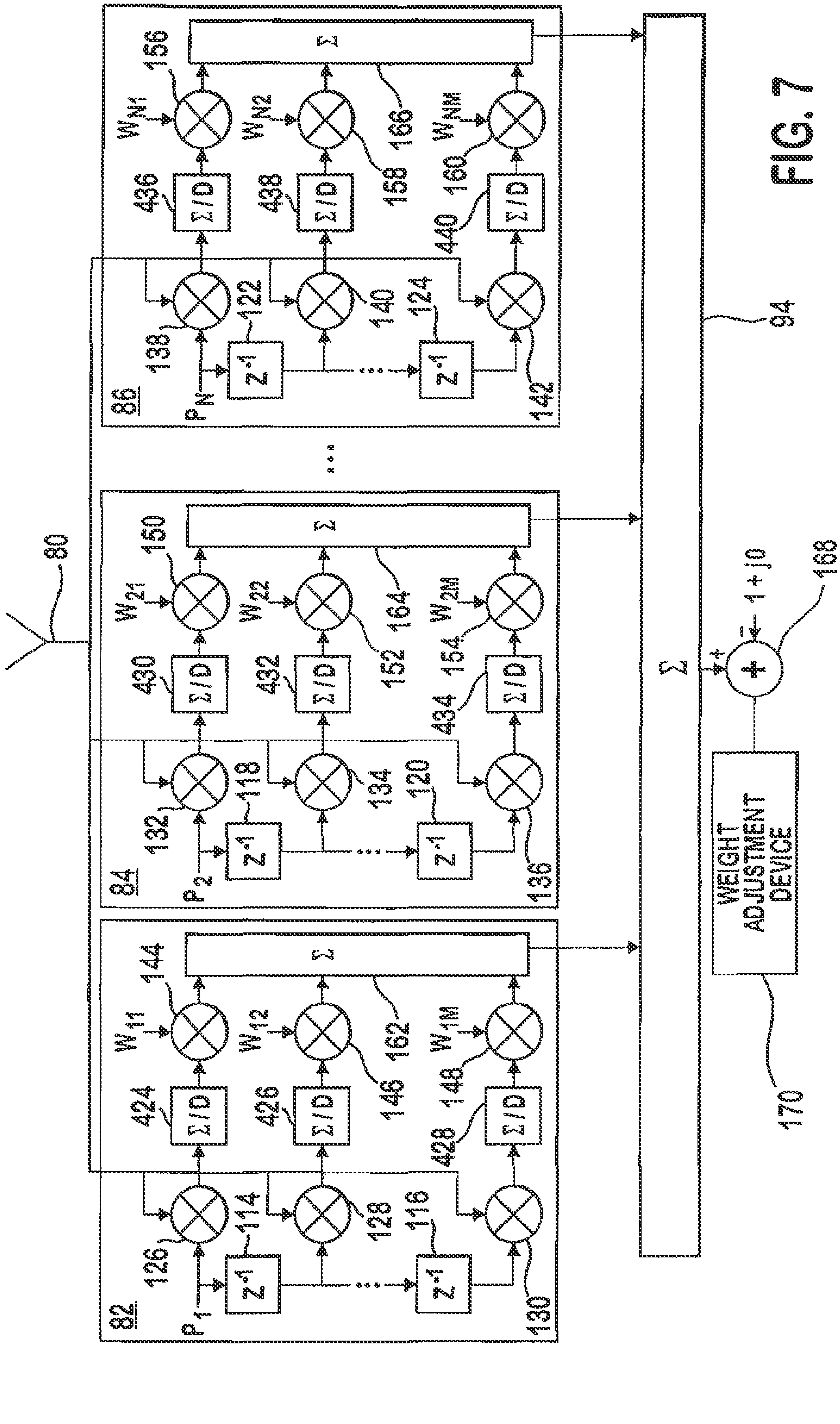
FIG. 5


80
82
84
86
88
90
92
94
96
98
PILOT RAKE 1
PILOT RAKE 2
PILOT RAKE N
WEIGHTING DEVICE 1
WEIGHTING DEVICE 2
WEIGHTING DEVICE N
Σ
ERROR SIGNAL GENERATOR
WEIGHT ADJUSTMENT DEVICE



80
DATA RAKE 1
DATA RAKE 2
DATA RAKE N
WEIGHTING DEVICE 1
WEIGHTING DEVICE 2
WEIGHTING DEVICE N
100
102
104
106
108
110
112
Σ
DATA SIGNAL

FIG. 6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82
84
86
P_1
P_2
P_N
z^{-1}
Σ / D
W_{11}
W_{12}
W_{1M}
W_{21}
W_{22}
W_{2M}
W_{N1}
W_{N2}
W_{NM}
Σ
94
168
1 + j0
WEIGHT ADJUSTMENT DEVICE
170

FIG. 7

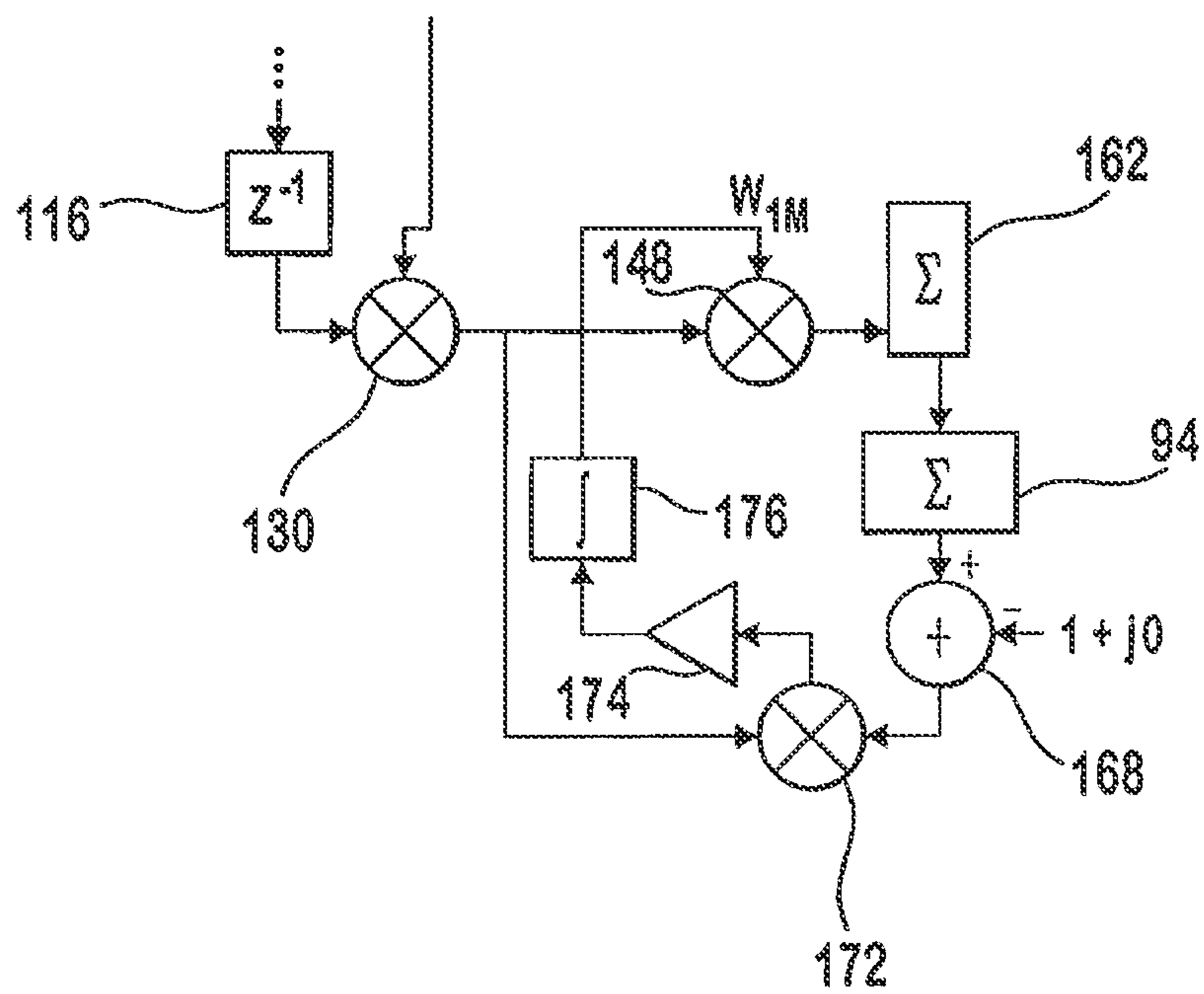


FIG. 8

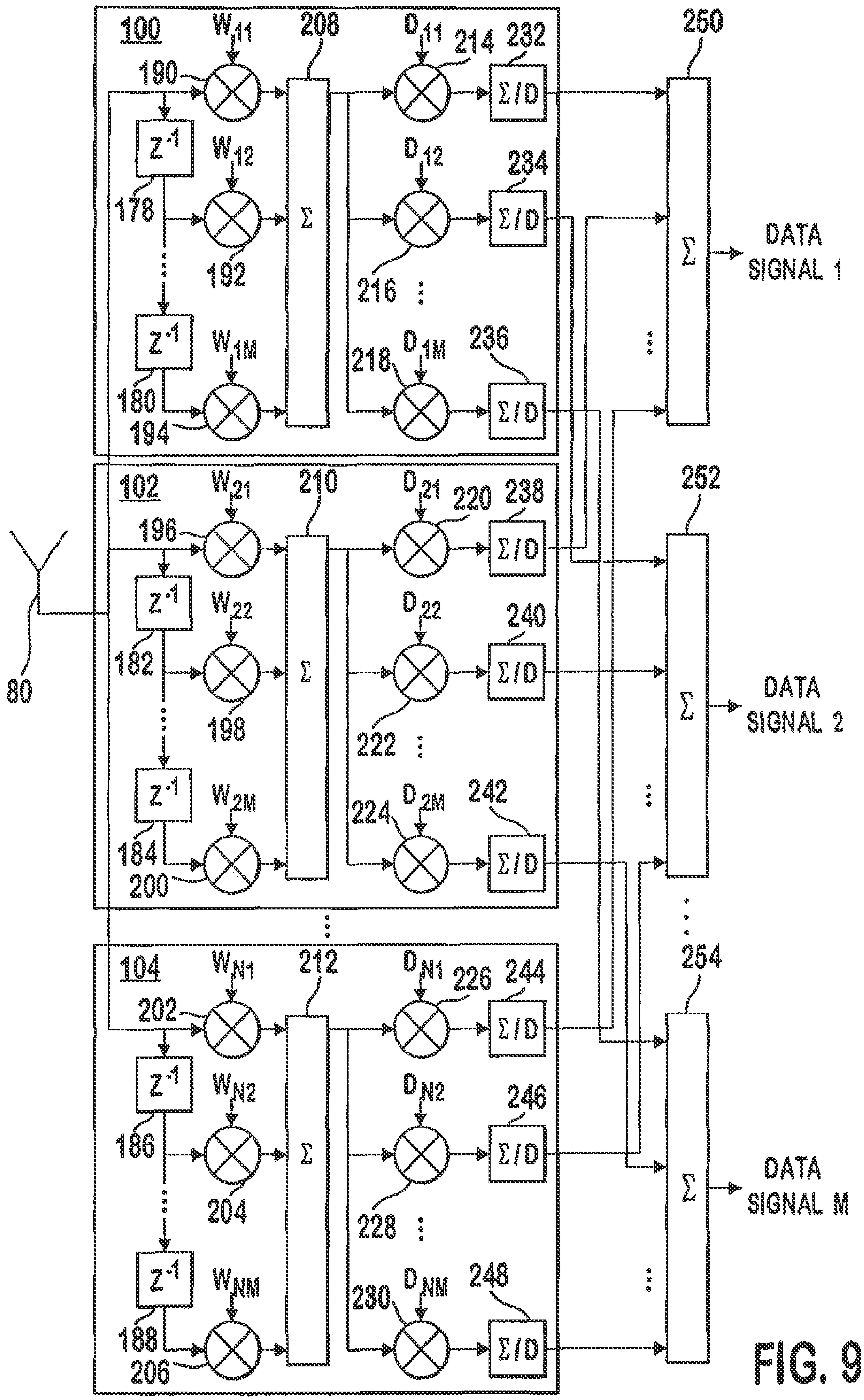

100
102
104
80
W11
W12
W1M
W21
W22
W2M
WN1
WN2
WNM
D11
D12
D1M
D21
D22
D2M
DN1
DN2
DNM
Z-1
Σ
Σ/D
178
180
182
184
186
188
190
192
194
196
198
200
202
204
206
208
210
212
214
216
218
220
222
224
226
228
230
232
234
236
238
240
242
244
246
248
250
252
254
DATA SIGNAL 1
DATA SIGNAL 2
DATA SIGNAL M

