US005642405A

United States Patent [19]

Fischer et al.

[11] Patent Number: 5,642,405

[45] Date of Patent: Jun. 24, 1997

[54] **CELLULAR COMMUNICATIONS SYSTEM WITH CENTRALIZED BASE STATIONS AND DISTRIBUTED ANTENNA UNITS**

[75] Inventors: **Larry G. Fischer; Philip M. Wala; Jeffrey Brennan**, all of Waseca, Minn.

[73] Assignee: **ADC Telecommunications, Inc.**, Bloomington, Minn.

[21] Appl. No.: **298,652**

[22] Filed: **Aug. 31, 1994**

Related U.S. Application Data

[60] Division of Ser. No. 204,660, Mar. 2, 1994, Pat. No. 5,627,879, which is a continuation-in-part of Ser. No. 183,221, Jan. 14, 1994, abandoned, which is a continuation-in-part of Ser. No. 68,389, May 28, 1993, abandoned, which is a continuation-in-part of Ser. No. 946,402, Sep. 17, 1992, abandoned, Ser. No. 946,964, Sep. 17, 1992, abandoned, Ser. No. 946,931, Sep. 17, 1992, abandoned, and Ser. No. 946,548, Sep. 17, 1992, abandoned.

[51] **Int. Cl.**[6] **H04Q 7/22**

[52] **U.S. Cl.** **379/60**; 379/59; 455/33.1; 455/33.2; 455/33.3; 455/33.4

[58] **Field of Search** 379/58, 59, 60, 379/63; 455/33.1, 33.2, 54.1, 54.2, 56.1, 33.4

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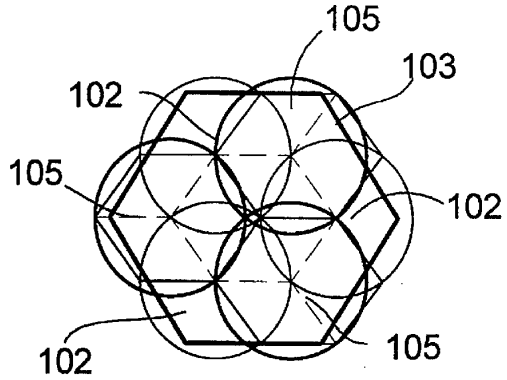
Primary Examiner—Curtis Kuntz
Assistant Examiner—G. J. Oehling
Attorney, Agent, or Firm—Schwegman, Lundberg, Woessner & Kluth, P.A.

[57] **ABSTRACT**

A microcellular communications network includes a plurality of base station units and corresponding antenna units. Each includes either conventional transmitters and receivers or all digital transmitter and receiver equipment, and interface circuitry to a mobile telecommunications switching office. The microcell traffic output is applied to a frame generator/multiplexer. The output of the frame generator/multiplexer is applied to a digitally modulated laser and conveyed by fiber to a remote antenna unit, which demultiplexes the microcell traffic signal, applies it to a digital-to-analog converter, and applies it to a power amplifier and a main antenna. The received signals are filtered, digitized, multiplexed together and transmitted over the optical fiber back to the base station. The strongest signal is selected for use. Deployment of an all digital microcellular communications system occurs in two stages. Digital filtering of the digitized RF signal is also provided, and a digital passive handoff system provides for an FFT analysis of all traffic in the cell and passive switching in response thereto.

3 Claims, 58 Drawing Sheets



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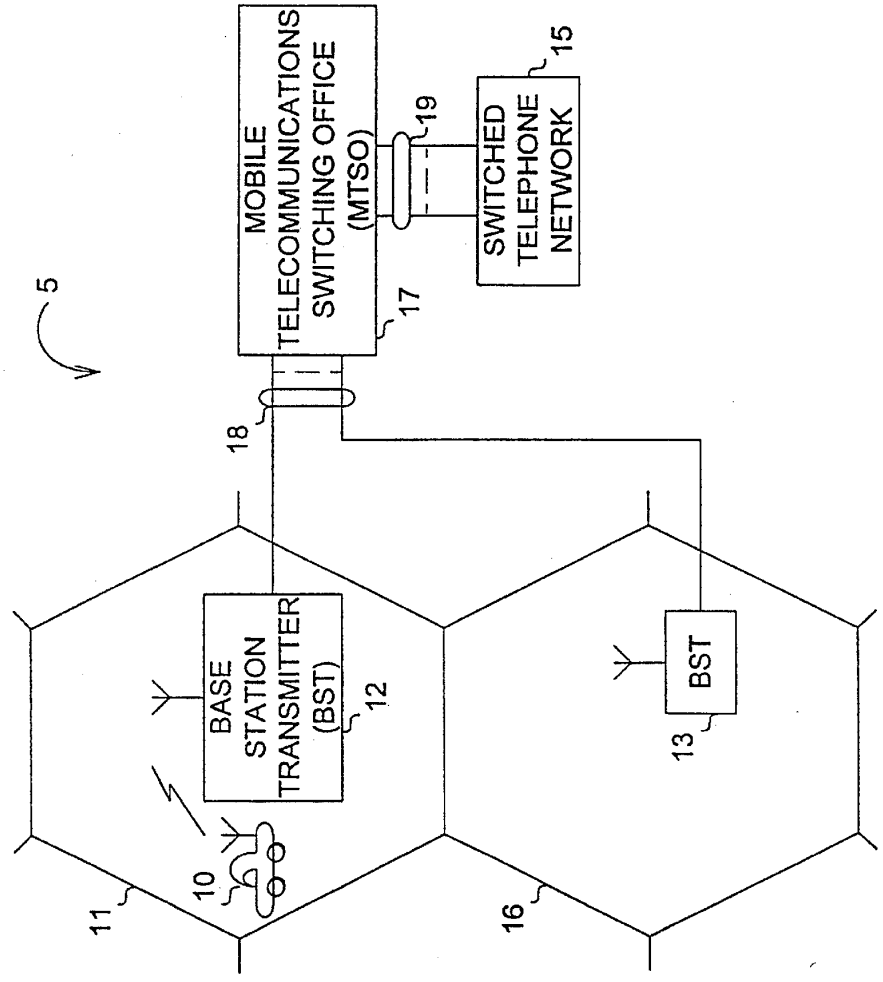

