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(54) Title: SPREAD SPECTRUM COMMUNICATION NETWORK SIGNAL PROCESSOR			
(57) Abstract			
A base station communicates with a plurality of mobile stations over a cellular network. In one embodiment, the base station includes a receiver configured to receive inbound information from the mobile station and a transmitter configured to transmit outbound information to the mobile station. The base station further has a central processor that includes a signal processor array. The signal processor architecture is designed to increase the throughput and task-based allocation of processing resources. The signal processing array has both series and parallel signal processing elements. A plurality of signal processor elements are disposed in series to form a signal processing string. A plurality of signal processing strings are disposed in parallel. Each of the signal processor strings includes at least two signal processor elements that are each dedicated to performing a specific task. As a result, the parallel processor strings simultaneously process information corresponding to predetermined criteria, such as TDMA time slots, while the series processors sequentially process that information by an efficient task-based pipeline processing. A preferred protocol is Global Systems for Mobile Communication (GSM).			

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SPREAD SPECTRUM COMMUNICATION NETWORK
SIGNAL PROCESSOR

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RELATED APPLICATIONS

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The present application incorporates the following
patent applications by reference:

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CELLULAR PRIVATE BRANCH EXCHANGES, U.S. Ser. No.
08/435,709, filed on May 4, 1995, Attorney docket No.
WAVEP001;

12

METHODS AND APPARATUSES FOR AN INTELLIGENT SWITCH, U.S.
Ser. No. 08/435,838, filed on May 4, 1995, Attorney docket
No. WAVEP004;

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SPREAD SPECTRUM COMMUNICATION NETWORK WITH ADAPTIVE
FREQUENCY AGILITY, U.S. Ser. No. 08/434,597, filed on May 4,
1995, Attorney docket No. A-60820; and

18

CELLULAR BASE STATION WITH INTELLIGENT CALL ROUTING,
U.S. Ser. No. 08/434,598, filed on May 4, 1995, Attorney
docket No. A-61115.

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FIELD

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The present invention relates to a spread spectrum
communication network signal processor. In particular, the
present invention is used in a cellular communication network
to improve the information channel capacity with a
distributed signal processing architecture.

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BACKGROUND

Spread spectrum communication typically includes two
type of techniques: direct sequence spread spectrum (DSSS),
where the information signal in-phase and quadrature-phase
are varied; and frequency hopping spread spectrum (FHSS),
where the information carrier frequency is varied. Moreover,
these techniques can include formats for what is known as
time division multiple access (TDMA) and frequency division
multiple access (FDMA). These formats dedicate a specific

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1 periodic time slot or frequency to each mobile station.
2 Advantages of DSSS, FHSS, TDMA and FDMA include reduced co-
3 channel interference and improved information channel
4 capacity over a given bandwidth. While these techniques can
5 be employed independently, they can also be combined.

6 One limitation of existing communication networks is
7 that the base station must have a multiplicity of dedicated
8 transmitters and receivers to adequately process all the
9 mobile station signals. Since each base station transmitter
10 and receiver can communicate only one frequency, a large
11 number of transmitters and receivers are required to serve
12 the communication network employing multiple frequencies.
13 For example, eight transmitters and eight receivers are
14 required to serve eight receive frequencies and eight
15 transmit frequencies.

16 Moreover, since existing communication networks use a
17 multiplicity of dedicated transmitters and receivers, a fault
18 can cause data to be lost, or even cause the network to
19 malfunction. When a transmitter or receiver is broken, the
20 network must operate in a reduced capacity, if it can operate
21 at all.

22 Another limitation of existing communication networks is
23 that the FHSS protocol sequence is predetermined. That is,
24 the frequency hops are periodic within the same frequency
25 set. This results in continual interference from other
26 operating electro-magnetic fields. The existing
27 communication protocols do not adapt to avoid interference.

28 Another limitation of existing communication networks is
29 that the processing is performed within a central signal
30 processor. A central signal processor employs software to
31 perform the procedures necessary to process the data. While
32 this configuration provides high flexibility, it is also slow
33 and requires high computational and memory overhead.

34 Another limitation of existing communication networks is
35 that in the communication protocol, the specific periodic
36 TDMA time slot is fixed. Each mobile station is entitled to
37 a single slot and may not receive an additional slot even if
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1 other mobile stations are not fully utilizing their
2 respective information channel capacity.

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SUMMARY

5 The present invention relates to a spread spectrum
6 communication network signal processor. In particular, the
7 present invention is used in a cellular communication network
8 to improve the information channel capacity with a
9 distributed signal processing architecture. Exemplary
10 embodiments are provided for use with the Global Systems for
11 Mobile Communication (GSM) protocol.

12 A base station communicates with a plurality of mobile
13 stations over a cellular network. In one embodiment, the
14 base station includes a receiver configured to receive
15 inbound information from the mobile station and a transmitter
16 configured to transmit outbound information to the mobile
17 station.

18 The base station further has a central processor that
19 includes a signal processor array. The signal processor
20 architecture is designed to increase the throughput and task-
21 based allocation of processing resources. The signal
22 processing array has both series and parallel signal
23 processing elements. A plurality of signal processor
24 elements are disposed in series to form a signal processing
25 string. A plurality of signal processing strings are
26 disposed in parallel. Each of the signal processor strings
27 includes at least two signal processor elements that are each
28 dedicated to performing a specific task. As a result, the
29 parallel processor strings simultaneously process information
30 corresponding to predetermined criteria, such as TDMA time
31 slots, while the series processors sequentially process that
32 information by an efficient task-based pipeline processing.

33 Once the inbound information is processed by the signal
34 processor array, the inbound information is sent to the
35 central processor. The central processor is responsible for
36 communicating information with a public switched telephone
37 network.

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1 The base station further receives outbound information
2 from the public switched telephone network and sends the
3 outbound information to the signal processor array to encode
4 the information and send it to a transmitter to be delivered
5 to the mobile station. The outbound signal processing is
6 similar to the inbound signal processing, only in reverse.

7 In another embodiment, the base station further includes
8 a plurality of receivers and transmitters (transceivers)
9 where each transceiver has a dedicated signal processor
10 array. This architecture promotes front end distributed
11 processing and relieves the processing load on the central
12 processor.

13 The advantages of the present invention include reduced
14 interference, improved communication bandwidth, fault
15 tolerance, modularity, scalability, and more efficient and
16 cost-effective base stations and mobile stations.

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18 BRIEF DESCRIPTION OF THE DRAWINGS

19 Additional advantages of the invention will become
20 apparent upon reading the following detailed description and
21 upon reference to the drawings, in which:

22 Figure 1 depicts a cellular network showing several base
23 stations and several mobile stations;

24 Figures 2A-C illustrate the frequency bands allocated to
25 GSM communication, a typical frequency hopping table, and the
26 GSM frequency hopping algorithm;

27 Figure 3 illustrates a speech waveform sampled and
28 assembled into a digital GSM format;

29 Figure 4 illustrates a GSM frame and associated data;

30 Figure 5 depicts one embodiment of a base station
31 architecture according to the invention;

32 Figure 6 is a flow chart showing steps performed by the
33 base station of Figure 5;

34 Figures 7A-B depict an embodiment of a signal processor
35 architecture according to the invention;

36 Figure 8 is a data processing chart showing information
37 demultiplexed to the plurality of parallel signal processor
38 elements of Figure 7;

1 Figure 9 is a flow chart showing steps performed by the
2 signal processor of Figure 7;

3 Figures 10A-B depict another embodiment of a signal
4 processor architecture according to the invention;

5 Figure 11 is a flow chart showing steps performed by the
6 signal processor of Figure 10;

7 Figures 12A-B depict another embodiment of a signal
8 processor architecture according to the invention; and

9 Figure 13 depicts another embodiment of a signal
10 processor architecture according to the invention.
11

12 DETAILED DESCRIPTION

13 The present invention relates to a spread spectrum
14 communication network signal processor. In particular, the
15 present invention is used in a cellular communication network
16 to improve the information channel capacity with a
17 distributed signal processing architecture. Exemplary
18 embodiments are provided for use with the Global Systems for
19 Mobile Communication (GSM) communication protocol.

20 The exemplary embodiments are described herein with
21 reference to specific configurations and protocols. Those
22 skilled in the art will appreciate that various changes and
23 modifications can be made to the exemplary embodiments while
24 remaining within the scope of the present invention.

25 A first embodiment is described with reference to
26 Figures 1 through 6. Figure 1 is a relatively general
27 illustration of a cellular communication network. A number
28 of base stations (BS) 10 are positioned to serve a number of
29 geographically distinct cells, for example cell A and cell B.
30 Each base station 10 is responsible for serving all the
31 mobile stations (MS) 12 within its respective cell boundary.
32 To perform this task, each base station 10 downloads a
33 frequency hopping table (also known as a mobile allocation
34 table) to each mobile station 12 so that the communication
35 between base station 10 and mobile station 12 is on
36 predefined frequencies, as explained more fully below.

37 A base station controller (BSC) 14 is coupled to every
38 base station 10, typically via land line 92, and controls the

1 communication between users, such as between mobile station
2 users or existing infrastructure telephone users. Moreover,
3 base station controller 14 controls the hand-off from one
4 base station 10 to another base station 10 as a mobile
5 station 12 moves among cells.