FIG. 9

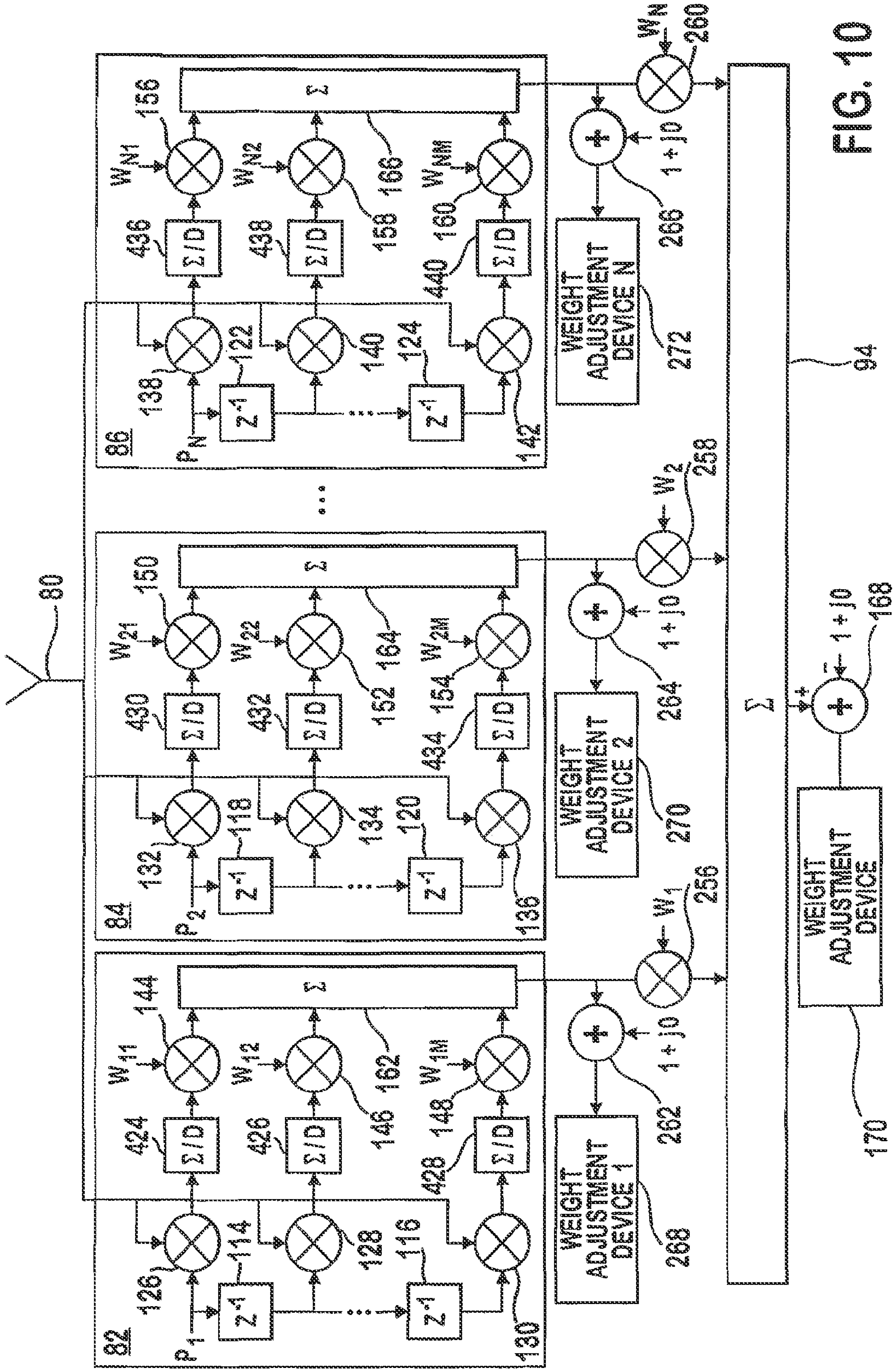
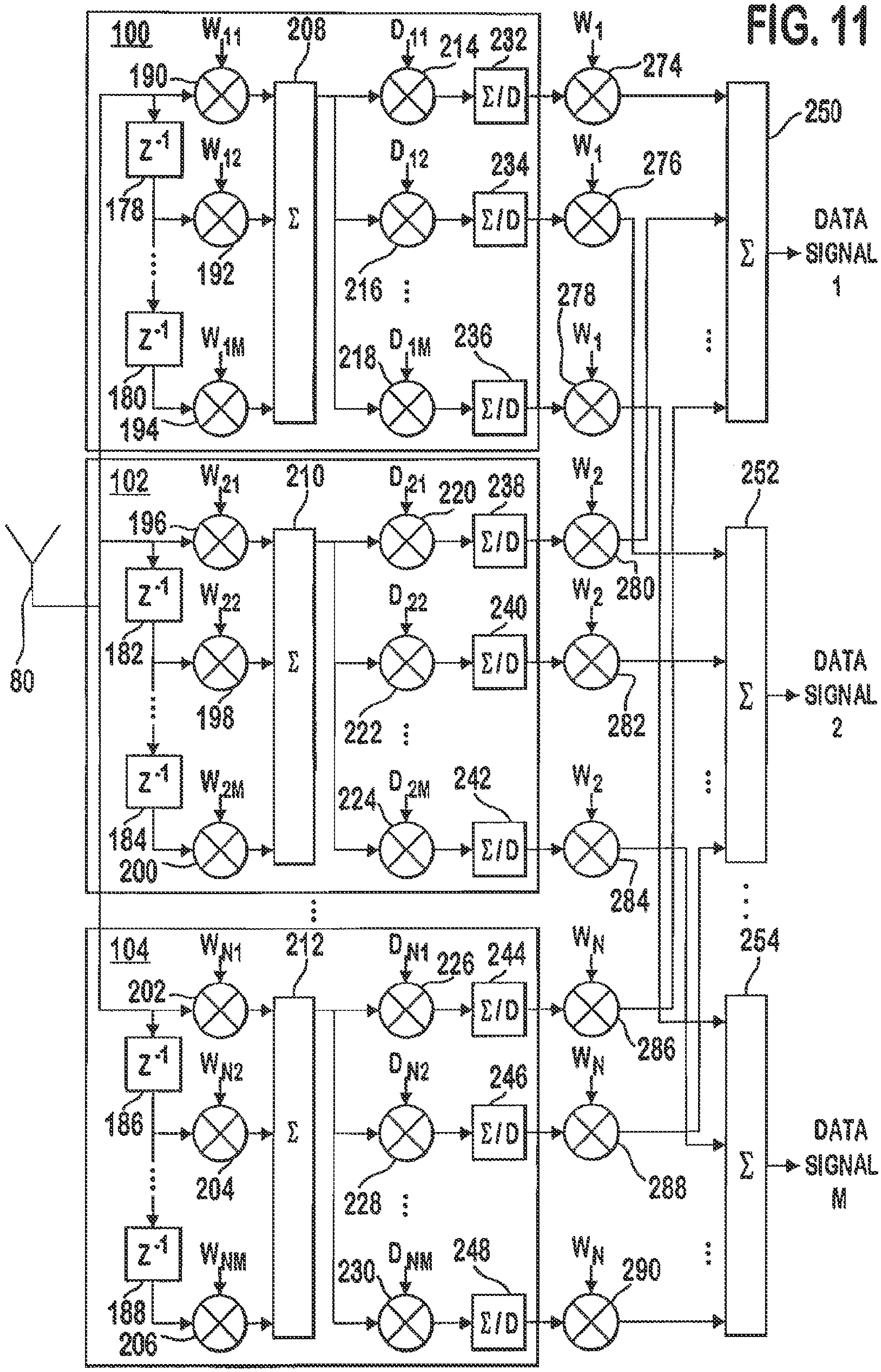