Figure 1A
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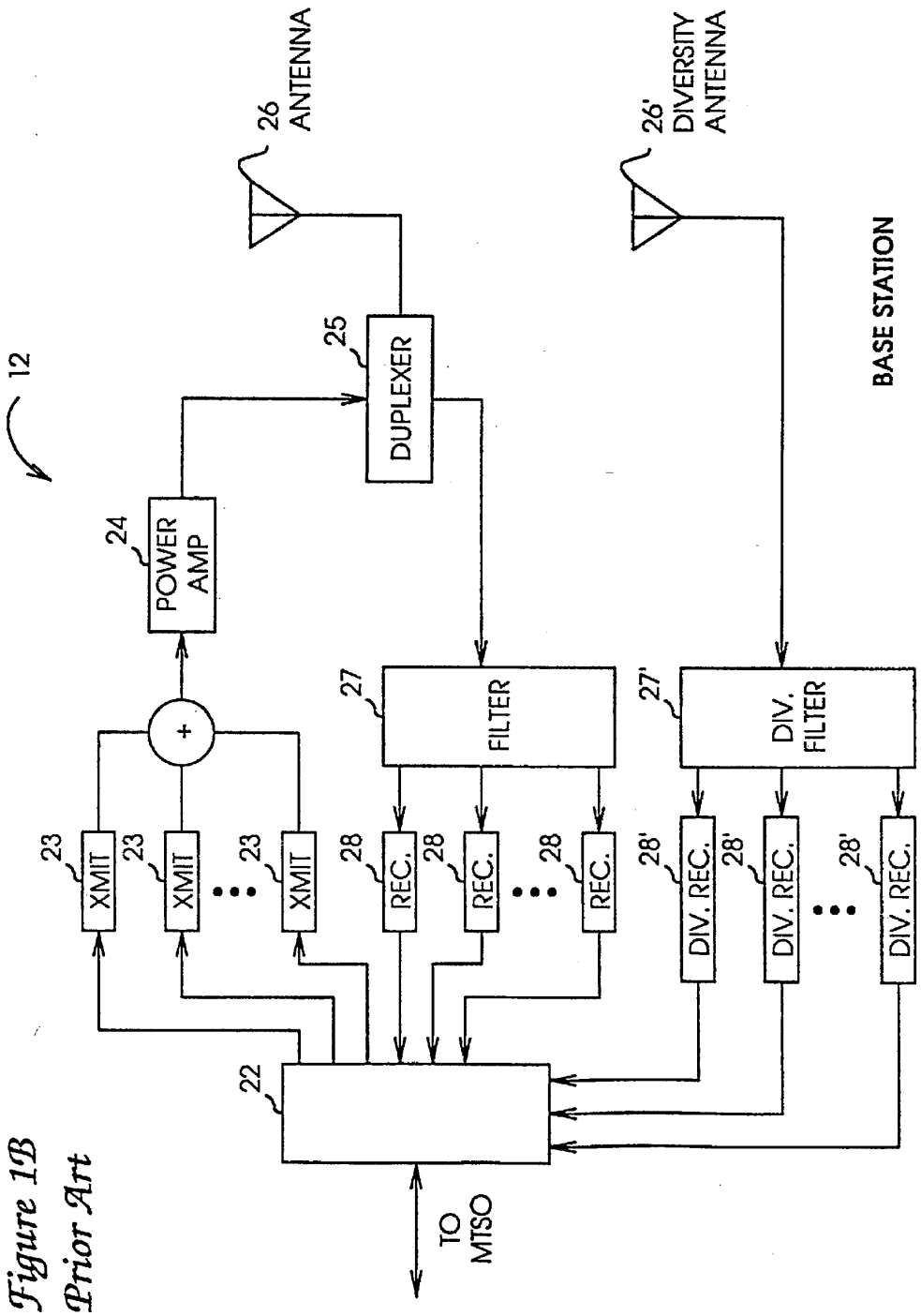