6 A protocol selected for the embodiments is the Global
7 Systems for Mobile Communication (GSM) protocol. The GSM
8 protocol is lengthy and complicated. Therefore, the salient
9 features are discussed with respect to the embodiments. For
10 additional information on the subject, the reader is referred
11 to the GSM specification. One important GSM protocol
12 requirement is frequency hopping spread spectrum (FHSS).
13 That is, sequentially communicating over more than one
14 frequency.

15 Figure 2A shows the allocated frequency spectrum for GSM
16 communication (from the mobile station standpoint). As can
17 be seen, the mobile station transmit frequency band (T_f) is
18 disjoint from the mobile station receive frequency band (R_f).
19 Each of these frequency bands occupies approximately 25MHz.
20 Within that 25MHz, there are 124 200KHz frequency steps on
21 which the communication frequencies are permitted to hop. An
22 extended GSM specification is currently under development,
23 and will include a broader range of operational frequencies.
24 The specific hopping sequence is a function of the GSM
25 hopping algorithm defined by the GSM specification and a
26 given frequency hopping table that is downloaded from base
27 station 10 to mobile station 12. An example frequency
28 hopping table is presented in Figure 2B. Based on the GSM
29 hopping algorithm (Figure 2C), the mobile station receiver
30 and transmitter operate on specified 200KHz frequencies in
31 their respective frequency bands T_f , R_f . Of course, the base
32 station T_f and R_f correspond to the mobile station R_f and T_f
33 respectively.

34 Since GSM is a digital data communication network,
35 Figure 3 shows how a speech waveform is sampled and digitally
36 encoded. Figure 4 shows how the encoded data is formatted
37 into the GSM frame structure. Note that the information from
38 one mobile station 12 is processed and placed into a specific

1 time slot reserved for that particular mobile station 12
2 within a TDMA frame. Further, note that after the TDMA frame
3 is collected, a multiframe is constructed from 26 TDMA
4 frames, including 24 TDMA speech frames and 2 control frames.
5 Beyond the multiframe are superframes and hyperframes. There
6 are 51 multiframes in a superframe, and there are 2048
7 superframes in a hyperframe. The hyperframe number is one
8 variable used by the GSM frequency hopping algorithm to
9 define the frequency hopping sequence.

10 Based on the GSM frequency hopping algorithm (Figure
11 2C), the TDMA frames are then frequency hopped over the
12 frequencies of the frequency hopping table. The mobile
13 station receivers are also periodically hopped onto a fixed
14 monitor frequency that is unique to each base station. The
15 frequency hopping serves to spread the communication signal
16 over the frequency bands T_f , R_f . One advantage of spread
17 spectrum is reduced interference effects from other electro-
18 magnetic sources and other base station/mobile station
19 communications. Another advantage is that it the avoidance
20 of frequency-selective nulls due to multipath effects. For
21 the mobile station, three frequencies are tuned onto in one
22 4.615ms TDMA time frame (transmit, receive, monitor). Each
23 mobile station transmitter and receiver synthesizer has 1 or
24 2 time slots (4.615ms times 1/8 or 2/8, i.e., .58ms or
25 1.15ms) to change frequencies. Frequency hopping once per
26 frame is easily accomplished because the synthesizers have
27 plenty of time (1 or 2 time slots) to settle before a new
28 reception or transmission is required. However, the base
29 station receiver and transmitter have only 30 μ s to change
30 frequencies (the time duration of the guard bits). This
31 short time period is difficult to accommodate, so the
32 invention incorporates a plurality of receiver synthesizers
33 and transmitter synthesizers as now explained.

34 Figure 5 depicts a base station 10 having a receiver 20,
35 a transmitter 40 and a processor 80. As shown, receiver 20
36 and transmitter 40 share common antenna 21 via diplexer 23.
37 This configuration is possible since the receive frequency
38 and transmit frequency are different (see Figure 2A).

1 Diplexer 23 is used to permit the receive frequency to pass
2 from antenna 21 to receiver 20, and to permit the transmit
3 frequency to pass from transmitter 40 to antenna 21.
4 Receiver 20 and transmitter 40 each employ two independent
5 synthesizers in order to facilitate fast frequency agility.
6 The detail of the embodiment and the operation is explained
7 with reference to the Figure 6 flow chart.

8 The reset step 102 is performed only at start-up, such
9 as when base station 10 initially comes on-line or when
10 recovering from a power failure. Step 104 is turns off
11 transmitter 40 to prevent invalid transmission before
12 initialization of the base station 10. Thereafter, step 106
13 waits for the processor 80 to perform its self-test and other
14 required procedures before base station 10 can become
15 operational in the cellular network. Step 108 calculates the
16 required first frequency and the subsequent second frequency
17 from the GSM hyperframe number and the frequency hopping
18 table. Once these first and second frequencies are
19 calculated, the first and second receiver synthesizers 32,
20 34, and transmitter synthesizers 52, 54 are programmed to
21 generate the required frequencies. At this point, the
22 switches 36, 56 are set to provide the mixers 24, 44 with the
23 frequencies from the first synthesizers 32, 52 respectively.

24 A loop sequence begins with step 110, where processor 80
25 waits for the transmitter interrupt from the CPU 82 to
26 indicate that the TDMA frame should be processed. If the
27 step 112 is being queried for the first time (i.e.,
28 transmitter 40 was turned off in step 104), step 114 is
29 performed to turn transmitter 40 on. Once transmitter 40 is
30 on, step 116 proceeds to transmit a TDMA frame and then to
31 toggle the transmitter synthesizer selector switch 56 to the
32 other transmitter synthesizer 54. Step 116 also calculates
33 the next transmitter frequency and programs the previously
34 active synthesizer 52 to generate that frequency.

35 When the receiver interrupt occurs in step 118, step
36 120 proceeds to receive a TDMA frame and then to toggle the
37 receiver synthesizer selector switch 36 to the other receiver
38 synthesizer 34. Step 120 also calculates the next receiver

1 frequency and programs the previously active synthesizer 32
2 to generate that frequency.

3 Steps 110 through 120 are then repeatedly performed to
4 transmit and receive the TDMA frames to and from the mobile
5 stations 12 on the proper frequencies. This configuration of
6 the dual synthesizer receiver 20 and dual synthesizer
7 transmitter 40 permits base station 10 to faithfully
8 accomplish all the frequency hops required for proper
9 communication.

10 It is important to note that base station 10 of Figure 5
11 employs processor 80 to orchestrate the synthesizers 32, 34,
12 52, 54 and the synthesizer switches 36, 56. Processor 80
13 includes a central processing unit (CPU) 82 for performing
14 many of the general procedures required to communicate over
15 the network with mobile station 12. Processor 80 also
16 performs procedures necessary to communicate with base
17 station controller 14. A digital signal processor (DSP) 84
18 is included in processor 80 to perform many of the
19 application specific and computationally intensive procedures
20 such as encoding and decoding the TDMA frame data. As shown,
21 the processor 80 also includes memory (RAM) 86, and may
22 optionally include bulk disk memory 88. Moreover, user
23 interface 90 is provided to receive instructions from a user
24 and to display requested information. Ground line 92 is also
25 provided to connect to base station controller 14 and other
26 base stations 10 as required by the GSM specification.

27 In another embodiment depicted in Figures 7 through 9,
28 the signal processing architecture is provided to increase
29 the throughput and task-based allocation of processing
30 resources. A first aspect of this embodiment is shown in
31 Figure 7A, where an array of 2 wide and 2 deep DSPs are
32 configured. A second aspect of this embodiment is shown in
33 Figure 7B, where an N by M array of DSPs are configured. In
34 essence, Figure 7A is Figure 7B where N=2 and M=2.

35 This embodiment shows how an array of signal processors
36 84 is arranged to process inbound information in parallel and
37 in series. A demultiplexer 26 distributes inbound
38 information to parallel digital signal processors 1A-NA, 2A-

1 NA, 1M-NM that simultaneously process inbound information
2 correlated with each of the TDMA time slots while the series
3 digital signal processors 1A-1M, 2A-2M, NA-NM sequentially
4 process information in each of the respective TDMA time slots
5 in efficient pipeline processing. This procedure is further
6 explained with reference to Figures 8 and 9.

7 The data processing chart of Figure 8 shows how the
8 inbound information is demultiplexed, by demultiplexer 26, to
9 the plurality of parallel signal processors of Figure 7. For
10 example, Figure 8 shows odd time slots distributed to a first
11 processing string 1A-1M, and even time slots distributed to a
12 Nth processing string NA-NM. For an information word of 8
13 time slots, up to 8 parallel processing strings are used,
14 where each string would be associated with one time slot.
15 One architectural principle is to balance the processing load
16 evenly on all the strings, whether there are as many as 8
17 strings or a few as 2 strings.