WEIGHT ADJUSTMENT DEVICE 1
WEIGHT ADJUSTMENT DEVICE 2
WEIGHT ADJUSTMENT DEVICE N
WEIGHT ADJUSTMENT DEVICE
1 + j0
Σ / D
Σ

FIG. 10

FIG. 11



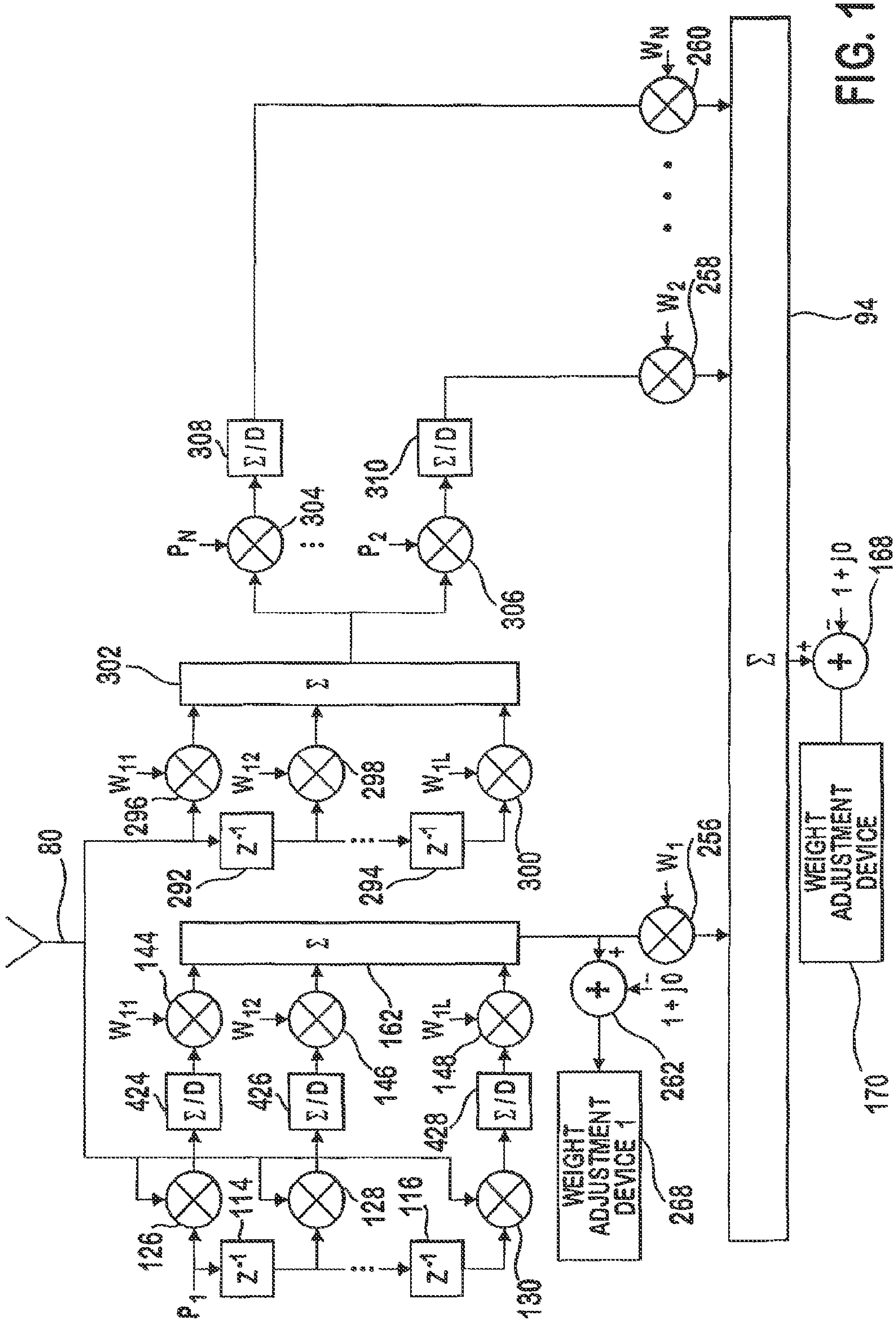
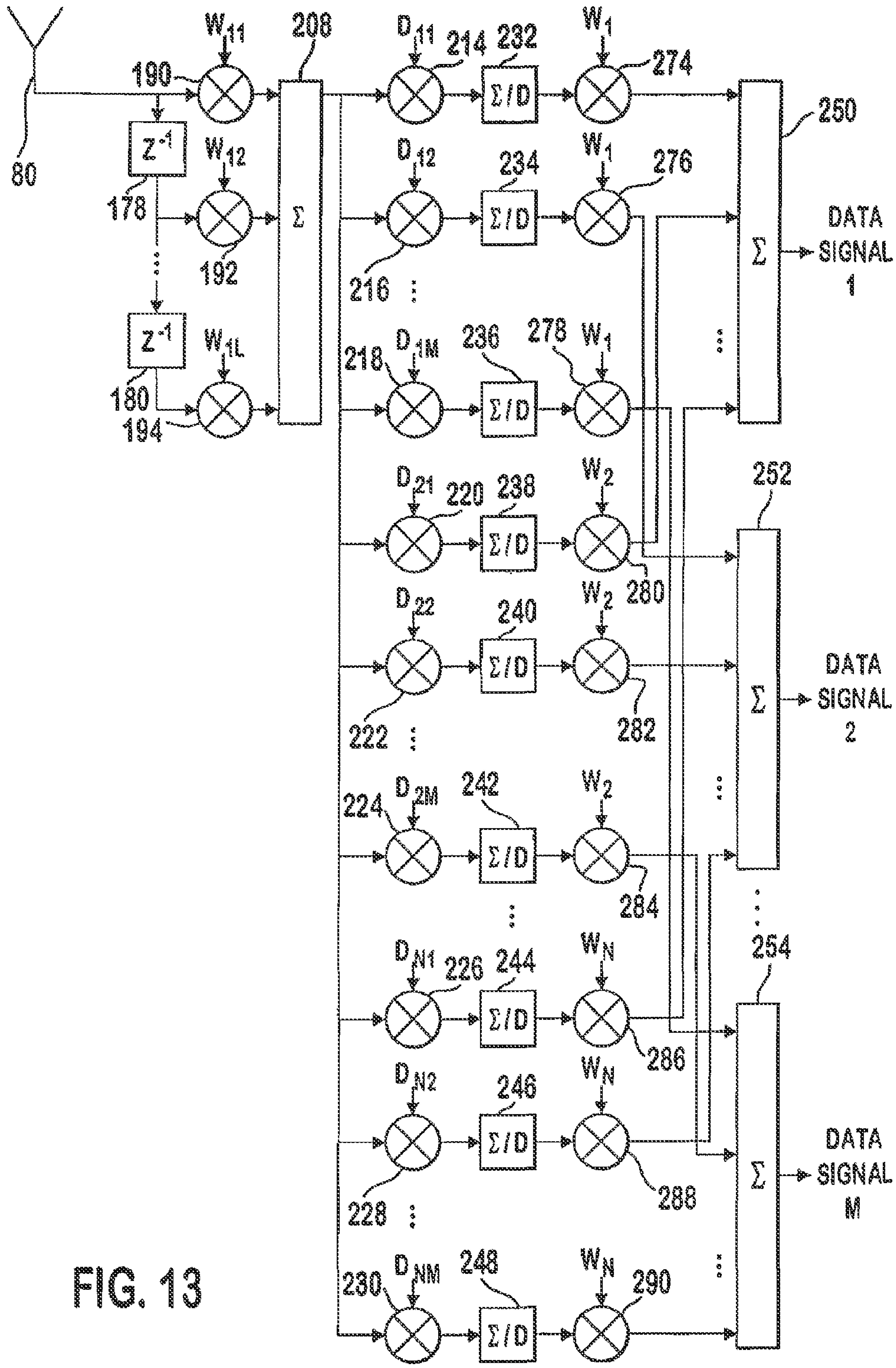

WEIGHT
ADJUSTMENT
DEVICE
WEIGHT
ADJUSTMENT
DEVICE 1
Σ / D
Σ
80
94
170
268
262
256
258
260
302
304
306
308
310

FIG. 12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190
178
180
194
192
W11
W12
W1L
Z-1
Z-1
208
Σ
D11
D12
D1M
D21
D22
D2M
DN1
DN2
DNM
214
216
218
220
222
224
226
228
230
232
234
236
238
240
242
244
246
248
Σ/D
W1
W2
WN
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286
288
290
250
252
254
DATA SIGNAL 1
DATA SIGNAL 2
DATA SIGNAL M

FIG. 13

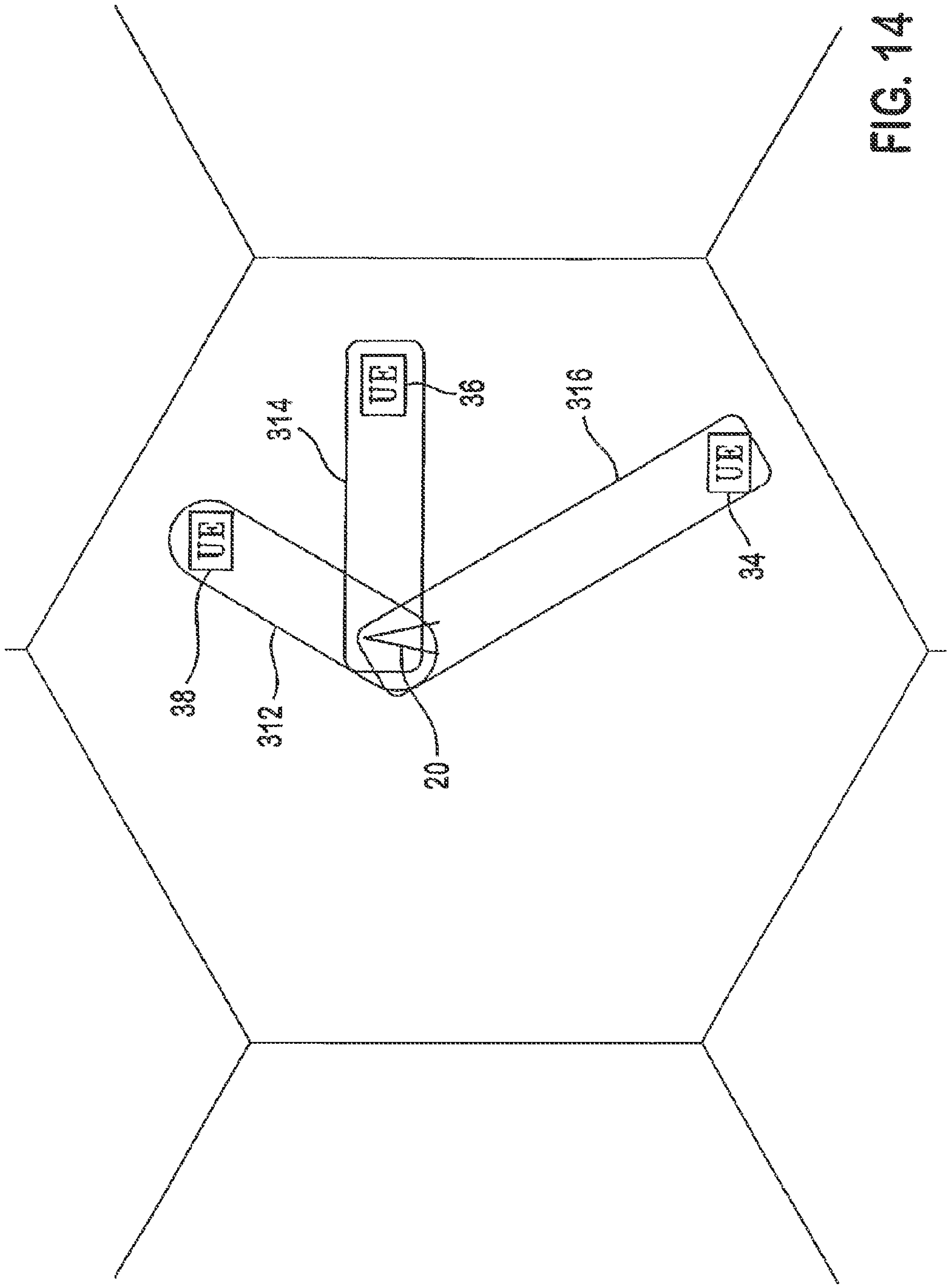
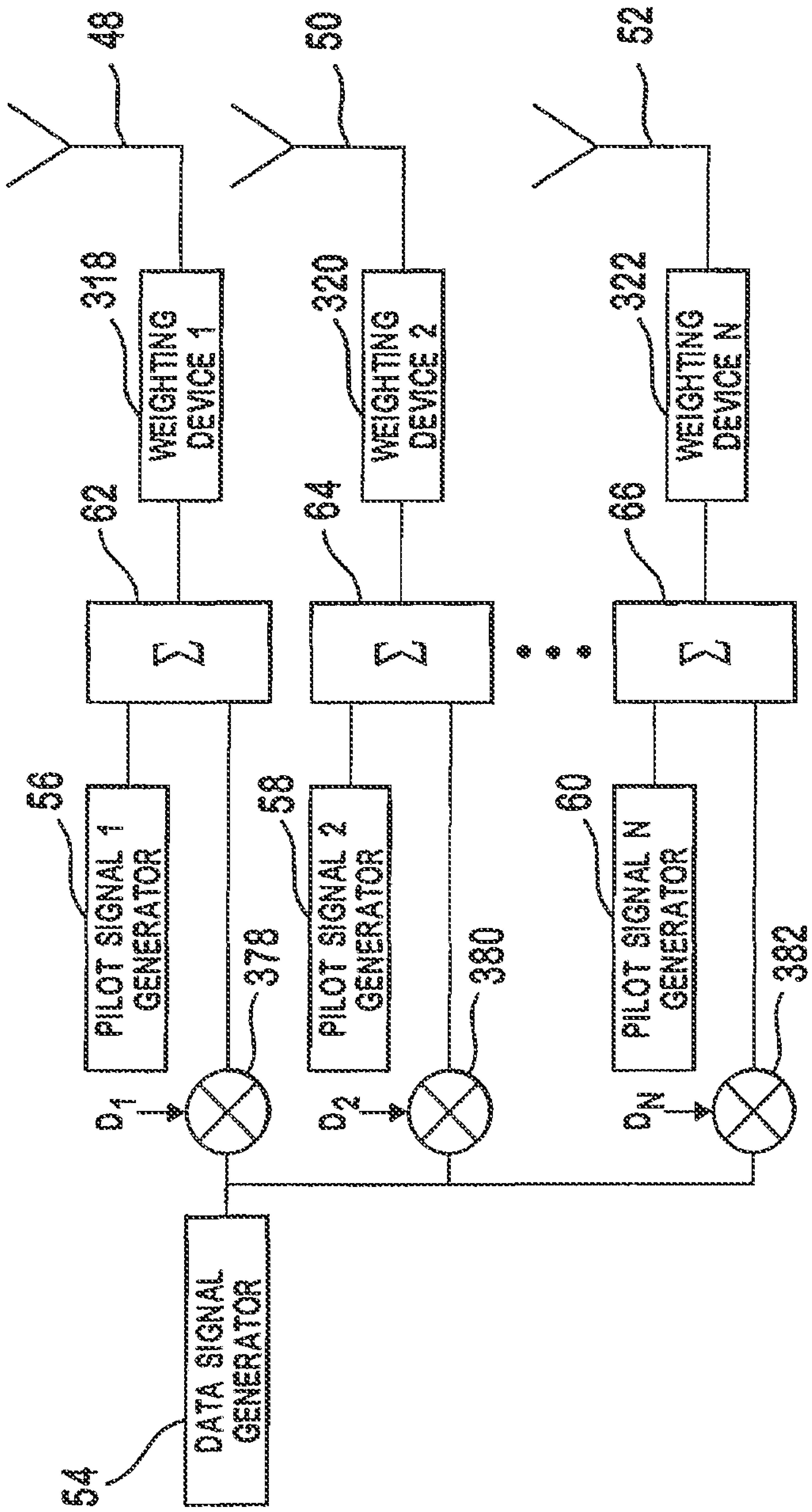