Figure 1B Prior Art

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Figure 1C
Prior Art

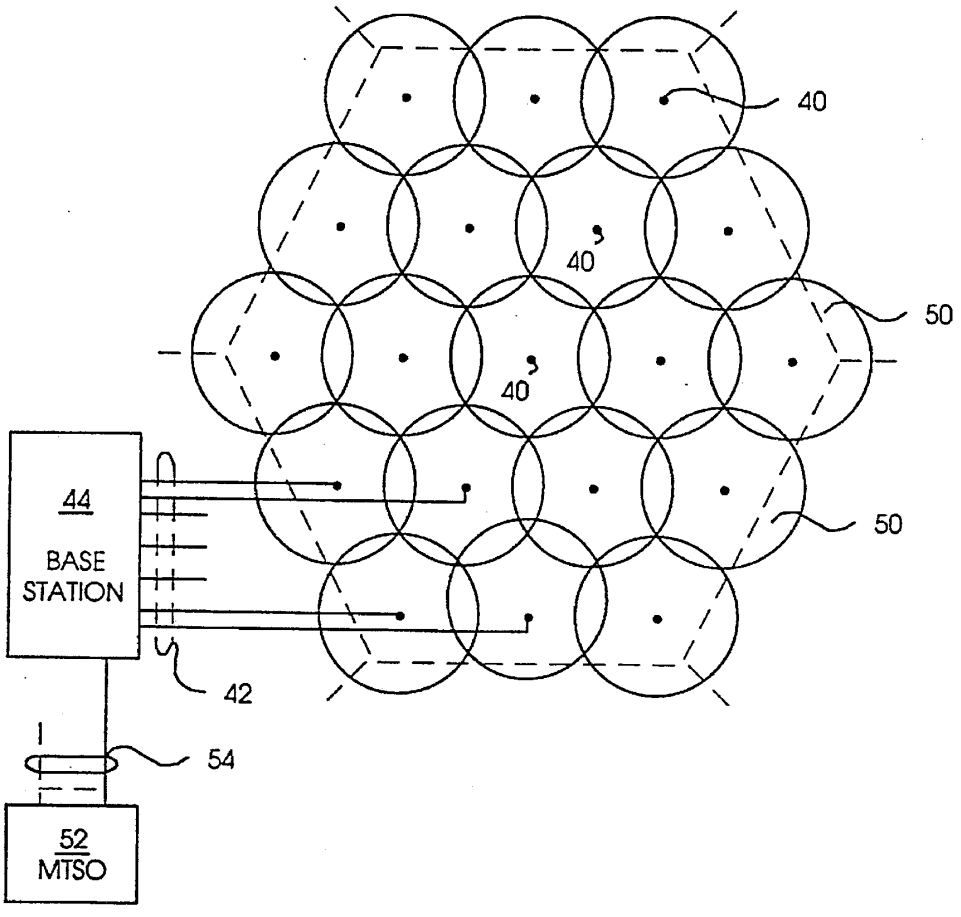

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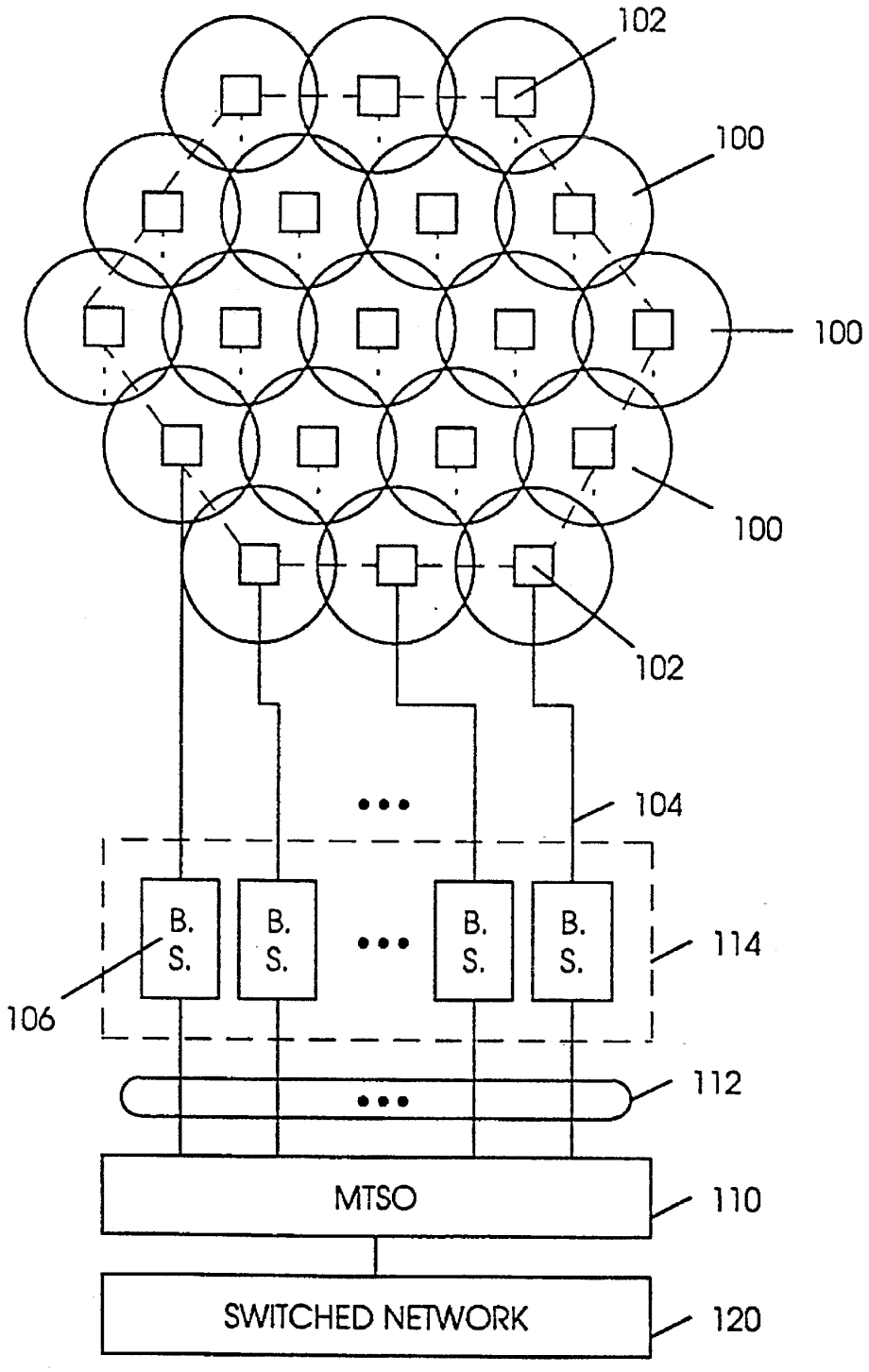
Figure 2



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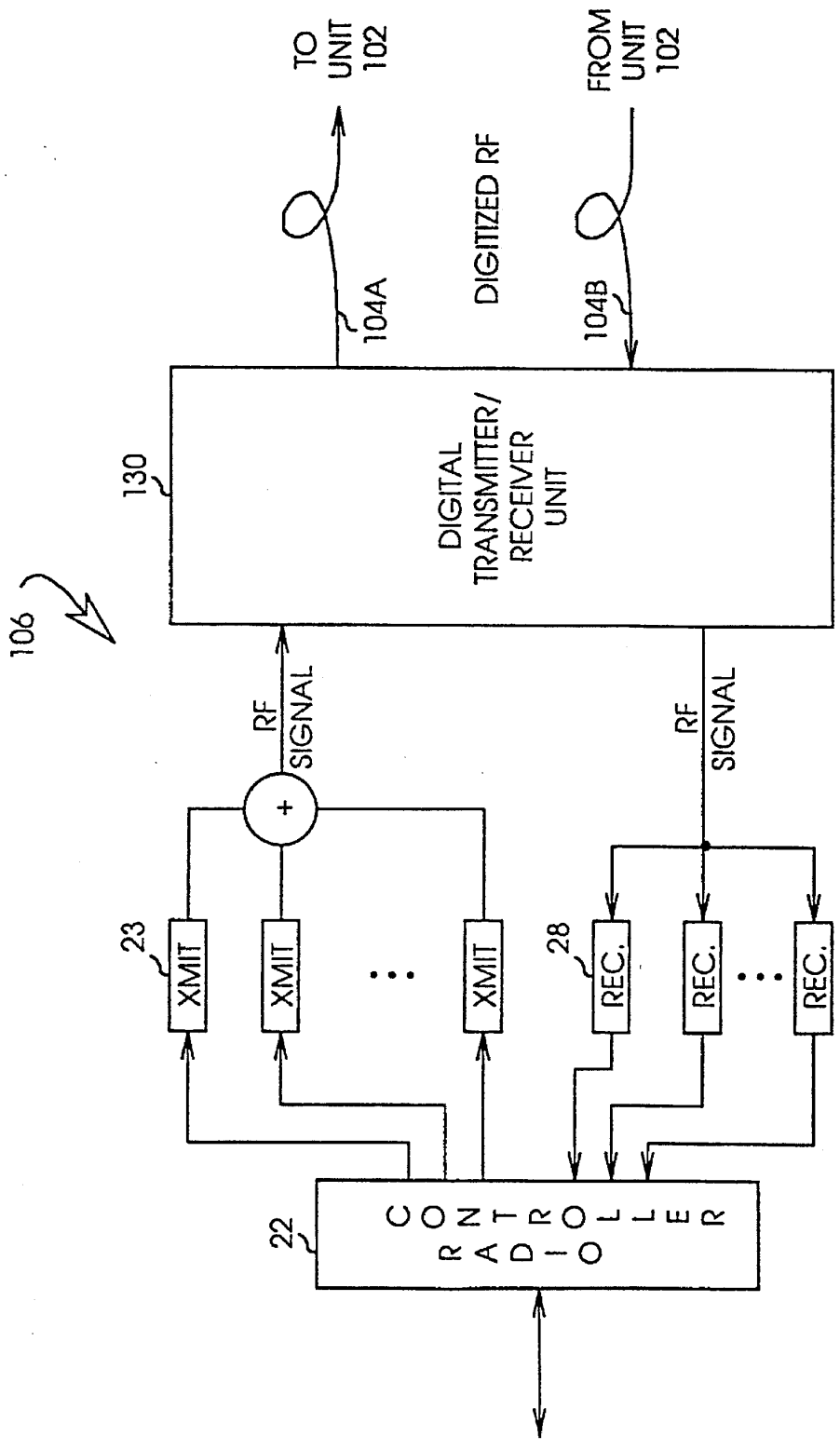