18 The flow chart of Figure 9 shows steps performed by
19 string 1 of the signal processor of Figure 7A to process the
20 inbound information. An equalization step 152 is performed
21 in DSP1A, where the inbound information is processed to
22 compensate for noise, multipath fading, and other propagation
23 related impairments. The equalized information is then
24 deciphered in step 154 to recover the original unenciphered
25 data bits, which is performed in DSP1A. Thereafter, step 156
26 burst formats the information in order to retrieve the
27 correct data pattern from the mobile station 12. This is
28 performed in DSP1A. Next, step 158 deinterleaves the data to
29 reconstruct the proper data words for each respective mobile
30 station 12. This is performed in DSP1B. Step 160 is
31 performed to decode the data in order to properly detect
32 errors and correct the data for errors when possible. This
33 is performed in DSP1B. Once the inbound information is error
34 corrected, then the information is delivered to central
35 processor 82. The central 82 processor may also further
36 process the information, switch the information to other
37 processors for further processing, communicate the
38 information to an outbound information link (e.g., E1 link),

1 or may use the information to modify its own processing
2 steps.

3 The same sequential steps shown in Figure 9 are also
4 performed on a different timeslot in second string DSP2A and
5 DSP2B shown in Figure 7A. The same sequential steps of
6 Figure 9 may also be performed in any array size in parallel
7 strings DSPNA-DSPNM shown in Figure 7B. Moreover, the steps
8 shown in Figure 9 can be distributed to even more DSPs in a
9 string if M is chosen greater than 2.

10 In another embodiment depicted in Figures 10 and 11, the
11 signal processing architecture is provided to increase the
12 throughput and task-based allocation of processing resources.
13 A first aspect of this embodiment is shown in Figure 10A,
14 where an array of 2 wide and 1 deep DSPs are configured. A
15 second aspect of this embodiment is shown in Figure 10B,
16 where an N by M array of DSPs are configured. In essence,
17 Figure 10A is Figure 10B where N=2 and M=1.

18 This embodiment shows how an array of signal processors
19 84 is arranged to process outbound information in parallel
20 and in series. Parallel digital signal processors 1A-NA, 2A-
21 NA, 1M-NM simultaneously process outbound information
22 correlated with each of the TDMA time slots while the series
23 digital signal processors 1A-1M, 2A-2M, NA-NM sequentially
24 process information in each of the respective TDMA time slots
25 in efficient pipeline processing. Then, multiplexer 46
26 distributes the information to transmitter 40. This
27 procedures is further explained with reference to Figure 11.

28 The flow chart of Figure 11 shows steps performed by
29 string 1 of the signal processor of Figure 10A to process the
30 outbound information. Central processor 82 obtains outbound
31 information to be transmitted to the mobile stations 12. The
32 outbound information is processed and prepared for delivery
33 to the signal processing array 84. DSP array 84 may also
34 receive speech traffic from a space/time switch included is
35 processor 82 that routes traffic to and from an information
36 link (e.g., E1 link) or other processors. Step 172 is
37 performed to encode the data so that the mobile station 12
38 can properly detect errors and correct the data for errors

1 when possible. This is performed in DSP1A. Next, step 174
2 interleaves the data to distribute the outbound information
3 over several TDMA frames. This is performed in DSP1A.
4 Thereafter, step 176 burst formats the information in order
5 to construct the correct data pattern for the mobile station
6 12. This is performed in DSP1A. A ciphering step 178 is
7 performed in DSP1A to encrypt the outbound information to
8 prevent interception by unauthorized mobile stations. When a
9 two deep ($N=2$) aspect of this embodiment is employed, step
10 178 is performed in DSP1B. Then the outbound information is
11 delivered to multiplexer 46 and sent to the transmitter 40 to
12 be transmitted to the mobile stations 12.

13 The same sequential steps shown in Figure 11 are also
14 performed on a different timeslot in second string DSP2A and
15 DSP2B shown in Figure 10A. The same sequential steps of
16 Figure 11 may also be performed in any array size in parallel
17 strings DSPNA-DSPNM shown in Figure 10B. Moreover, the steps
18 shown in Figure 11 can be distributed to even more DSPs in a
19 string if M is chosen greater than 2.

20 Figure 12 depicts another embodiment of a signal
21 processor architecture according to the invention. A first
22 aspect of this embodiment is shown in Figure 12A, where an
23 array of 2 wide and 2 deep DSPs are configured. A second
24 aspect of this embodiment is shown in Figure 12B, where an N
25 by M array of DSPs are configured. In essence, Figure 12A is
26 Figure 12B where $N=2$ and $M=2$. Separate receive antenna 22
27 and transmit antenna 42 are shown in Figure 12, but they
28 could be combined into a common antenna 21 as shown in Figure
29 5.

30 In this embodiment, the inbound processing functions and
31 the outbound processing functions are combined in signal
32 processing array 84. This configuration employs the
33 processing steps described with respect to Figures 9 and 11.
34 One advantage to this architecture is that the duty cycles of
35 the various DSP elements are well balanced. This feature
36 promotes efficient processing.

37 For example, in the receive only processing of Figure
38 7A, the DSP1A element have a high duty cycle because the

1 initial processing (equalization) is intensive. However, the
2 DSP1B element has a lower duty cycle because the subsequent
3 processing (decoding) is less intensive. In this embodiment
4 shown in Figure 12A, the outbound information processing
5 (encoding) is combined with the inbound information
6 processing (decoding) to efficiently increase the duty cycle
7 of the DSP1B element. An approximate measure of
8 computational intensity is that the equalization is twice as
9 intensive as the decoding. Hence, in a two deep array, if
10 the inbound equalization is performed in DSP1A, and the
11 inbound decoding and outbound encoding is performed in DSP1B,
12 then both DSPs are equally loaded. Moreover, this processing
13 allocation is also efficient because the outbound encoding
14 employs similar, or reciprocal, processing steps as the
15 inbound decoding, but often in reverse. Thus, much of the
16 program memory and lookup tables are the same.

17 DSP1B keeps track of which information it is processing
18 so that the inbound information is sent to processor 82 (or
19 DSP1M in Figure 12B) and the outbound information is sent to
20 the multiplexer 46. The processing of DSP2A and DSP2B are
21 similarly allocated, as are DSPNA and DSPNB. Moreover, if
22 the processing is further distributed in the array 84 of
23 Figure 12B, the processing allocation is distributed within
24 all the parallel processing pipelines DSP1A-DSP1M through
25 DSPNA-DSPNM.

26 Note that this embodiment also shows CPU 82 with a
27 space/time switch for routing information to and from a
28 plurality of transcoder rate adapting units 94, echo
29 cancelers 96, and public switched telephone network 98. This
30 configuration permits the processor 80 to control the entire
31 operation of the inbound information and outbound
32 information.

33 Note also that the described control functions of CPU 82
34 can be distributed among several processors. In one
35 implementation, CPU 82 includes several subordinate
36 microcontrollers resident with the DSPs or with the
37 space/time switch, all linked to and reporting to a central
38 processor.

1 In actual implementation, it is useful to employ a
2 plurality of receivers and transmitters in order to perform
3 both TDMA and FDMA, as provided by the GSM specification.
4 For example, in a conventional configuration, each receiver
5 is tuned to a fixed frequency and frequency-hopped
6 information from the mobile stations is received and
7 transmitted by various receivers depending on the specified
8 communication frequency. Then the conventional processor
9 must re-assemble inbound information from a plurality of
10 receivers to obtain data from one mobile station. Moreover,
11 the conventional processor must dis-assemble outbound
12 information and deliver it to a plurality of transmitters to
13 properly transmit information to a mobile station.

14 Figure 13 depicts another embodiment of a base station
15 10 according to the invention. There are provided a
16 plurality of transceivers 200A-P that are frequency agile (as
17 shown in Figure 5). Hence, transceivers 200A-P can be
18 programmed to receive various frequencies over time and can
19 receive information from each mobile station 12 on a
20 respective one of transceivers 200A-P. This feature permits
21 both TDMA received signals and FDMA received signals
22 associated with one mobile station 12 to be received by one
23 of the transceivers 200A-P. Because processor 80 programs
24 the receiver synthesizers, processor 80 has a priori
25 knowledge of which transceiver 200A-P is receiving
26 communication signals from which mobile station 12. This
27 information permits the processor to more efficiently process
28 the inbound data. For example, if the signal from one mobile
29 station 12 is always received in transceiver card one 200A,
30 then the processor 80 can reduce its control logic (hardware,
31 software, or both) to avoid the conventional step of re-
32 assembling a mobile station's data from a number of different
33 receivers. Also, configuring a plurality of frequency agile
34 transceivers 200A-P in parallel permits processor 80 to
35 reconfigure transceivers 200A-P at any time a fault is
36 detected. If, for example, processor 80 detects a fault in
37 transceiver 200A (e.g., by self-test, null data, or corrupted
38 data), processor 80 re-programs another transceiver, such as

1 transceiver 200P, to operate on the parameters that were
2 previously assigned to transceiver 200A. The feature of
3 agile transceivers and enhanced processing resource
4 allocation reduces overhead, permits fault tolerance, and
5 increases throughput since it eliminates a processing step.
6 Moreover, the features discussed with respect to receiving
7 information from the mobile stations 12 is equally applicable
8 to transmitting outbound information to the mobile stations
9 12 via transceivers 200A-P.