FIG. 14

FIG. 15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50
52
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318
WEIGHTING DEVICE 2
320
WEIGHTING DEVICE N
322
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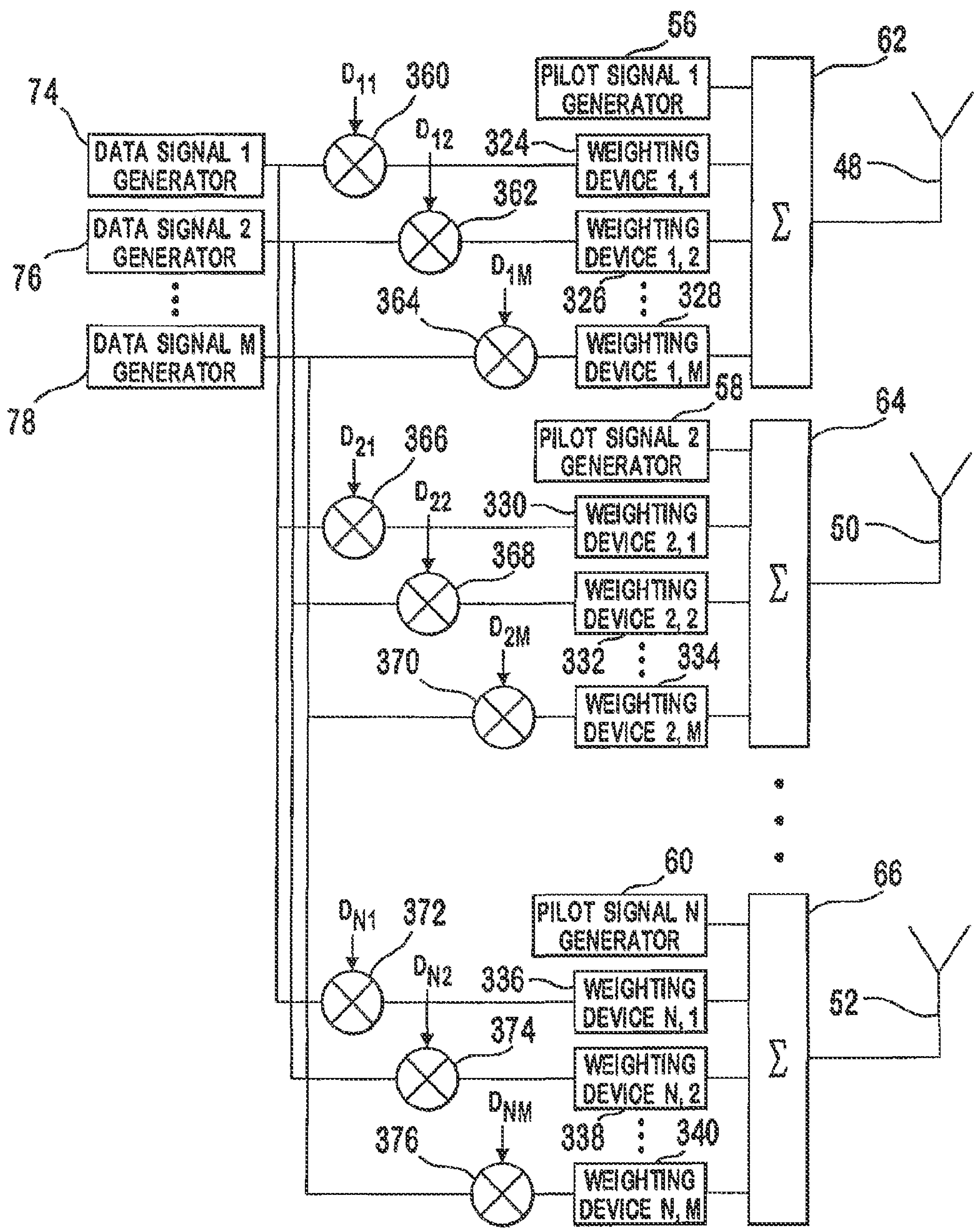
64
66
Σ
Σ
Σ
PILOT SIGNAL 1 GENERATOR
56
PILOT SIGNAL 2 GENERATOR
58
PILOT SIGNAL N GENERATOR
60
378
380
382
D1
D2
DN
DATA SIGNAL GENERATOR
54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DATA SIGNAL 2 GENERATOR
76
DATA SIGNAL M GENERATOR
78
D11
360
D12
324
362
D1M
364
326
328
56
PILOT SIGNAL 1 GENERATOR
WEIGHTING DEVICE 1, 1
WEIGHTING DEVICE 1, 2
WEIGHTING DEVICE 1, M
62
48
58
PILOT SIGNAL 2 GENERATOR
64
D21
366
D22
330
WEIGHTING DEVICE 2, 1
368
WEIGHTING DEVICE 2, 2
D2M
370
332
334
WEIGHTING DEVICE 2, M
50
60
PILOT SIGNAL N GENERATOR
66
DN1
372
DN2
336
WEIGHTING DEVICE N, 1
374
WEIGHTING DEVICE N, 2
DNM
376
338
340
WEIGHTING DEVICE N, M
52
Σ