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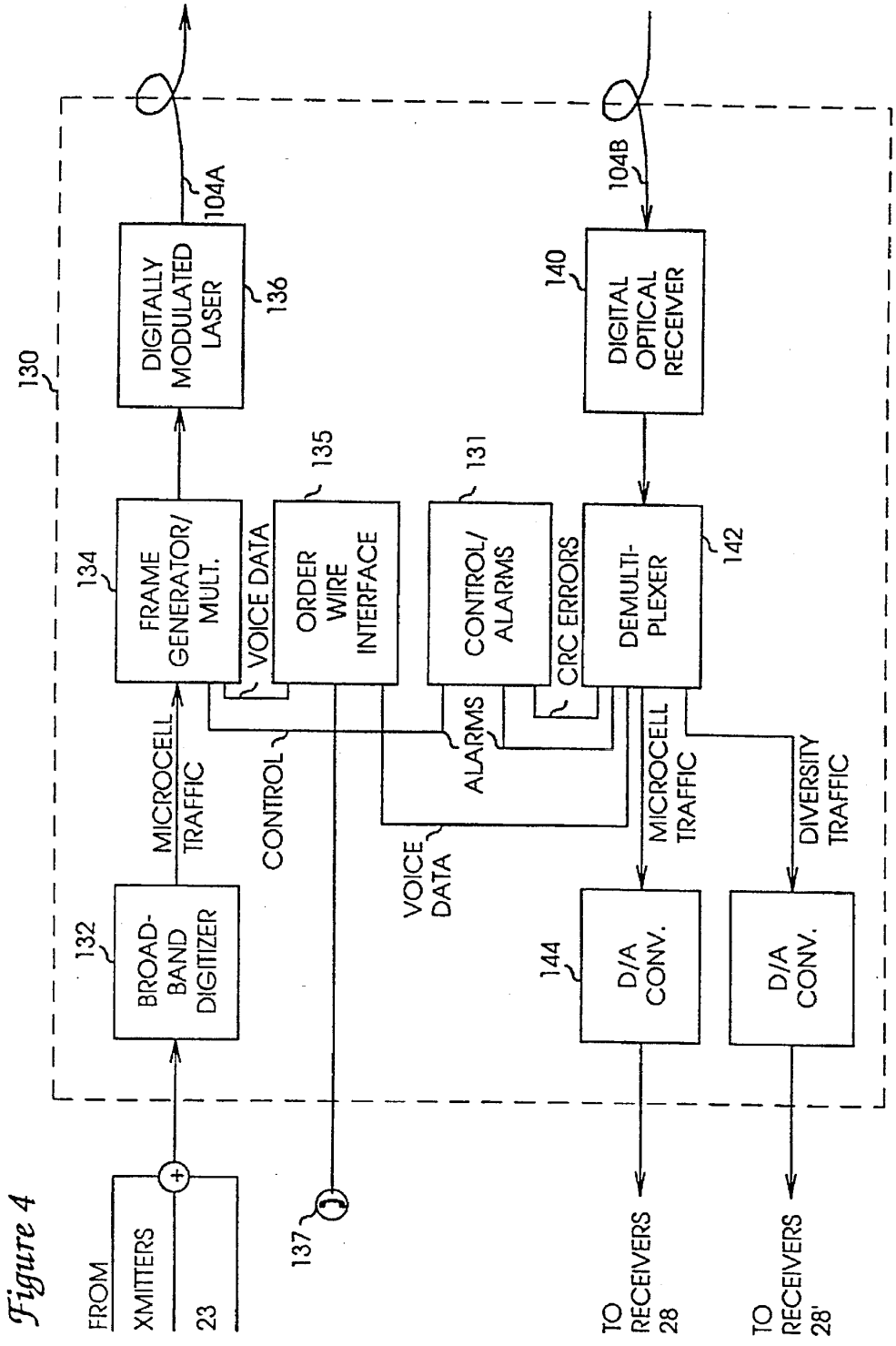