10 As shown, transceivers 200A-P can be coupled to a common
11 transmit antenna 42. However, if transceivers 200A-P are
12 sensitive to back propagation of each other's transmissions,
13 a plurality of transmit antennas (42A-P) can be employed with
14 each transceiver having its own transmit antenna. Moreover,
15 separate receive antennas 22A-P and transmit antennas 42A-P
16 are shown in Figure 13, but they could be combined into a
17 common antennas 21A-P as shown in Figure 5.

18 Additional base station embodiments are described in
19 CELLULAR BASE STATION WITH INTELLIGENT CALL ROUTING, U.S.
20 Ser. No. 08/434,598, filed on May 4, 1995, Attorney docket
21 No. A-61115, which is incorporated herein by reference.

22 Advantages of the present invention include reduced
23 interference, improved communication bandwidth, fault
24 tolerance, modularity, scalability, and more efficient and
25 cost-effective base stations and mobile stations.

26 An additional advantage of the embodiment shown in
27 Figure 13 is that the transceivers 200A-P can be removed from
28 or inserted into an operational station 12. This permits a
29 technician to remove a broken transceiver and insert a new
30 transceiver while the base station remains operational. The
31 broken transceiver card can then be repaired and returned to
32 service when needed.

33 As used herein, when a first element and a second
34 element are coupled, they are related to one another, but
35 need not have a direct path to one another. For example, a
36 signal processing element may be coupled to a receiver
37 element via a demultiplexer. However, when a first element
38

1 and second element are connected, they are required to have a
2 direct path to one another.

3

4 ALTERNATIVE EMBODIMENTS

5 Having disclosed exemplary embodiments and the best
6 mode, modifications and variations may be made to the
7 disclosed embodiments while remaining within the scope of the
8 present invention as defined by the following claims.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A base station for communicating with a first mobile station and a second mobile station, and wherein inbound information includes a first time slot associated with the first
5 mobile station and a second time slot associated with the second mobile station, and outbound information includes a first time slot associated with the first mobile station and a second time slot associated with the second mobile station, said base station comprising:
a receiver configured to receive inbound information from the first mobile station and the second mobile station;
10 demultiplexer coupled to said receiver and configured to route said inbound information associated with the first time slot to a first output and said inbound information associated with the second time slot to a second output;
a first signal processor coupled to said first output and configured to equalize said inbound information associated with the first time slot;
15 a second signal processor coupled to said first signal processor and configured to decode said inbound information associated with the first time slot;
a third signal processor coupled to said second output and configured to equalize said inbound information associated with the second time slot;
a fourth signal processor coupled to said third signal processor and configured to
20 decode said inbound information associated with the second time slot;
a central processor coupled to said second signal processor and said fourth signal processor and configured to process said inbound information and to communicate said inbound information with a public switched telephone network, said central processor further configured to communicate outbound information with the public switched telephone network
25 and to process said outbound information; and
wherein:
said second signal processor is configured to encode said outbound information associated with said first time slot; and
said fourth signal processor is configured to encode said outbound information associated with said second time slot; and



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said base station further comprises:

- a multiplexer coupled to said second signal processor and said fourth signal processor and configured to route said outbound information associated with the first time slot to a multiplexer output and to route said outbound information associated with the second time slot to said multiplexer output; and
- a transmitter coupled to said multiplexer output and configured to transmit said outbound information to the first mobile station and the second mobile station.

2. A base station for communicating with a first mobile station and a second mobile station, and wherein inbound information includes a first time slot associated with the first mobile station and a second time slot associated with the second mobile station, and outbound information includes a first time slot associated with the first mobile station and a second time slot associated with the second mobile station, said base station comprising:

a receiver configured to receive inbound information from the first mobile station and the second mobile station;

demultiplexer coupled to said receiver and configured to route said inbound information associated with the first time slot to a first output and said inbound information associated with the second time slot to a second output;

a first signal processor coupled to said first output and configured to equalize said inbound information associated with the first time slot;

a second signal processor coupled to said first signal processor and configured to decode said inbound information associated with the first time slot;

a third signal processor coupled to said second output and configured to equalize said inbound information associated with the second time slot;

a fourth signal processor coupled to said third signal processor and configured to decode said inbound information associated with the second time slot;

a central processor coupled to said second signal processor and said fourth signal processor and configured to process said inbound information and to communicate said inbound information with a public switched telephone network, said central processor further

configured to communicate outbound information with the public switched telephone network



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and to process said outbound information; and

wherein:

said second signal processor is configured to encode said outbound information associated with said first time slot;

5 said first signal processor is configured to encrypt said outbound information associated with said first time slot;

said fourth signal processor is configured to encode said outbound information associated with said second time slot; and

10 said third signal processor is configured to encrypt said outbound information associated with said first time slot; and

said base station further comprises:

15 a multiplexer coupled to said first signal processor and said third signal processor and configured to route said outbound information associated with the first time slot to a multiplexer output and to route said outbound information associated with the second time slot to said multiplexer output; and

a transmitter coupled to said multiplexer output and configured to transmit said outbound information to the first mobile station and the second mobile station.

3. A base station for communicating over a cellular network with a first mobile station
20 and a second mobile station, and wherein inbound information includes a first time slot associated with the first mobile station and a second time slot associated with the second mobile station, and outbound information includes a first time slot associated with the first mobile station and a second time slot associated with the second mobile station, said base station comprising:

25 a receiver configured to receive inbound information from the first mobile station and the second mobile station;

demultiplexer coupled to said receiver and configured to route said inbound information associated with the first time slot to a first output and said inbound information associated with the second time slot to a second output;

a first signal processor coupled to said first output and configured to equalize said



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inbound information associated with the first time slot;

a second signal processor coupled to said first signal processor and configured to decode said inbound information associated with the first time slot;

a third signal processor coupled to said second output and configured to equalize said
5 inbound information associated with the second time slot;

a fourth signal processor coupled to said third signal processor and configured to decode said inbound information associated with the second time slot;

a central processor coupled to said second signal processor and said fourth signal processor and configured to process said inbound information and to communicate said
10 inbound information with a public switched telephone network, said central processor further configured to communicate outbound information with the public switched telephone network and to process said outbound information;

a fifth signal processor coupled to said central processor and configured to encode said outbound information associated with said first time slot;

15 a sixth signal processor coupled to said central processor and configured to encode said outbound information associated with said second time slot;

a multiplexer coupled to said fifth signal processor and said sixth signal processor and configured to route said outbound information associated with the first time slot to a multiplexer output and to route said outbound information associated with the second time slot
20 to said multiplexer output; and

a transmitter coupled to said multiplexer output and configured to transmit said outbound information to the first mobile station and the second mobile station.

4. A base station for communicating over a cellular network with a first mobile station
25 and a second mobile station, and wherein outbound information includes a first time slot associated with the first mobile station and a second time slot associated with the second mobile station, said base station comprising:

a central processor coupled to a public switched telephone network and configured to communicate outbound information with the public switched telephone network and to process
30 said outbound information;



a first signal processor coupled to said central processor and configured to encode said outbound information associated with said first time slot;

a second signal processor coupled to said central processor and configured to encode said outbound information associated with said second time slot;

5 a multiplexer coupled to said first signal processor and said second signal processor and configured to route said outbound information associated with said first time slot to a multiplexer output and to route said outbound information associated with said second time slot to said multiplexer output; and

a transmitter coupled to said multiplexer output and configured to transmit said
10 outbound information to the first mobile station and the second mobile station.

5. A base station for communicating over a cellular network with a first mobile station and a second mobile station, and wherein outbound information includes a first time slot associated with the first mobile station and a second time slot associated with the second
15 mobile station, said base station comprising:

a central processor coupled to a public switched telephone network and configured to communicate outbound information with the public switched telephone network and to process said outbound information;

a first signal processor coupled to said central processor and configured to encode said
20 outbound information associated with said first time slot;

a second signal processor coupled to said first signal processor and configured to encrypt said outbound information associated with said first time slot;

a third signal processor coupled to said central processor and configured to encode said outbound information associated with said second time slot;

25 a fourth signal processor coupled to said first signal processor and configured to encrypt said outbound information associated with said second time slot;

a multiplexer coupled to said second signal processor and said fourth signal processor and configured to route said outbound information associated with the first time slot to a multiplexer output and to route said outbound information associated with the second time slot

30 to said multiplexer output; and



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a transmitter coupled to said multiplexer output and configured to transmit said outbound information to the first mobile station and the second mobile station.

6. A base station for communicating over a cellular network with a plurality of mobile stations, comprising:

a central processor;

a plurality of transceivers coupled to said central processor and configured to receive inbound information from the mobile stations and to transmit outbound information to the mobile stations; and

10 wherein each of said transceivers includes a demultiplexer coupled to a receiver and to an array of signal processors having at least two parallel processing paths for equalizing and decoding the inbound signal and for encoding the outbound signal, said demultiplexer configured to route said inbound information to said array, and a multiplexer coupled to said array and to a transmitter, said multiplexer configured to route said outbound information to
15 said transmitter.