FIG. 16

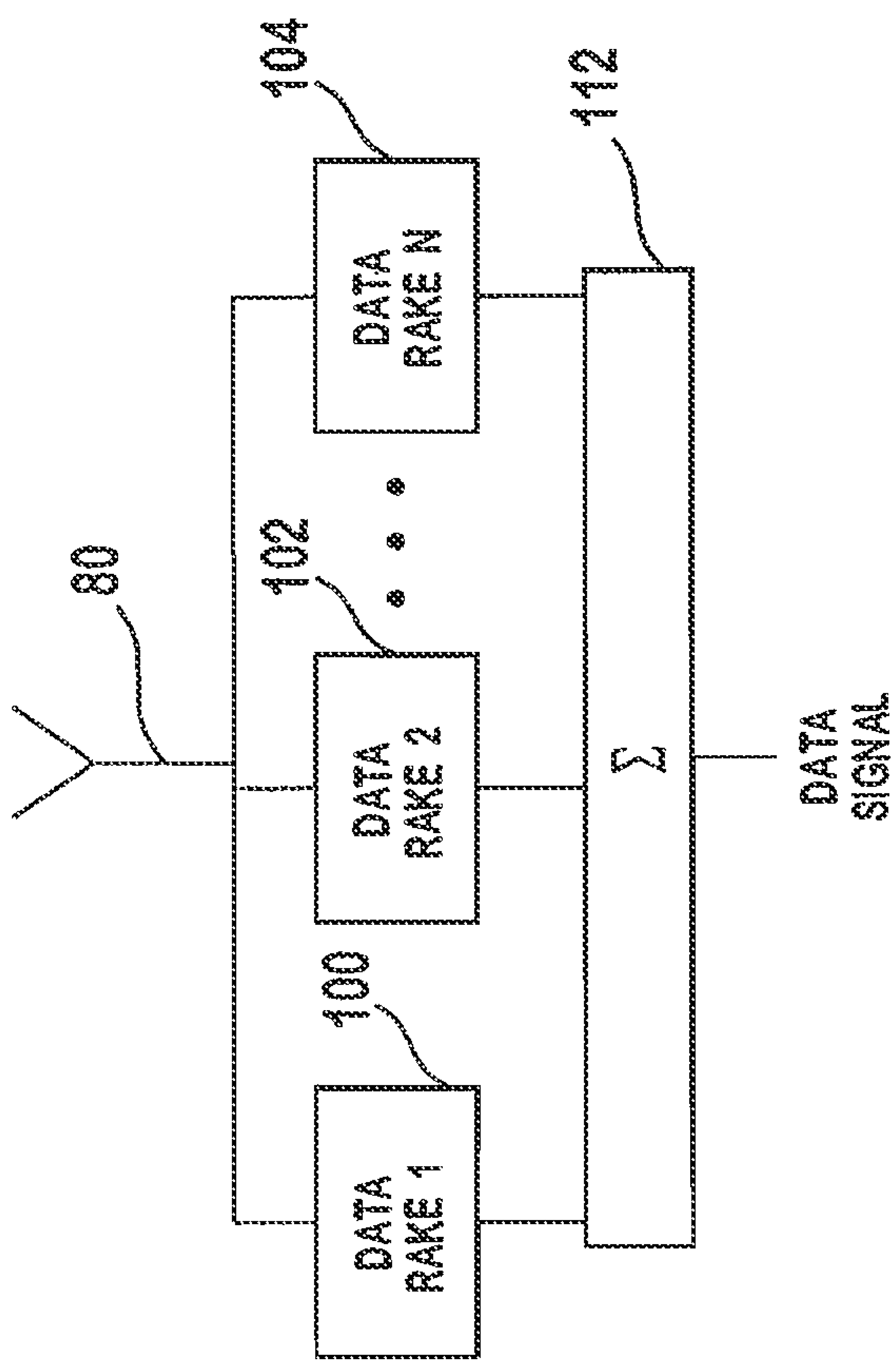

80
100
102
104
112
DATA RAKE 1
DATA RAKE 2
DATA RAKE N
Σ
DATA SIGNAL

FIG. 17

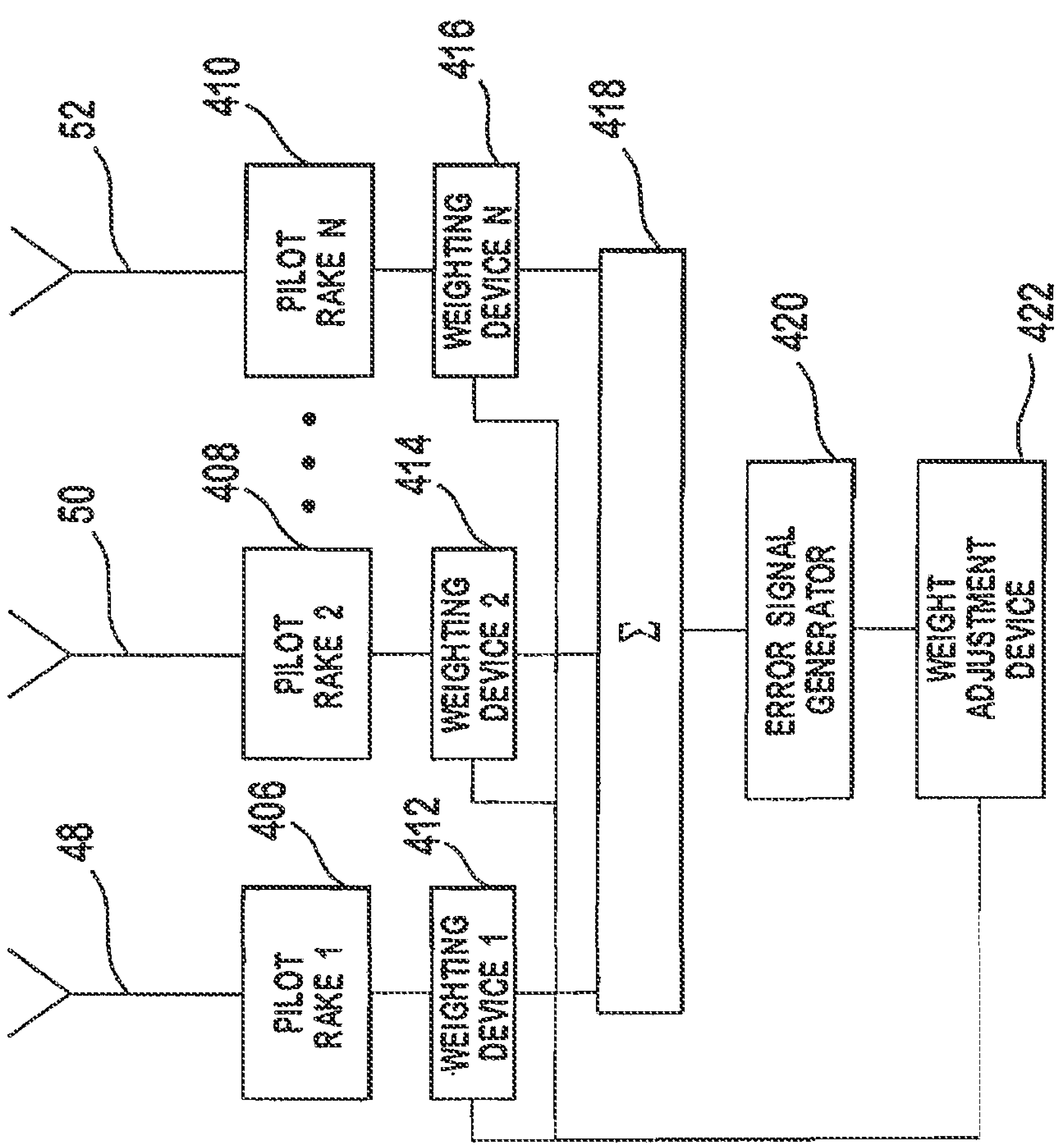

48
50
52
406
408
410
PILOT RAKE 1
PILOT RAKE 2
PILOT RAKE N
412
414
416
WEIGHTING DEVICE 1
WEIGHTING DEVICE 2
WEIGHTING DEVICE N
418
Σ
420
ERROR SIGNAL GENERATOR
422
WEIGHT ADJUSTMENT DEVICE

FIG. 18

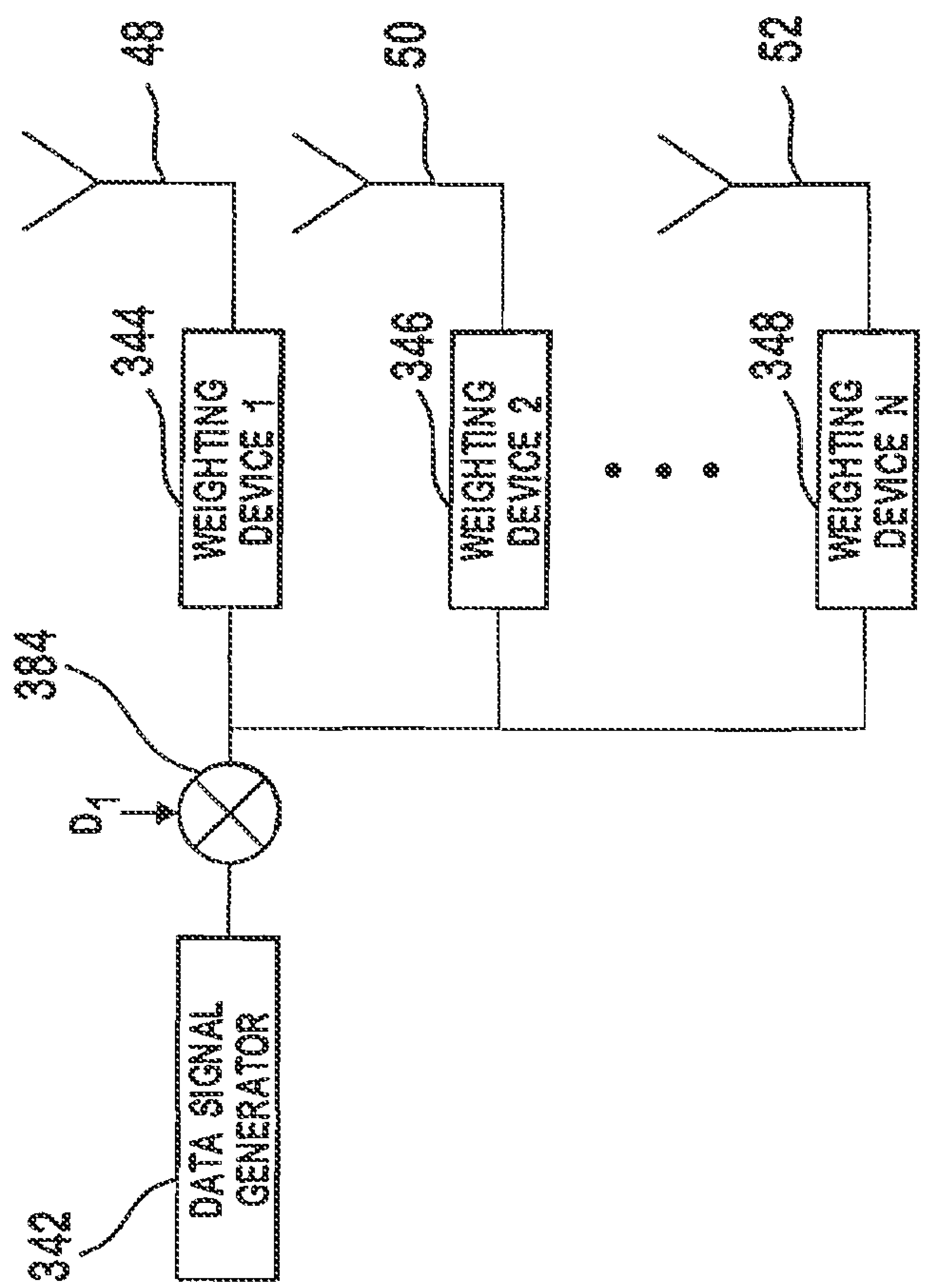
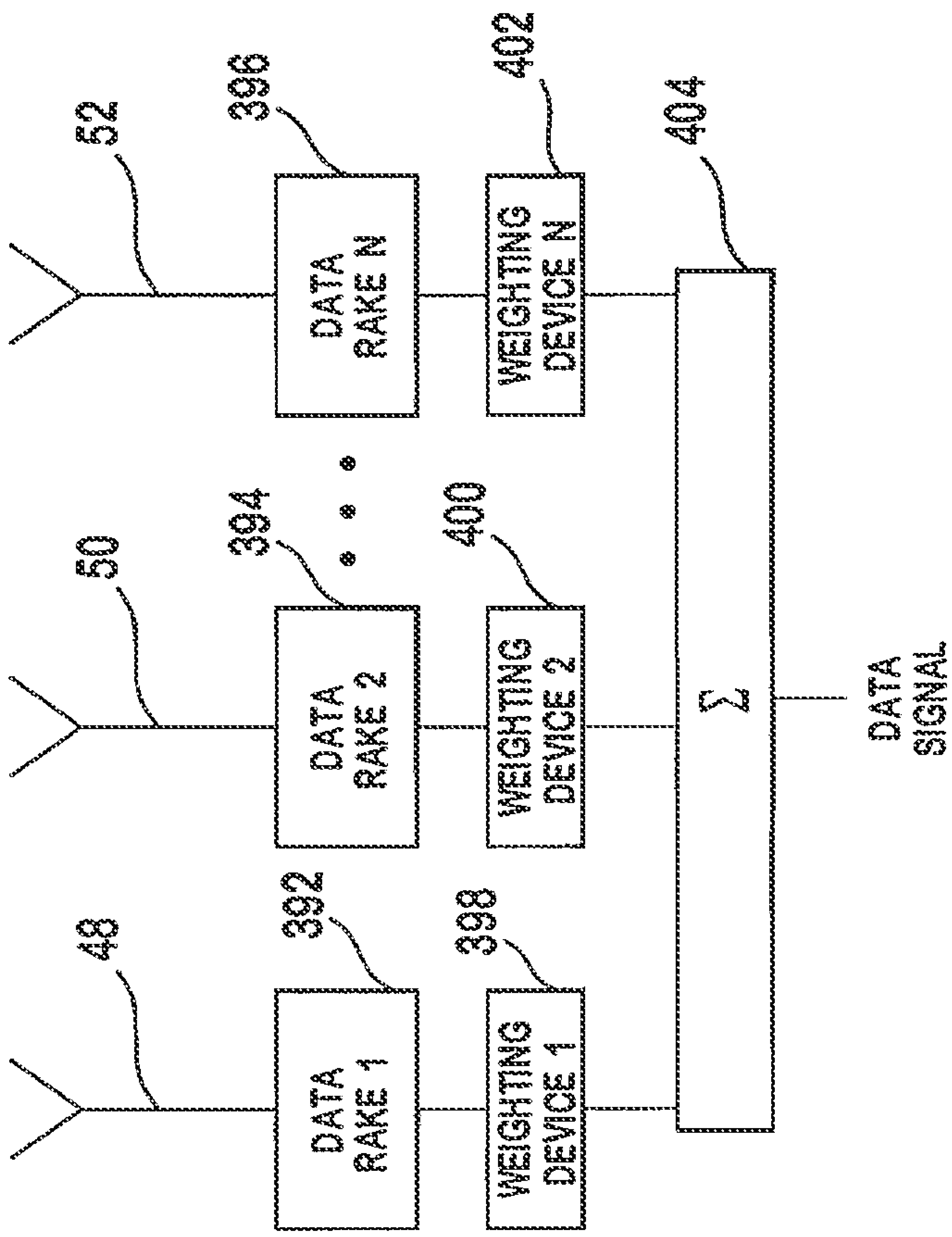