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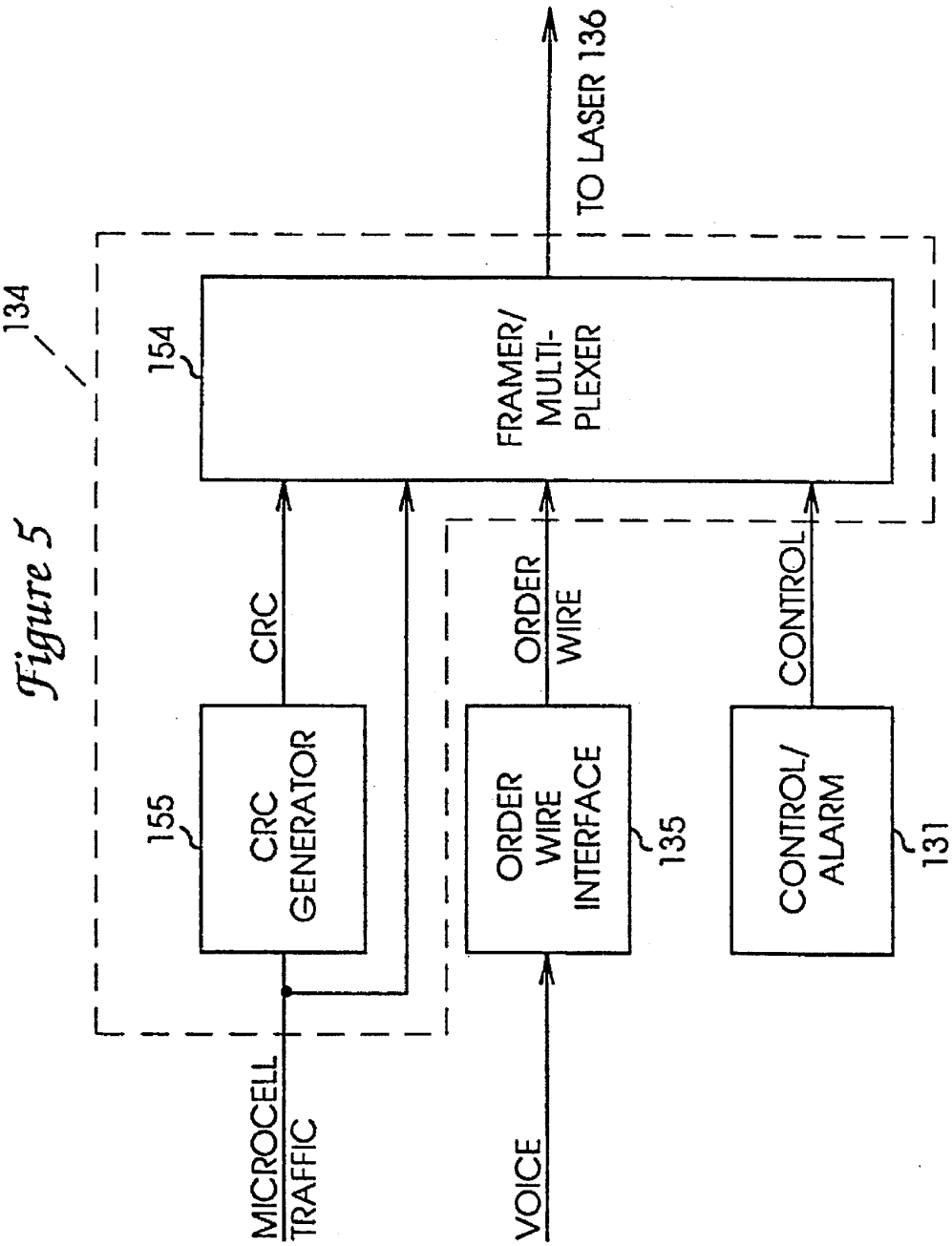

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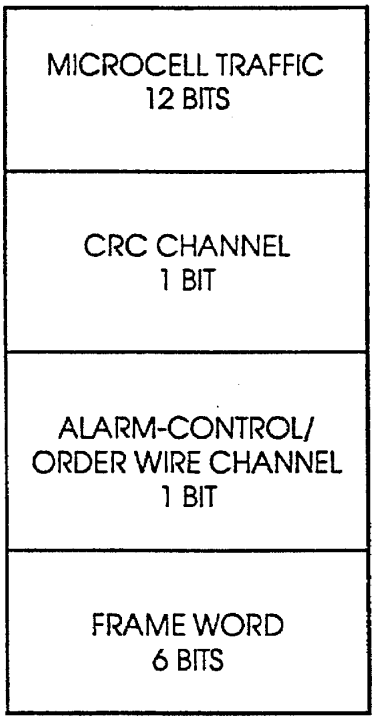

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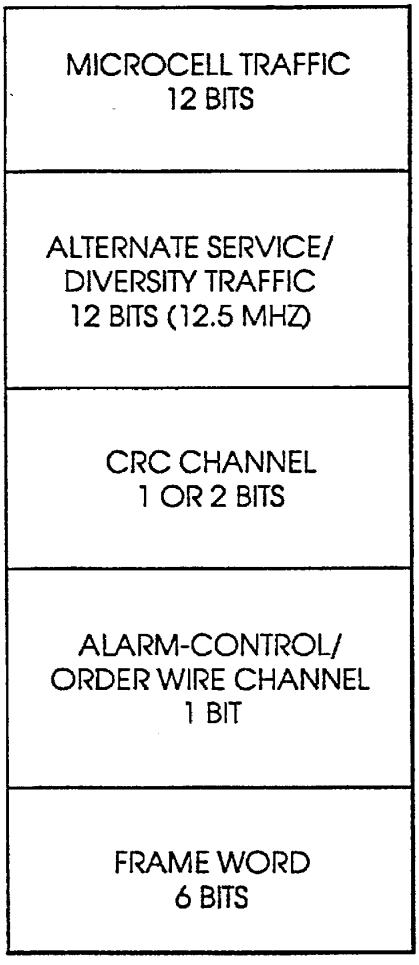