7. A method of processing inbound information transmitted from a first mobile station and a second mobile station and received at a base station having a transceiver, a demultiplexer, a first signal processor, a second signal processor, a third signal processor, a
20 fourth signal processor, a central processor and a multiplexer, and processing outbound information from a public switched telephone network via the base station, destined for the first mobile station and the second mobile station, wherein the inbound information includes a first time slot associated with the first mobile station and a second time slot associated with the second mobile station, and the outbound information includes a first time slot associated
25 with the first mobile station and a second time slot associated with the second mobile station, said method comprising the steps of:

receiving the inbound information in the transceiver; dividing the inbound information into the inbound information associated with the first time slot and the inbound information associated with the second time slot in the demultiplexer and delivering the inbound
30 information associated with the first time slot to the first signal processor and the inbound



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- information associated with the second time slot to the third signal processor;
- equalizing the inbound information associated with the first time slot in the first signal processor;
- decoding the inbound information associated with the first time slot in the second
- 5 signal processor;
- equalizing the inbound information associated with the second time slot in the third signal processor;
- decoding the inbound information associated with the second time slot in the fourth signal processor;
- 10 processing the inbound information in the central processor in preparation for presenting the inbound information to a public telephone switched network;
- receiving the outbound information in the central processor and delivering outbound information associated with the first time slot to the second signal processor and outbound information associated with the second time slot to the fourth signal processor;
- 15 encoding the outbound information associated with the first time slot in the second signal processor;
- encoding the outbound information associated with the second time slot in the fourth signal processor;
- combining the outbound information associated with the first time slot and the
- 20 outbound information associated with the second time slot in the multiplexer and delivering the outbound information to the transmitter; and
- transmitting the outbound information in the transceiver.
- 8. The method of claim 7, further comprising the steps of:
- 25 encrypting the outbound information associated with the first time slot in the first signal processor; and
- encrypting the outbound information associated with the second time slot in the third signal processor.

- 30 9. A method of processing outbound information from a public switched telephone



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network in a base station having a transceiver, a first signal processor, a second signal processor, a central processor, and a multiplexer, the outbound information destined for a first mobile station and a second mobile station, said method comprising the steps of:

receiving the outbound information in the central processor, where the outbound
5 information includes a first time slot associated with the first mobile station and a second time slot associated with the second mobile station and delivering outbound information associated with the first time slot to the first signal processor and outbound information associated with the second time slot to the second signal processor;

encoding the outbound information associated with the first time slot in the first signal
10 processor;

encoding the outbound information associated with the second time slot in the second signal processor; and

transmitting the outbound information in the transceiver.

15 10. The method of claim 9, wherein the base station further has a third signal processor and a fourth signal processor, said method further comprising the steps of:

encrypting the outbound information associated with the first time slot in the third signal processor;

encrypting the outbound information associated with the second time slot in the fourth
20 signal processor.

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25 DATED this 27th day of July, 1998

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LTD. and JEROME C. TU and GREGORY J. GERST

By their Patent Attorneys

30 DAVIES COLLISON CAVE



1/13

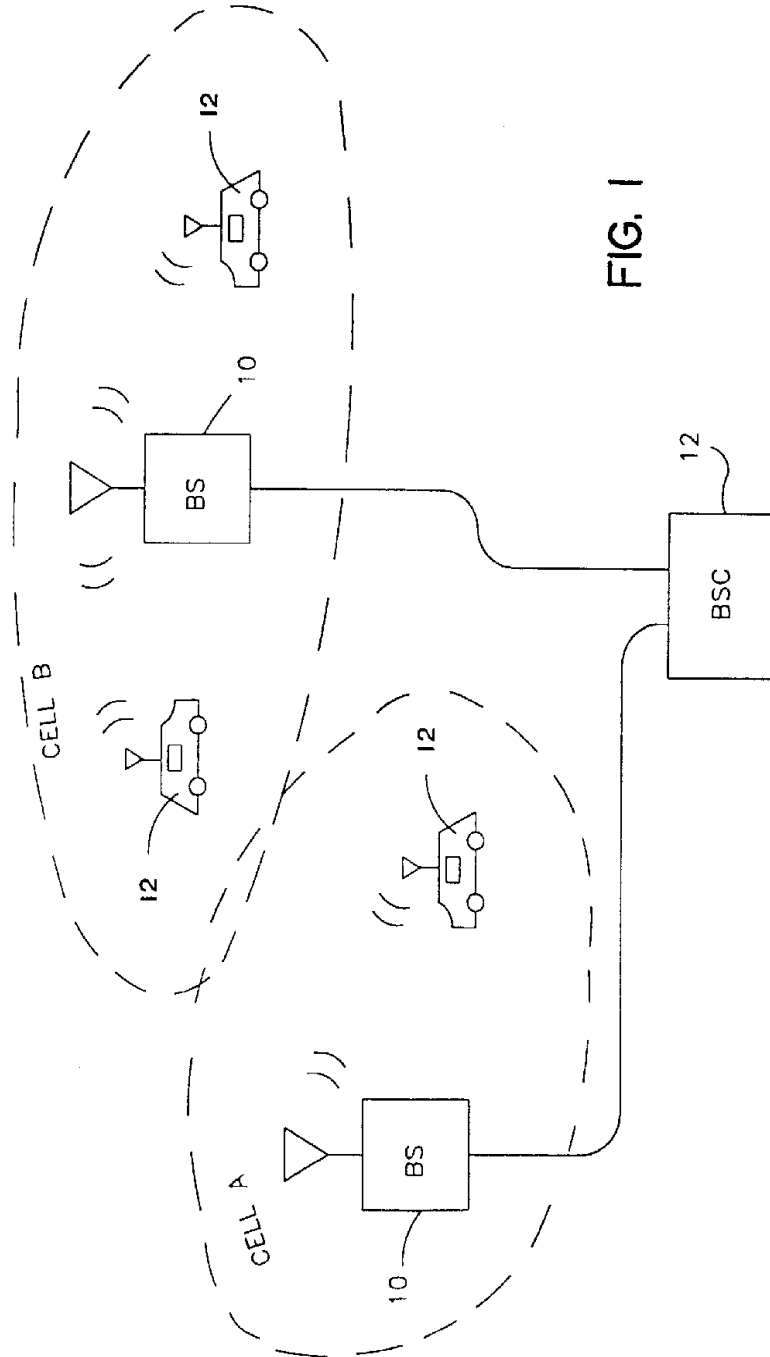


FIG. 1

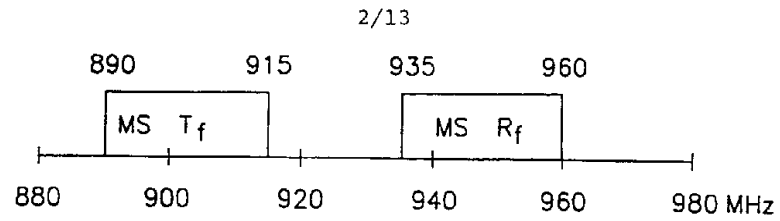


FIG. 2A

#	MS TRANSMIT	MS RECEIVE
0	m0	m0+45MHz
1	m1	m1+45MHz
2	m2	m2+45MHz
3	m3	m3+45MHz
⋮	⋮	⋮
N-1	mN-1	mN-1+45MHz

FIG. 2B

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FN FRAME NUMBER
 HSN HOPPING SEQUENCE NUMBER - 0...63
 MA MOBILE ALLOCATION - SET OF N FREQUENCIES
 AVAILABLE FOR USE $m_0 \dots m_{N-1}$
 MAIO MOBILE ALLOCATION INDEX - OFFSET IN MA TABLE
 N NUMBER OF FREQUENCIES IN MA
 RFCHN RAIDO FREQUENCY CHANNEL NUMBER