342
DATA SIGNAL GENERATOR
D_1
384
344
WEIGHTING DEVICE 1
346
WEIGHTING DEVICE 2
348
WEIGHTING DEVICE N
48
50
52

FIG. 19

FIG. 20


52
396
402
404
DATA RAKE N
WEIGHTING DEVICE N
50
394
400
DATA RAKE 2
WEIGHTING DEVICE 2
Σ
DATA SIGNAL
48
392
398
DATA RAKE 1
WEIGHTING DEVICE 1

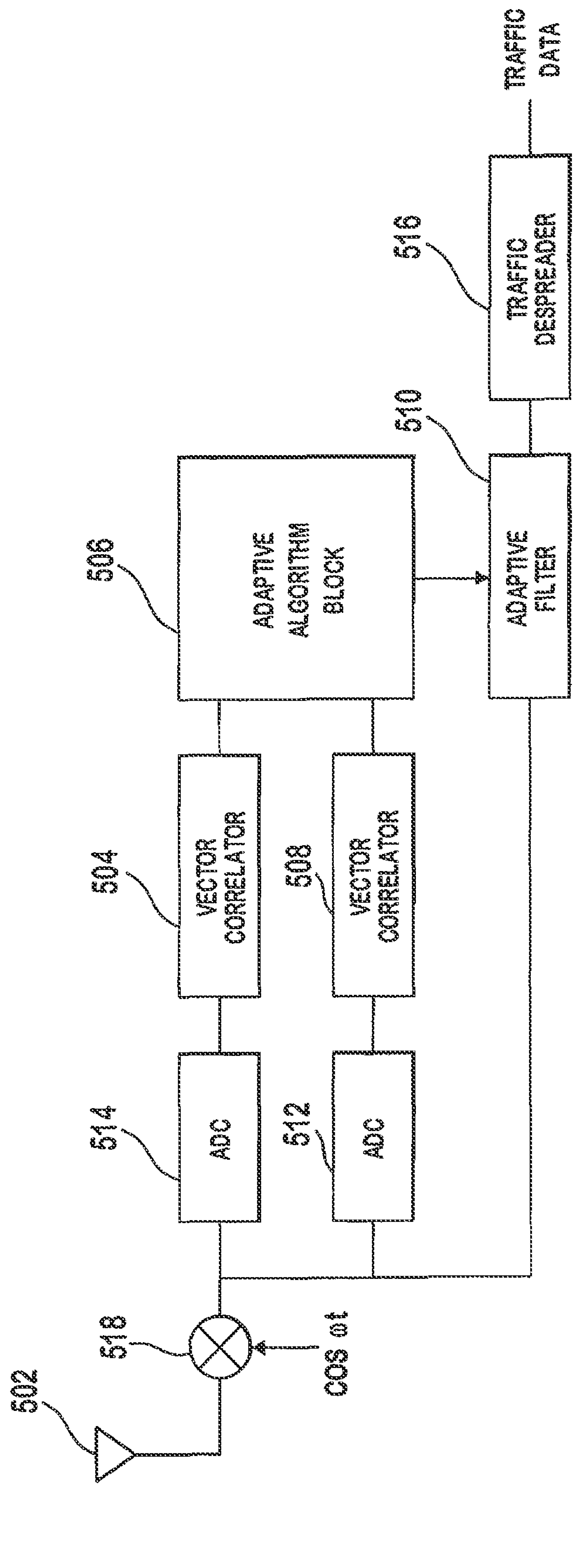
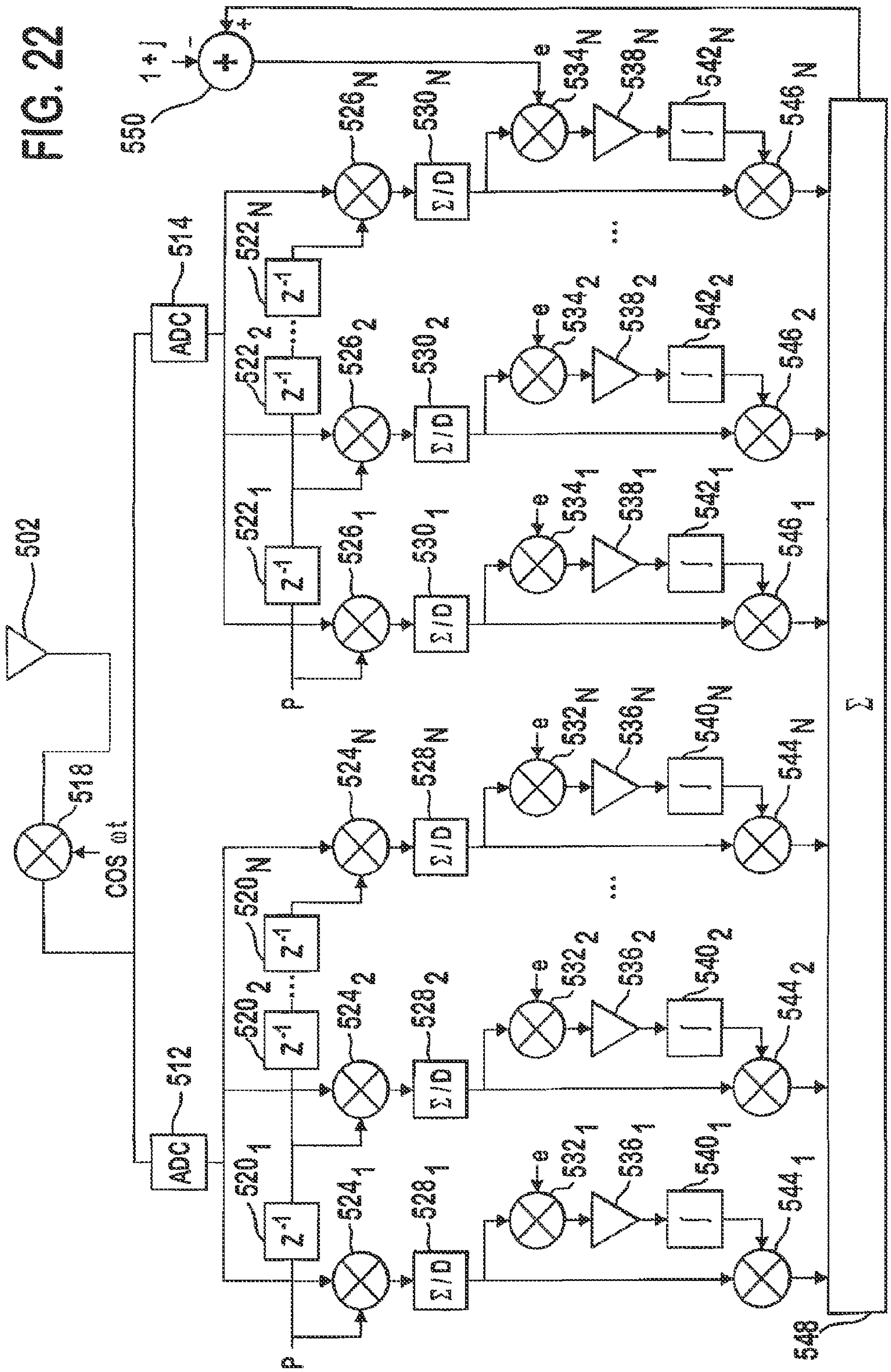

TRAFFIC DATA
516
TRAFFIC DESPREADER
510
ADAPTIVE FILTER
506
ADAPTIVE ALGORITHM BLOCK
504
VECTOR CORRELATOR
508
VECTOR CORRELATOR
514
ADC
512
ADC
518
COS ωt
502

FIG. 21

FIG. 22


502
518
COS ωt
ADC
512
ADC
514
Z^{-1}
520_1
520_2
520_N
522_1
522_2
522_N
P
524_1
524_2
524_N
526_1
526_2
526_N
Σ/D
528_1
528_2
528_N
530_1
530_2
530_N
e
532_1
532_2
532_N
534_1
534_2
534_N
536_1
536_2
536_N
538_1
538_2
538_N
∫
540_1
540_2
540_N
542_1
542_2
542_N
544_1
544_2
544_N
546_1
546_2
546_N
Σ
548
550
1 + j

INTERFERENCE CANCELLATION IN A SPREAD SPECTRUM COMMUNICATION SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 13/117,233 filed on May 27, 2011, which is a continuation of U.S. patent application Ser. No. 12/480,337 filed Jun. 8, 2009, now U.S. Pat. No. 7,953,139 which issued on May 31, 2011, which is a continuation of U.S. patent application Ser. No. 11/301,666 filed Dec. 13, 2005, now U.S. Pat. No. 7,545,846 which issued on Jun. 9, 2009, which is a continuation of U.S. patent application Ser. No. 10/923,950, filed Aug. 23, 2004, now U.S. Pat. No. 6,985,515 issued Jan. 10, 2006, which is a continuation of Ser. No. 10/423,230, filed Apr. 25, 2003, now U.S. Pat. No. 6,782,040 issued Aug. 24, 2004, which is a continuation of Ser. No. 09/892,369 filed Jun. 27, 2001, now U.S. Pat. No. 6,574,271 issued Jun. 3, 2003, which is a continuation of Ser. No. 09/659,858, filed on Sep. 11, 2000, now U.S. Pat. No. 6,278,726, issued on Aug. 21, 2001, which is a continuation-in-part of Ser. No. 09/602,963 filed Jun. 23, 2000, now U.S. Pat. No. 6,373,877, issued Apr. 16, 2002, which is a continuation of Ser. No. 09/394,452 filed Sep. 10, 1999, now U.S. Pat. No. 6,115,406, issued Sep. 5, 2000, which are incorporated by reference as if fully set forth.

FIELD OF INVENTION

The present invention relates generally to signal transmission and reception in a wireless code division multiple access (CDMA) communication system. More specifically, the invention relates to reception of signals to reduce interference in a wireless CDMA communication system.

BACKGROUND

A prior art CDMA communication system is shown in FIG. **1**. The communication system has a plurality of base stations **20**-**32**. Each base station **20** communicates using spread spectrum CDMA with user equipment (UEs) **34**-**38** within its operating area. Communications from the base station **20** to each UE **34**-**38** are referred to as downlink communications and communications from each UE **34**-**38** to the base station **20** are referred to as uplink communications.

Shown in FIG. **2** is a simplified CDMA transmitter and receiver. A data signal having a given bandwidth is mixed by a mixer **40** with a pseudo random chip code sequence producing a digital spread spectrum signal for transmission by an antenna **42**. Upon reception at an antenna **44**, the data is reproduced after correlation at a mixer **46** with the same pseudo random chip code sequence used to transmit the data. By using different pseudo random chip code sequences, many data signals use the same channel bandwidth. In particular, a base station **20** will communicate signals to multiple UEs **34**-**38** over the same bandwidth.