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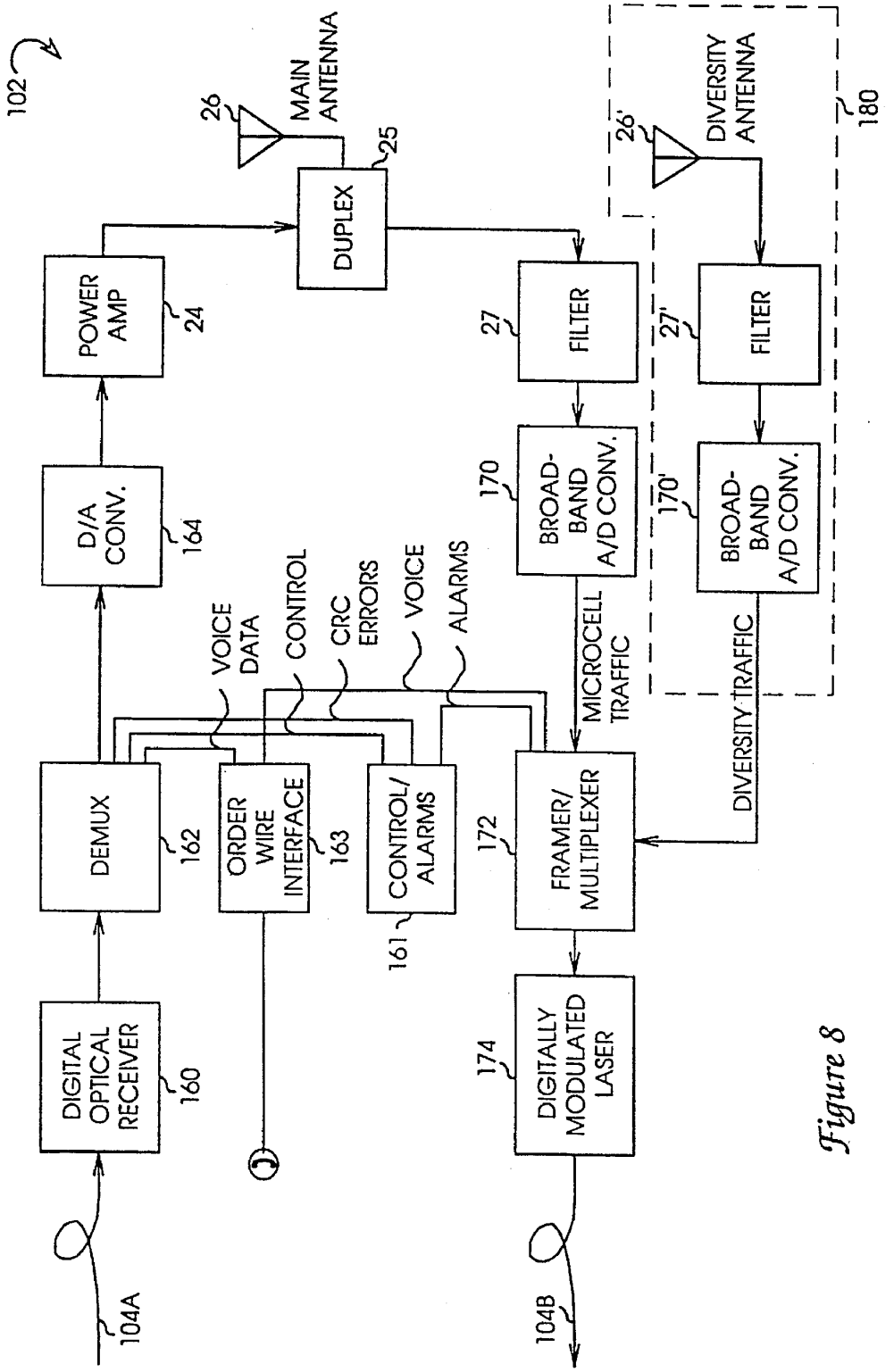

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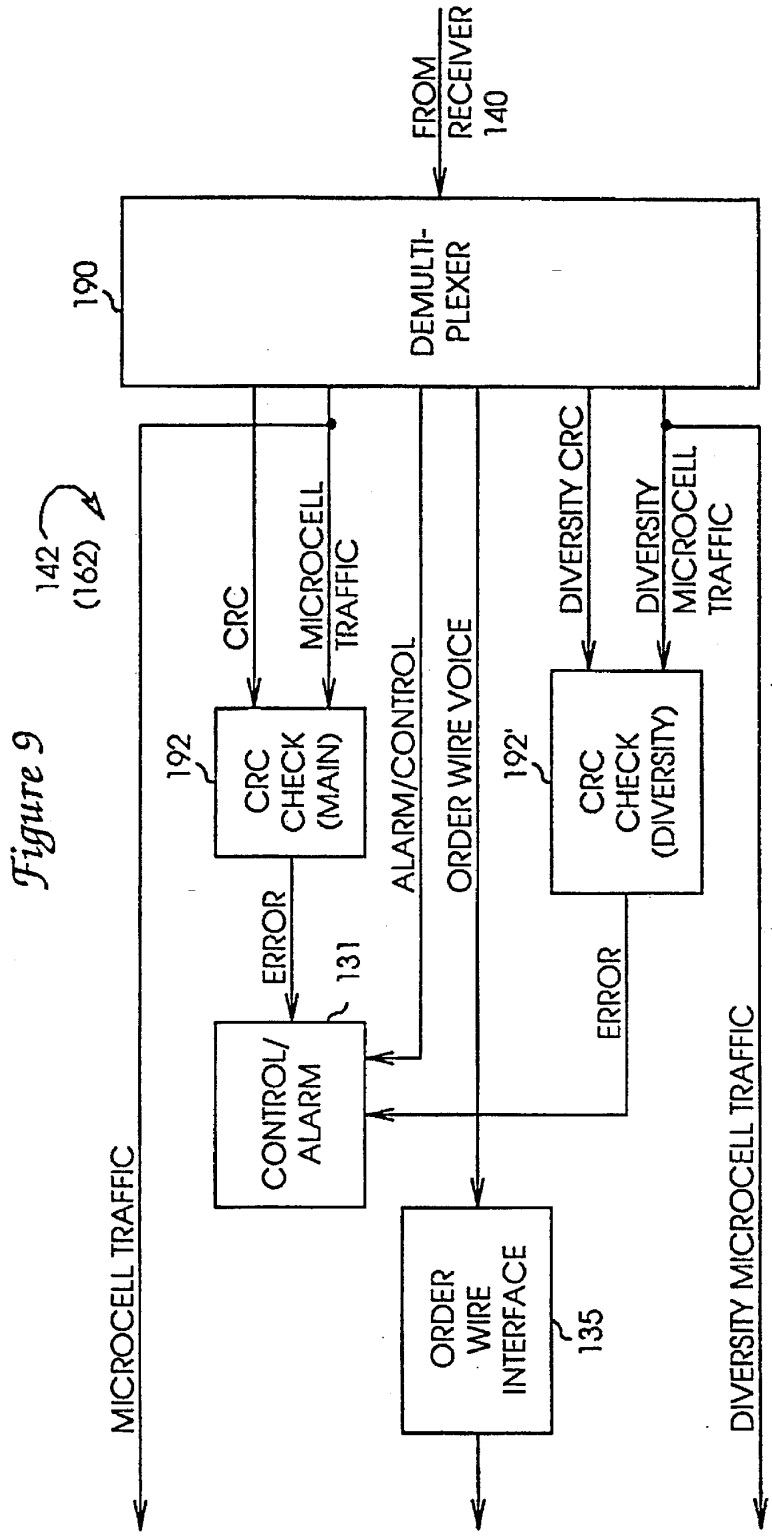