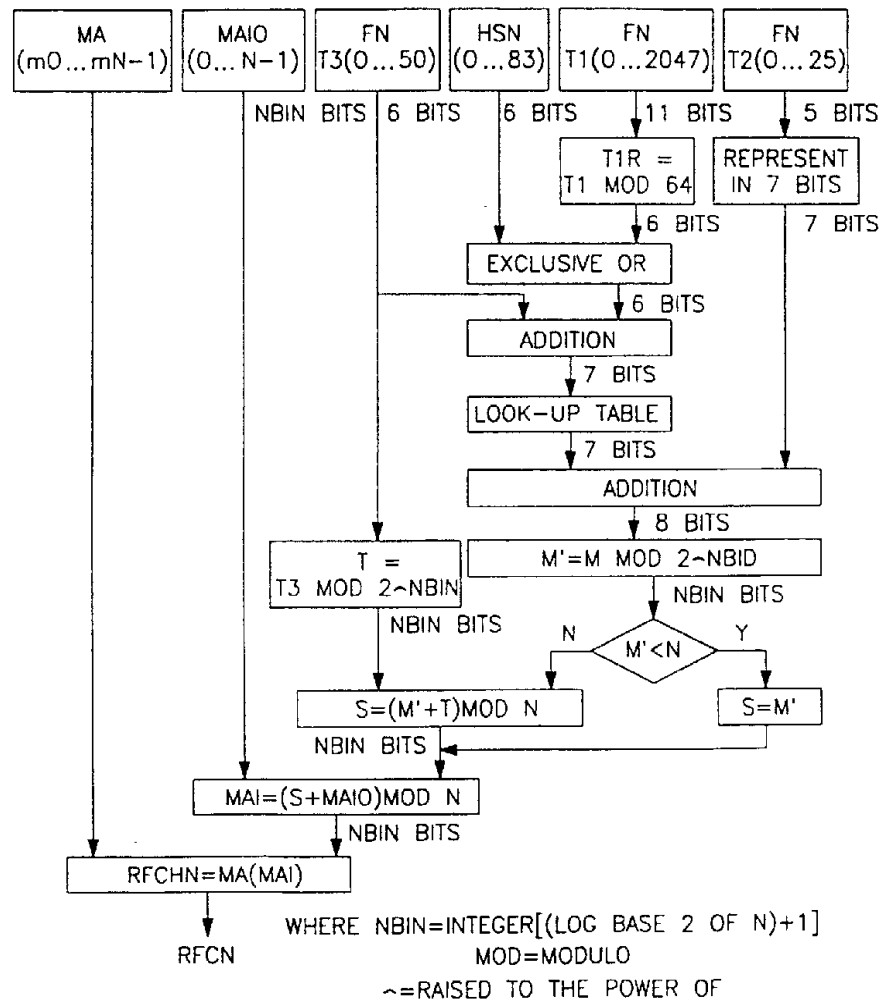


FIG. 2C

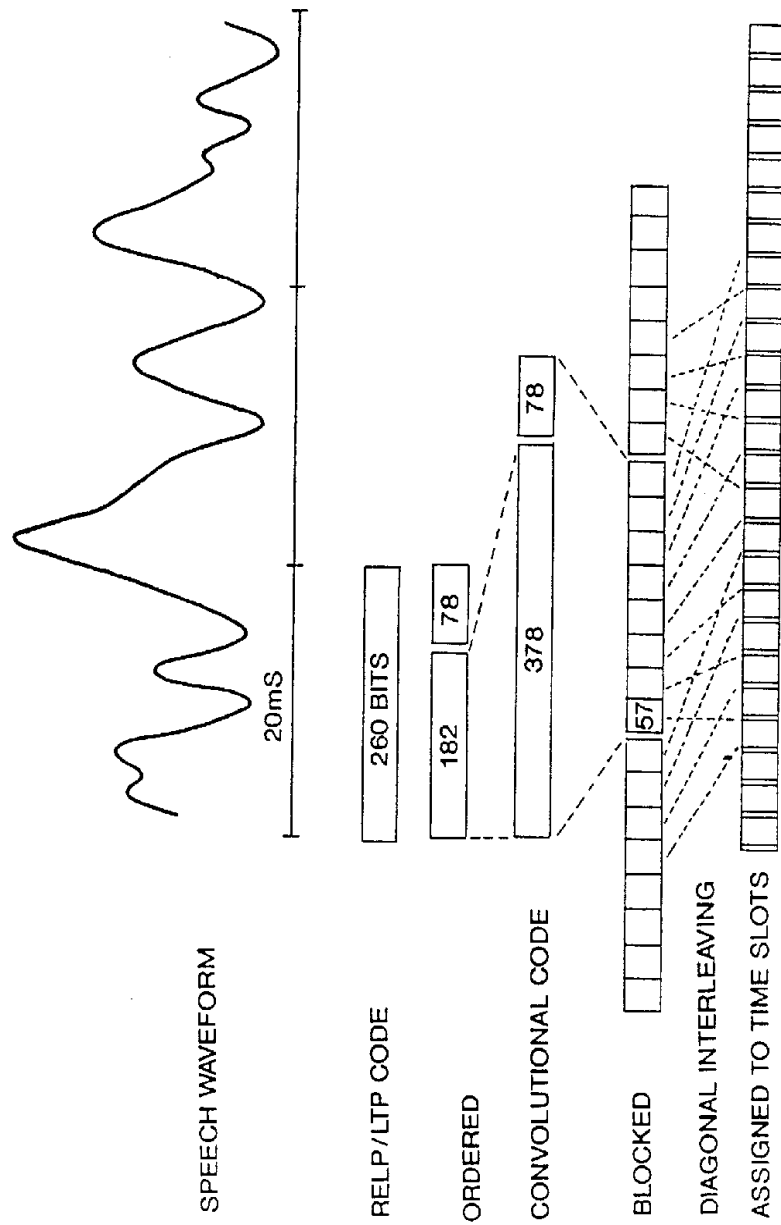


FIG. 3

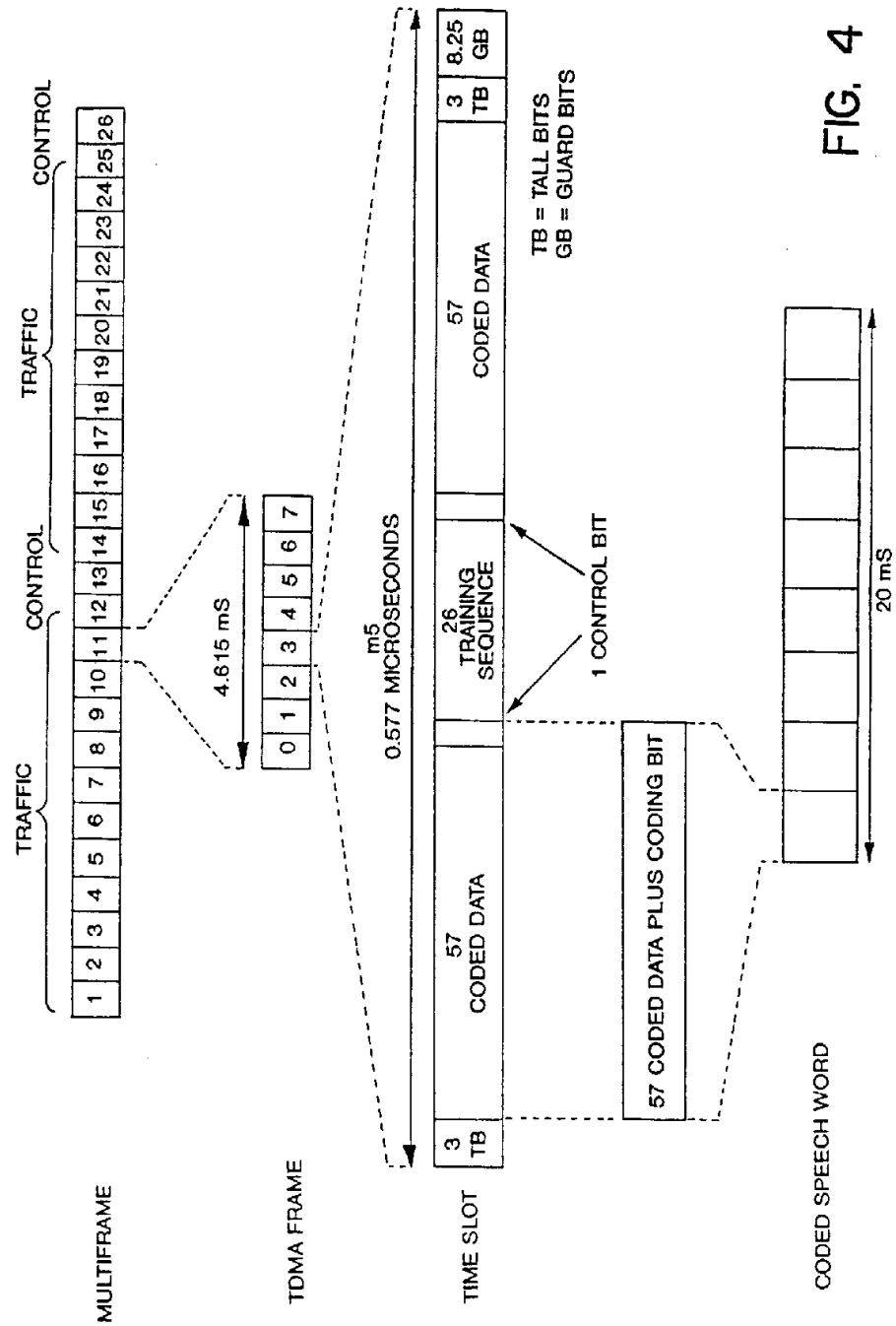


FIG. 4

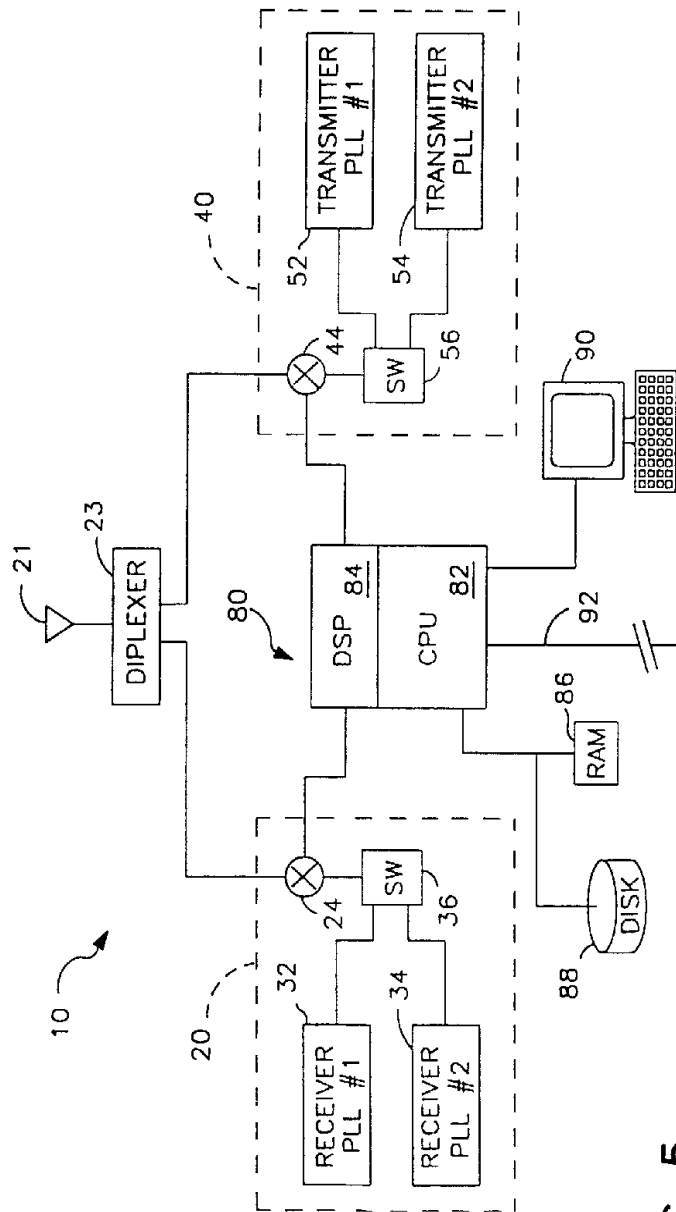
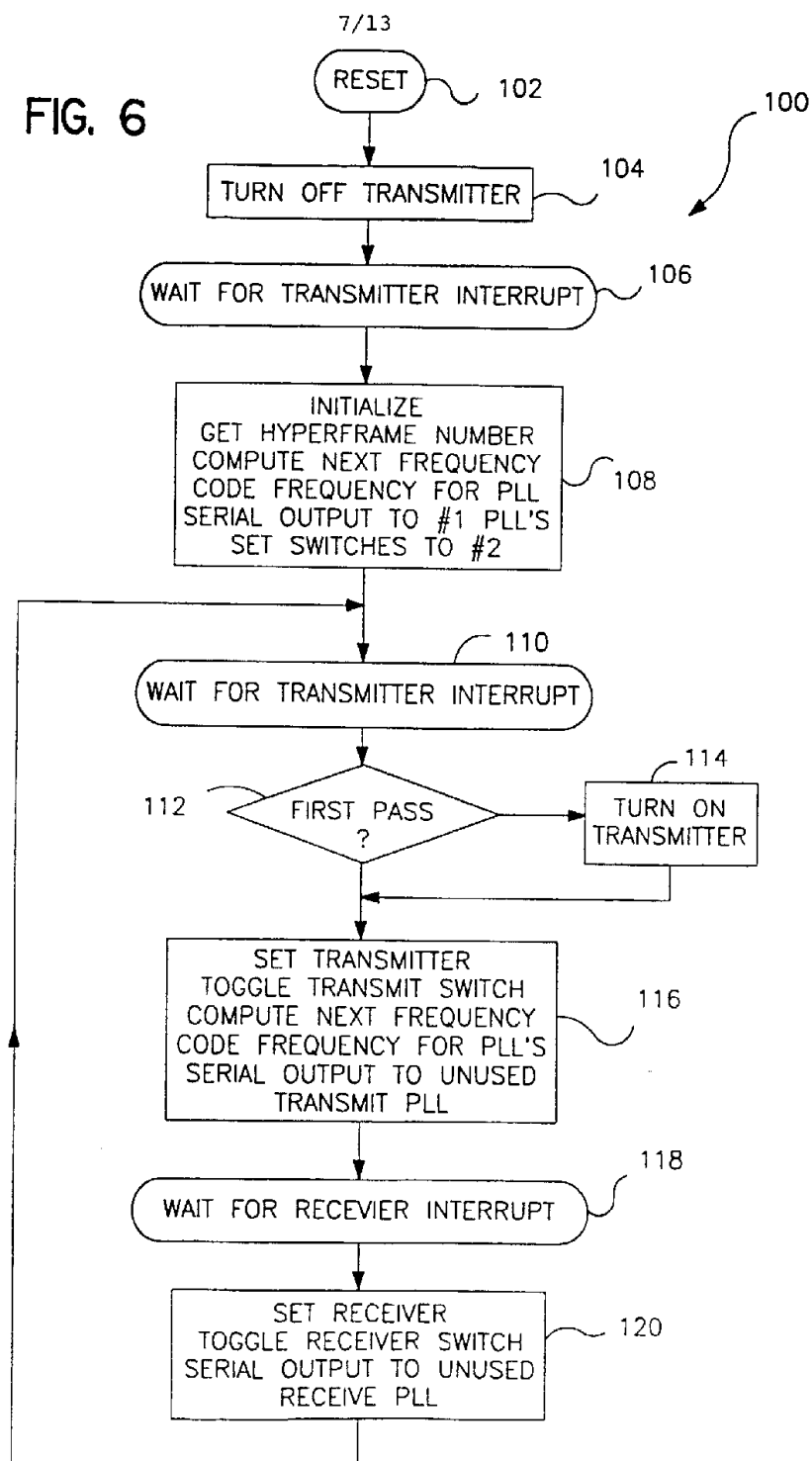