For timing synchronization with a receiver, an unmodulated pilot signal is used. The pilot signal allows respective receivers to synchronize with a given transmitter allowing despreading of a data signal at the receiver. In a typical CDMA system, each base station **20** sends a unique pilot signal received by all UEs **34**-**38** within communicating range to synchronize forward link transmissions. Conversely, in some CDMA systems, for example in the B-CDMA™ air interface, each UE **34**-**38** transmits a unique assigned pilot signal to synchronize reverse link transmissions.

When a UE **34**-**38** or a base station **20**-**32** is receiving a specific signal, all the other signals within the same bandwidth are noise-like in relation to the specific signal. Increasing the power level of one signal degrades all other signals within the same bandwidth. However, reducing the power level too far results in an undesirable received signal quality. One indicator used to measure the received signal quality is the signal to noise ratio (SNR). At the receiver, the magnitude of the desired received signal is compared to the magnitude of the received noise. The data within a transmitted signal received with a high SNR is readily recovered at the receiver. A low SNR leads to loss of data.

To maintain a desired signal to noise ratio at the minimum transmission power level, most CDMA systems utilize some form of adaptive power control. By minimizing the transmission power, the noise between signals within the same bandwidth is reduced. Accordingly, the maximum number of signals received at the desired signal to noise ratio within the same bandwidth is increased.

Although adaptive power control reduces interference between signals in the same bandwidth, interference still exists limiting the capacity of the system. One technique for increasing the number of signals using the same radio frequency (RF) spectrum is to use sectorization. In sectorization, a base station uses directional antennas to divide the base station's operating area into a number of sectors. As a result, interference between signals in differing sectors is reduced. However, signals within the same bandwidth within the same sector interfere with one another. Additionally, sectorized base stations commonly assign different frequencies to adjoining sectors decreasing the spectral efficiency for a given frequency bandwidth. Accordingly, there exists a need for a system which further improves the signal quality of received signals without increasing transmitter power levels.

SUMMARY

A method and apparatus used to transmit and receive weighted data transmissions over a plurality of antennas using a plurality of different pilot signals. Different pilot signals are produced and a different pilot signal of the plurality of pilot signals is transmitted on each of a plurality of antennas. Each of the pilot signals is derived from a pseudo noise (PN) sequence and a bit sequence of the PN sequence for each of the pilot signals is different. A plurality of data streams are produced in which each of the data streams has data bits combined with bits of a PN sequence. The data streams are weighted in response to weight information received from a receiving device and the plurality of weighted data streams are transmitted using the plurality of antennas.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a prior art wireless spread spectrum CDMA communication system.

FIG. **2** is a prior art spread spectrum CDMA transmitter and receiver.

FIG. **3** is the transmitter of the invention.

FIG. **4** is the transmitter of the invention transmitting multiple data signals.

FIG. **5** is the pilot signal receiving circuit of the invention.

FIG. **6** is the data signal receiving circuit of the invention.

FIG. **7** is an embodiment of the pilot signal receiving circuit.

FIG. **8** is a least mean squared weighting circuit.

FIG. **9** is the data signal receiving circuit used with the pilot signal receiving circuit of FIG. **7**.

FIG. **10** is an embodiment of the pilot signal receiving circuit where the output of each RAKE is weighted.

FIG. **11** is the data signal receiving circuit used with the pilot signal receiving circuit of FIG. **10**.

FIG. **12** is an embodiment of the pilot signal receiving circuit where the antennas of the transmitting array are closely spaced.

FIG. **13** is the data signal receiving circuit used with the pilot signal receiving circuit of FIG. **12**.

FIG. **14** is an illustration of beam steering in a CDMA communication system.

FIG. **15** is a beam steering transmitter.

FIG. **16** is a beam steering transmitter transmitting multiple data signals.

FIG. **17** is the data receiving circuit used with the transmitter of FIG. **14**.

FIG. **18** is a pilot signal receiving circuit used when uplink and downlink signals use the same frequency.

FIG. **19** is a transmitting circuit used with the pilot signal receiving circuit of FIG. **18**.

FIG. **20** is a data signal receiving circuit used with the pilot signal receiving circuit of FIG. **18**.

FIG. **21** is a simplified receiver for reducing interference.

FIG. **22** is an illustration of a vector correlator/adaptive algorithm block using a least mean square error algorithm.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

The preferred embodiments will be described with reference to the drawing figures where like numerals represent like elements throughout. FIG. **3** is a transmitter of the invention. The transmitter has an array of antennas **48-52**, preferably 3 or 4 antennas. For use in distinguishing each antenna **48-52**, a different signal is associated with each antenna **56-60**. The preferred signal to associate with each antenna is a pilot signal as shown in FIG. **3**. Each spread pilot signal is generated by a pilot signal generator **56-60** using a different pseudo random chip code sequence and is combined by combiners **62-66** with the respective spread data signal. Each spread data signal is generated using data signal generator **54** by mixing at mixers **378-382** the generated data signal with a different pseudo random chip code sequence per antenna **48-52**, D_1-D_N. The combined signals are modulated to a desired carrier frequency and radiated through the antennas **48-52** of the array.

By using an antenna array, the transmitter utilizes spacial diversity. If spaced far enough apart, the signals radiated by each antenna **48-52** will experience different multipath distortion while traveling to a given receiver. Since each signal sent by an antenna **48-52** will follow multiple paths to a given receiver, each received signal will have many multipath components. These components create a virtual communication channel between each antenna **48-52** of the transmitter and the receiver. Effectively, when signals transmitted by one antenna **48-52** over a virtual channel to a given receiver are fading, signals from the other antennas **48-52** are used to maintain a high received SNR. This effect is achieved by the adaptive combining of the transmitted signals at the receiver.

FIG. **4** shows the transmitter as used in a base station **20** to send multiple data signals. Each spread data signal is generated by mixing at mixers **360-376** a corresponding data signal from generators **74-78** with differing pseudo random chip code sequences D_{11}-D_{NM}. Accordingly, each data signal is spread using a different pseudo random chip code sequence per antenna **48-52**, totaling N×M code sequences. N is the number of antennas and M is the number of data signals. Subsequently, each spread data signal is combined with the spread pilot signal associated with the antenna **48-52**. The combined signals are modulated and radiated by the antennas **48-52** of the array.

The pilot signal receiving circuit is shown in FIG. **5**. Each of the transmitted pilot signals is received by the antenna **80**. For each pilot signal, a despreading device, such as a RAKE **82-86** as shown in the FIG. **5** or a vector correlator, is used to despread each pilot signal using a replica of the corresponding pilot signal's pseudo random chip code sequence. The despreading device also compensates for multipath in the communication channel. Each of the recovered pilot signals is weighted by a weighting device **88-92**. Weight refers to both magnitude and phase of the signal. Although the weighting is shown as being coupled to a RAKE, the weighting device preferably also weights each finger of the RAKE. After weighting, all of the weighted recovered pilot signals are combined in a combiner **94**. Using an error signal generator **98**, an estimate of the pilot signal provided by the weighted combination is used to create an error signal. Based on the error signal, the weights of each weighting device **88-92** are adjusted to minimize the error signal using an adaptive algorithm, such as least mean squared (LMS) or recursive least squares (RLS). As a result, the signal quality of the combined signal is maximized.

FIG. **6** depicts a data signal receiving circuit using the weights determined by the pilot signal recovery circuit. The transmitted data signal is recovered by the antenna **80**. For each antenna **48-52** of the transmitting array, the weights from a corresponding despreading device, shown as a RAKE **82-86**, are used to filter the data signal using a replica of the data signal's spreading code used for the corresponding transmitting antenna. Using the determined weights for each antenna's pilot signal, each weighting device **106-110** weights the RAKE's despread signal with the weight associated with the corresponding pilot. For instance, the weighting device **88** corresponds to the transmitting antenna **48** for pilot signal **1**. The weight determined by the pilot RAKE **82** for pilot signal **1** is also applied at the weighting device **106** of FIG. **6**. Additionally, if the weights of the RAKE's fingers were adjusted for the corresponding pilots signal's RAKE **82-86**, the same weights will be applied to the fingers of the data signal's RAKE **100-104**. After weighting, the weighted signals are combined by the combiner **112** to recover the original data signal.

By using the same weights for the data signal as used with each antenna's pilot signal, each RAKE **82-86** compensates for the channel distortion experienced by each antenna's signals. As a result, the data signal receiving circuit optimizes the data signal's reception over each virtual channel. By optimally combining each virtual channel's optimized signal, the received data signal's signal quality is increased.

FIG. **7** shows an embodiment of the pilot signal recovery circuit. Each of the transmitted pilots are recovered by the receiver's antenna **80**. To despread each of the pilots, each RAKE **82-86** utilizes a replica of the corresponding pilot's pseudo random chip code sequence, P_1-P_N. Delayed versions of each pilot signal are produced by delay devices **114-124**. Each delayed version is mixed by a mixer **126-142** with the received signal. The mixed signals pass through sum and dump circuits **424-440** and are weighted using mixers **144-160** by an amount determined by the weight adjustment device **170**. The weighted multipath components for each pilot are combined by a combiner **162-164**. Each pilot's combined output is combined by a combiner **94**. Since a pilot signal has no data, the combined pilot signal should have a value of 1+j0. The combined pilot signal is compared to the ideal value, 1+j0, at a subtractor **168**. Based on the deviation of the combined pilot signal from the ideal, the weight of the weighting devices **144-160** are adjusted using an adaptive algorithm by the weight adjustment device **170**.

An LMS algorithm used for generating a weight is shown in FIG. **8**. The output of the subtractor **168** is multiplied using a mixer **172** with the corresponding despread delayed version of the pilot. The multiplied result is amplified by an amplifier **174** and integrated by an integrator **176**. The integrated result is used to weight, W_{1M}, the RAKE finger.

The data receiving circuit used with the embodiment of FIG. **7** is shown for a base station receiver in FIG. **9**. The received signal is sent to a set of RAKEs **100-104** respectively associated with each antenna **48-52** of the array. Each RAKE **100-104**, produces delayed versions of the received signal using delay devices **178-188**. The delayed versions are weighted using mixers **190-206** based on the weights determined for the corresponding antenna's pilot signal. The weighted data signals for a given RAKE **100-104** are combined by a combiner **208-212**. One combiner **208-212** is associated with each of the N transmitting antennas **48-52**. Each combined signal is despread M times by mixing at a mixer **214-230** the combined signal with a replica of the spreading codes used for producing the M spread data signals at the transmitter, D_{11}-D_{NM}. Each despread data signal passes through a sum and dump circuit **232-248**. For each data signal, the results of the corresponding sum and dump circuits are combined by a combiner **250-254** to recover each data signal.

Another pilot signal receiving circuit is shown in FIG. **10**. The despreading circuits **82-86** of this receiving circuit are the same as FIG. **7**. The output of each RAKE **82-86** is weighted using a mixer **256-260** prior to combining the despread pilot signals. After combining, the combined pilot signal is compared to the ideal value and the result of the comparison is used to adjust the weight of each RAKE's output using an adaptive algorithm. To adjust the weights within each RAKE **82-86**, the output of each RAKE **82-86** is compared to the ideal value using a subtractor **262-266**. Based on the result of the comparison, the weight of each weighting device **144-160** is determined by the weight adjustment devices **268-272**.