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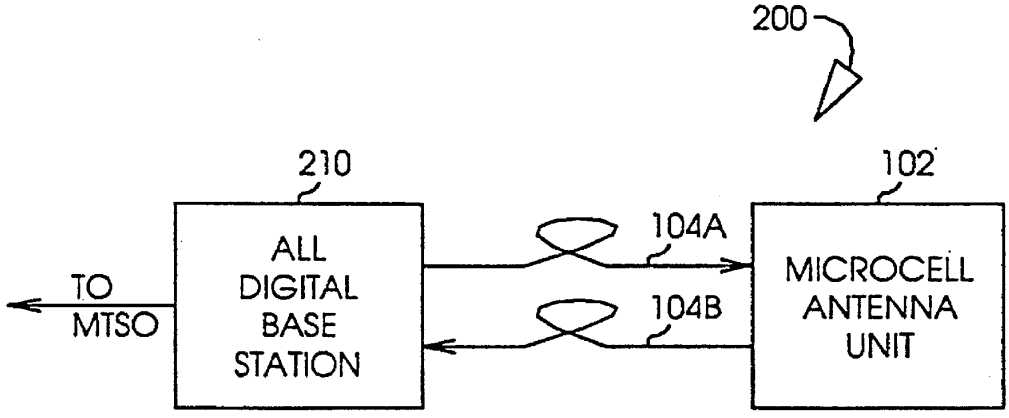
Figure 10



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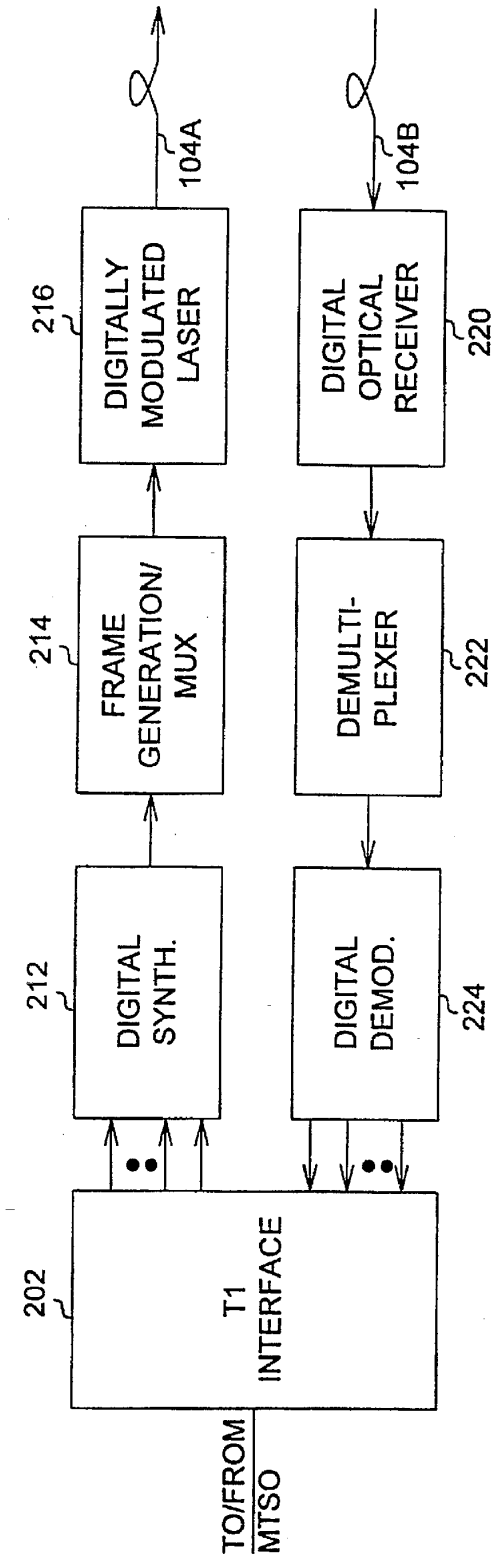

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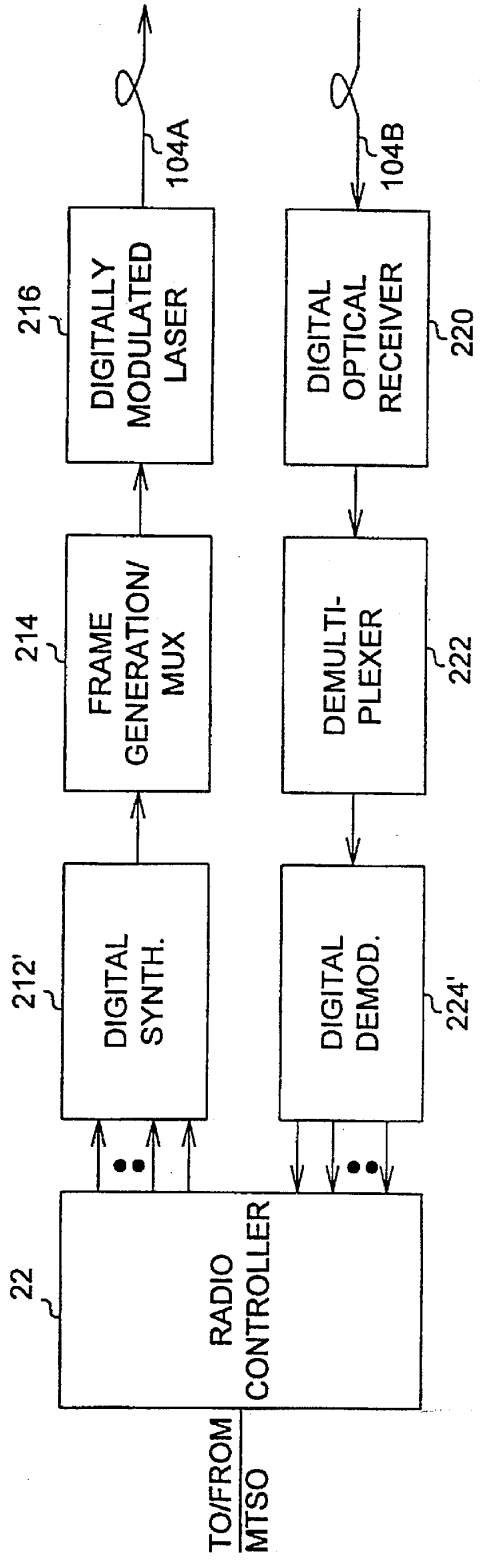