FIG. 5

FIG. 6



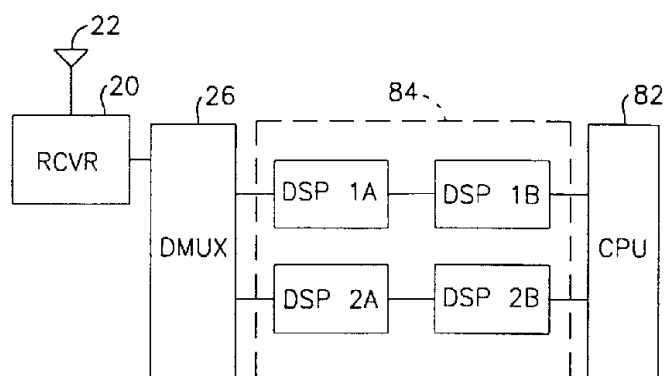


FIG. 7A

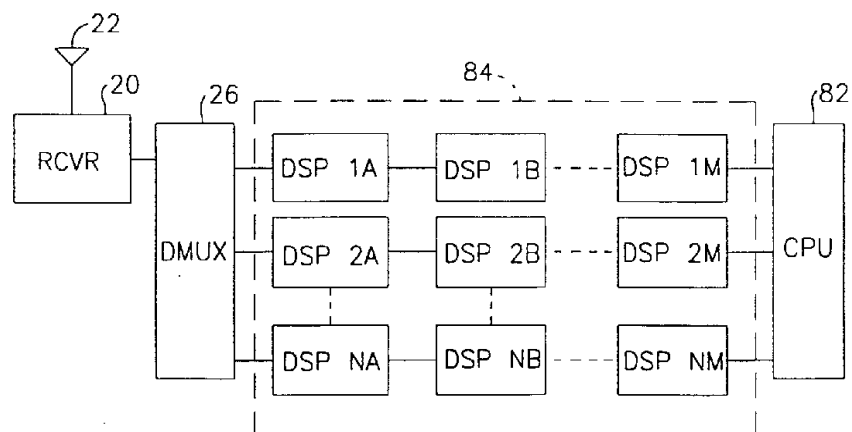


FIG. 7B

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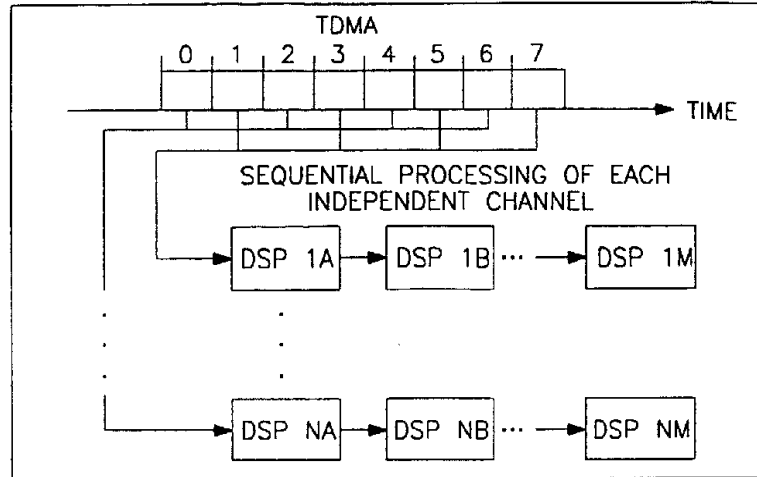