The data signal receiving circuit used with the embodiment of FIG. **10** is shown in FIG. **11**. This circuit is similar to the data signal receiving circuit of FIG. **9** with the addition of mixers **274-290** for weighting the output of each sum and dump circuit **232-248**. The output of each sum and dump circuit **232-248** is weighted by the same amount as the corresponding pilot's RAKE **82-86** was weighted. Alternatively, the output of each RAKE's combiner **208-212** may be weighted prior to mixing by the mixers **214-230** by the amount of the corresponding pilot's RAKE **82-86** in lieu of weighting after mixing.

If the spacing of the antennas **48-52** in the transmitting array is small, each antenna's signals will experience a similar multipath environment. In such cases, the pilot receiving circuit of FIG. **12** may be utilized. The weights for a selected one of the pilot signals are determined in the same manner as in FIG. **10**. However, since each pilot travels through the same virtual channel, to simplify the circuit, the same weights are used for despreading the other pilot signals. Delay devices **292-294** produce delayed versions of the received signal. Each delayed version is weighted by a mixer **296-300** by the same weight as the corresponding delayed version of the selected pilot signal was weighted. The outputs of the weighting devices are combined by a combiner **302**. The combined signal is despread using replicas of the pilot signals' pseudo random chip code sequences, P_2-P_n, by the mixers **304-306**. The output of each pilot's mixer **304-306** is passed through a sum and dump circuit **308-310**. In the same manner as FIG. **10**, each despread pilot is weighted and combined.

The data signal recovery circuit used with the embodiment of FIG. **12** is shown in FIG. **13**. Delay devices **178-180** produce delayed versions of the received signal. Each delayed version is weighted using a mixer **190-194** by the same weight as used by the pilot signals in FIG. **12**. The outputs of the mixers are combined by a combiner **208**. The output of the combiner **208** is inputted to each data signal despreader of FIG. **13**.

The invention also provides a technique for adaptive beam steering as illustrated in FIG. **14**. Each signal sent by the antenna array will constructively and destructively interfere in a pattern based on the weights provided each antenna **48-52** of the array. As a result, by selecting the appropriate weights, the beam **312-316** of the antenna array is directed in a desired direction.

FIG. **15** shows the beam steering transmitting circuit. The circuit is similar to the circuit of FIG. **3** with the addition of weighting devices **318-322**. A target receiver will receive the pilot signals transmitted by the array. Using the pilot signal receiving circuit of FIG. **5**, the target receiver determines the weights for adjusting the output of each pilot's RAKE. These weights are also sent to the transmitter, such as by using a signaling channel. These weights are applied to the spread data signal as shown in FIG. **15**. For each antenna, the spread data signal is given a weight by the weighting devices **318-322** corresponding to the weight used for adjusting the antenna's pilot signal at the target receiver providing spatial gain. As a result, the radiated data signal will be focused towards the target receiver. FIG. **16** shows the beam steering transmitter as used in a base station sending multiple data signals to differing target receivers. The weights received by the target receiver are applied to the corresponding data signals by weighting devices **324-340**.

FIG. **17** depicts the data signal receiving circuit for the beam steering transmitter of FIGS. **15** and **16**. Since the transmitted signal has already been weighted, the data signal receiving circuit does not require the weighting devices **106-110** of FIG. **6**.

The advantage of the invention's beam steering is two-fold. The transmitted data signal is focused toward the target receiver improving the signal quality of the received signal. Conversely, the signal is focused away from other receivers reducing interference to their signals. Due to both of these factors, the capacity of a system using the invention's beam steering is increased. Additionally, due to the adaptive algorithm used by the pilot signal receiving circuitry, the weights are dynamically adjusted. By adjusting the weights, a data signal's beam will dynamically respond to a moving receiver or transmitter as well as to changes in the multipath environment.

In a system using the same frequency for downlink and uplink signals, such as time division duplex (TDD), an alternate embodiment is used. Due to reciprocity, downlink signals experience the same multipath environment as uplink signals sent over the same frequency. To take advantage of reciprocity, the weights determined by the base station's receiver are applied to the base station's transmitter. In such a system, the base station's receiving circuit of FIG. **18** is co-located, such as within a base station, with the transmitting circuit of FIG. **19**.

In the receiving circuit of FIG. **18**, each antenna **48-52** receives a respective pilot signal sent by the UE. Each pilot is filtered by a RAKE **406-410** and weighted by a weighting device **412-416**. The weighted and filtered pilot signals are combined by a combiner **418**. Using the error signal generator **420** and the weight adjustment device **422**, the weights associated with the weighting devices **412-416** are adjusted using an adaptive algorithm.

The transmitting circuit of FIG. **19** has a data signal generator **342** to generate a data signal. The data signal is spread using mixer **384**. The spread data signal is weighted by weighting devices **344-348** as were determined by the receiving circuit of FIG. **19** for each virtual channel.

The circuit of FIG. **20** is used as a data signal receiving circuit at the base station. The transmitted data signal is received by the multiple antennas **48-52**. A data RAKE **392-396** is coupled to each antenna **48-52** to filter the data signal. The filtered data signals are weighted by weighting devices **398-402** by the weights determined for the corresponding antenna's received pilot and are combined at combiner **404** to recover the data signal. Since the transmitter circuit of FIG. **19** transmits the data signal with the optimum weights, the recovered data signal at the UE will have a higher signal quality than provided by the prior art.

An adaptive algorithm can also be used to reduce interference in received signals for a spread spectrum communication system. A transmitter in the communication system, which can be located in either a base station **20** to **32** or UE **34** to **36**, transmits a spread pilot signal and a traffic signal over the same frequency spectrum. The pilot signal is spread using a pilot code, P, and the traffic signal is spread using a traffic code, C.

The simplified receiver **500** of FIG. **21** receives both the pilot and traffic signals using an antenna **502**. The received signals are demodulated to a baseband signal by a demodulator **518**. The baseband signal is converted into digital samples, such as by two analog to digital converters (ADC) **512**, **514**. Each ADC **512**, **514** typically samples at the chip rate. To obtain a half-chip resolution, one ADC **514** is delayed with respect to the other ADC **512** by a one-half chip delay. The samples are processed by a filtering device, such two vector correlators **504**, **508** as shown in FIG. **21** or a RAKE, to process the pilot signal. The vector correlators **504**, **508**, are used to despread various multipath components of the received pilot signal using the pilot code, P. By using two vector correlators **504**, **508** as in FIG. **21**, each half-chip component is despread, such as for a 10 chip window to despread 21 components. Each despread component is sent to an adaptive algorithm block **506** to determine an optimum weight for each despread component to minimize interference in the received pilot signal. The adaptive algorithm block **506** may use a minimum mean square error (MMSE) algorithm such as a least mean square error algorithm.

One combination vector correlator/adaptive algorithm block using an LMS algorithm and half-chip resolution is shown in FIG. **22**. The pilot code is delayed by a group of delay devices **5201** to **520**N and **5221** to **522**N. Each of the ADC samples is despread such as by mixing it with timed versions of the pilot code, P, by mixers **5241** to **524**N and **5261** to **526**N. The mixed signals are processed by sum and dump circuits **5281** to **528**N and **5301** to **530**N to produce despread components of the pilot signal. By using two ADCs **512**, **514** with a half-chip sampling delay and two vector correlators **504**, **508**, despread components at half-chip intervals are produced such as 21 components for a 10 chip window. Each despread version is weighted by a weight, W_{11} to W_{2N}, such as by using a weighting device, **544**$_1$ to **544**$_N$ and **546**$_1$ to **546**$_N$. The weighted versions are combined, such as by using a summer **528**. The combined signal is compared to the complex transmitted value of pilot signal, such as 1+j for a pilot signal in the third generation wireless standard, to produce an error signal, e. The comparison may be performed by a subtractor **550** by subtracting the combined signal from the ideal, 1+j. The error signal, e, is mixed using mixers **532**$_1$ to **532**$_N$ and **534**$_1$ to **534**$_N$ with each despread version. Each mixed version is amplified and integrated, such as by using an amplifier **536**$_1$ to **536**$_N$ and **538**$_1$ to **538**$_N$ and an integrator **540**$_1$ to **540**$_N$ and **542**$_1$ to **542**$_N$. The amplified and integrated results are refined weights, W_{11} to W_{2N}, for further weighting of the despread versions. Using the least mean square algorithm, the weights, W_{11} to W_{2N}, will be selected as to drive the combined signal to its ideal value.

The received signal is also processed by an adaptive filter **510** with the weights, W_{11} to W_{2N}, determined for the pilot signal components. Since the pilot signal and the traffic signal are transmitted over the same frequency spectrum, the two signals experience the same channel characteristics. As a result, the pilot weights, W_{11} to W_{2N}, applied to the traffic signal components reduces interference in the received traffic signal. Additionally, if the pilot and channel signals were sent using orthogonal spreading codes, the orthogonality of the received channel signal is restored after weighting. The restored orthogonality substantially reduces correlated interference from other traffic channels that occur as a result of the deorthogonalization due to channel distortion. The weighted received signal is despread by a traffic despreader **516** using the corresponding traffic code to recover the traffic data.

Although the features and elements of the present invention are described in the preferred embodiments in particular combinations, each feature or element can be used alone (without the other features and elements of the preferred embodiments) or in various combinations with or without other features and elements of the present invention.

What is claimed is:

1. A transmitting device comprising:

circuitry configured to produce a plurality of pilot signals; wherein a different pilot signal of the plurality of pilot signals is transmitted on each of a plurality of antennas; wherein each of the pilot signals is derived from a pseudo noise (PN) sequence and a bit sequence of the PN sequence for each of the pilot signals is different;

the circuitry is further configured to produce a plurality of data streams; wherein each of the data streams has data bits combined with bits of a PN sequence; and

the circuitry is further configured to weight the data streams in response to weight information received from a receiving device and transmit the plurality of weighted data streams using the plurality of antennas.

2. The transmitting device of claim **1** wherein the plurality of weighted data streams are transmitted to the receiving device.

3. A method for use by a transmitting device, the method comprising:

producing a plurality of pilot signals; wherein a different pilot signal of the plurality of pilot signals is to be transmitted on a respective one of a plurality of antennas; wherein each of the pilot signals is derived from a pseudo noise (PN) sequence and a bit sequence of the PN sequence for each of the pilot signals is different;

producing a plurality of data streams; wherein bits of each of the data streams has data bits combined with bits of a PN sequence;

weighing the data streams in response to weight information received from a receiving device; and

transmitting the plurality of pilots signals and the weighted data streams using the plurality of antennas.

4. The method of claim **3** wherein the plurality of data streams are transmitted to the receiving device.

5. A receiving device comprising:

circuitry configured to transmit weight information to a transmitting device for use in weighting a plurality of data streams;

the circuitry is further configured to receive a downlink signal including a plurality of pilot signals and a plurality of data streams; wherein a different pilot signal of the plurality of pilot signals was transmitted from a different antenna of a plurality of antennas of a transmitting device; wherein each of the pilot signals was derived from a pseudo noise (PN) sequence and a bit sequence of the PN sequence for each of the pilot signals is different; and

the circuitry is further configured to recover data from the plurality of data streams; wherein each of the data streams has data bits combined with bits of a PN sequence; wherein each of the data streams was weighted based on the transmitted weight information.

* * * * *