FIG. 8

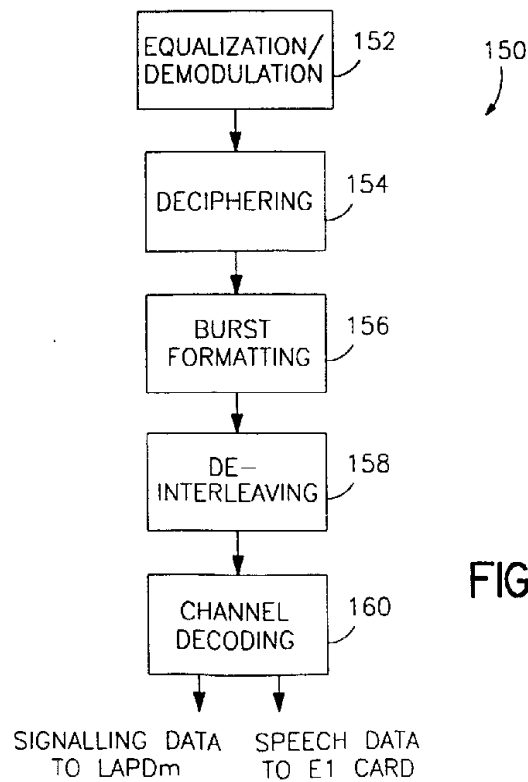


FIG. 9

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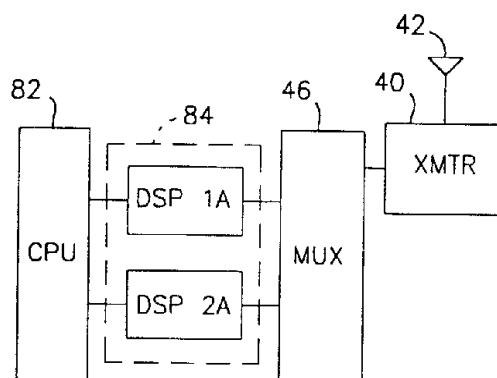


FIG. 10A

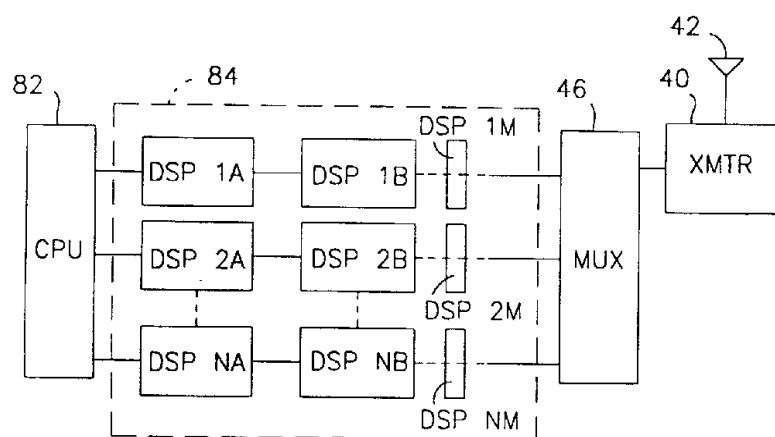


FIG. 10B

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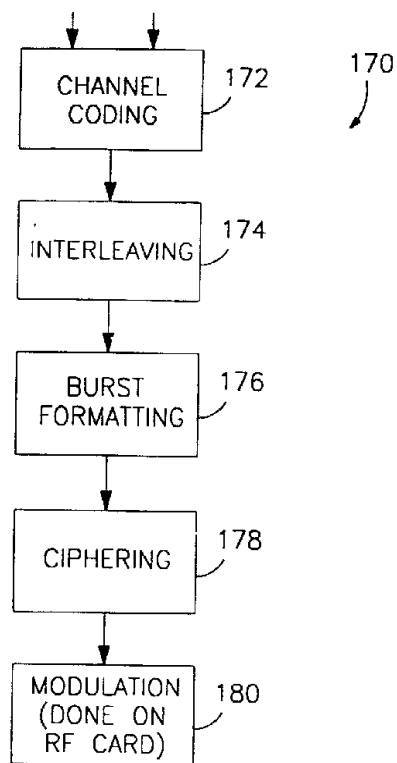
SIGNALLING DATA FROM LAPD_m SPEECH DATA FROM E1 CARD

FIG. 11

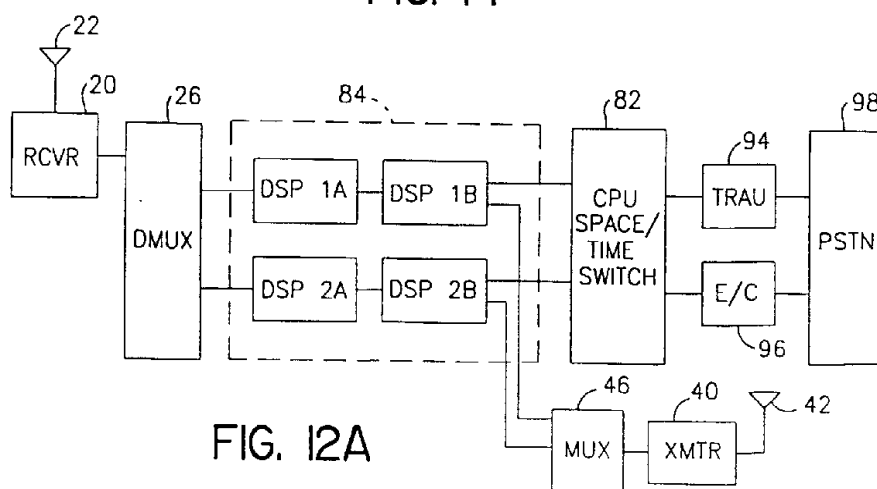


FIG. 12A

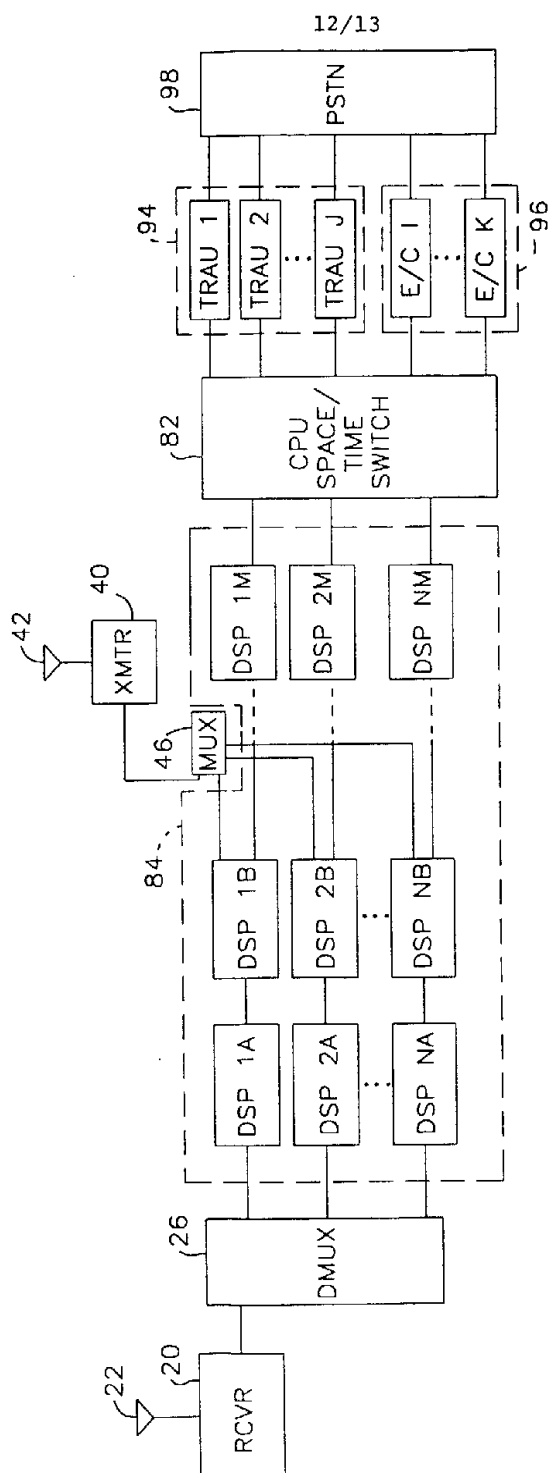


FIG. 12B

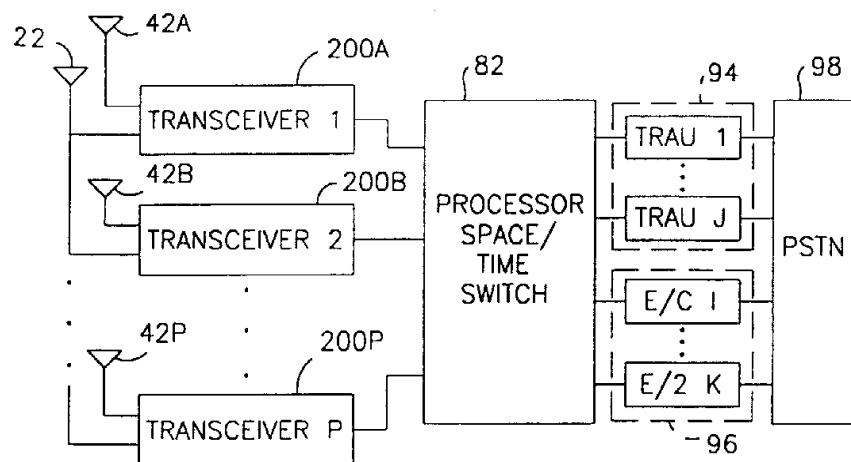


FIG. 13