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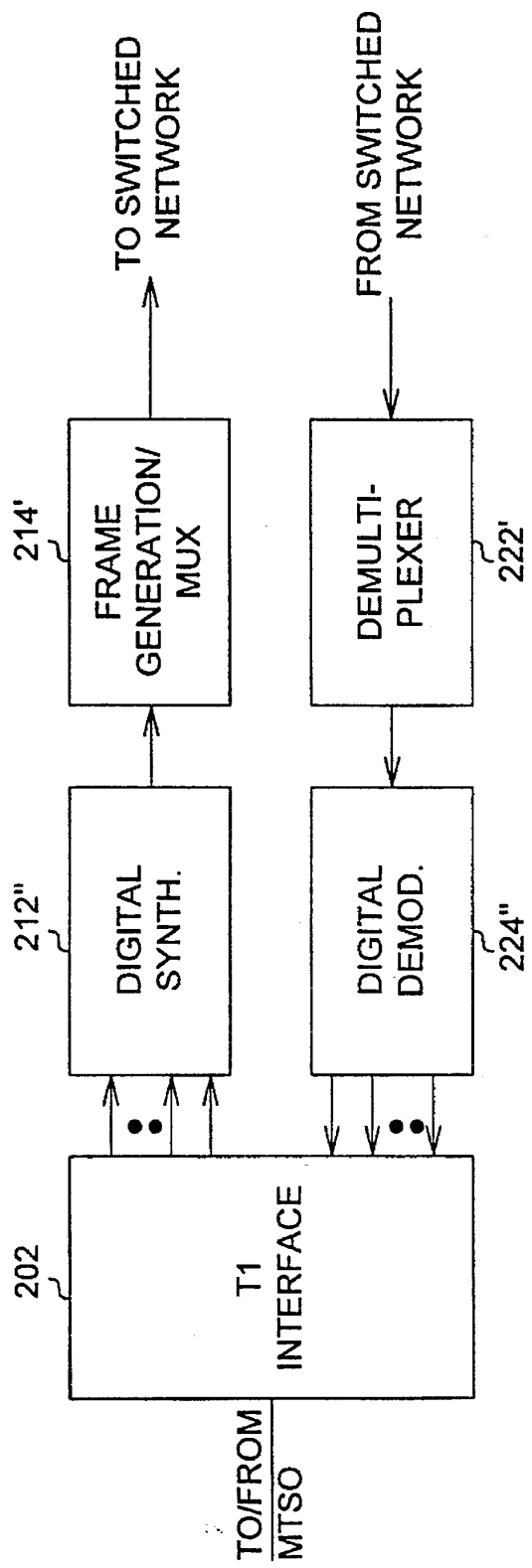

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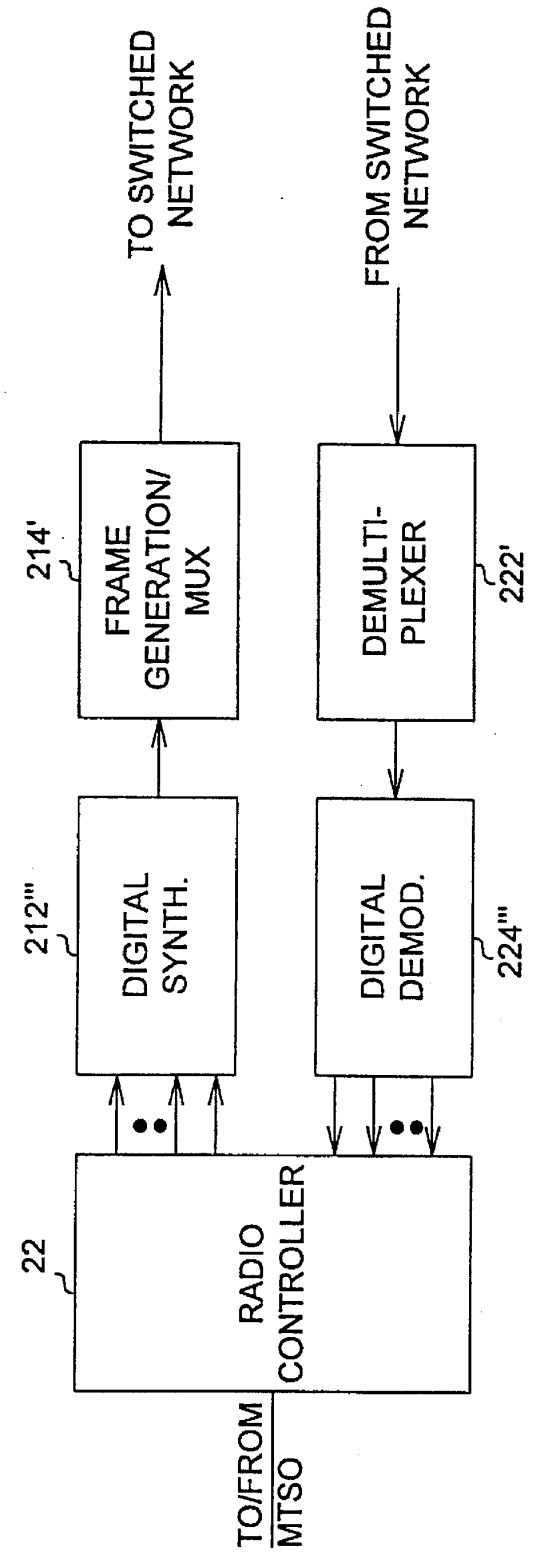

Figure 11D

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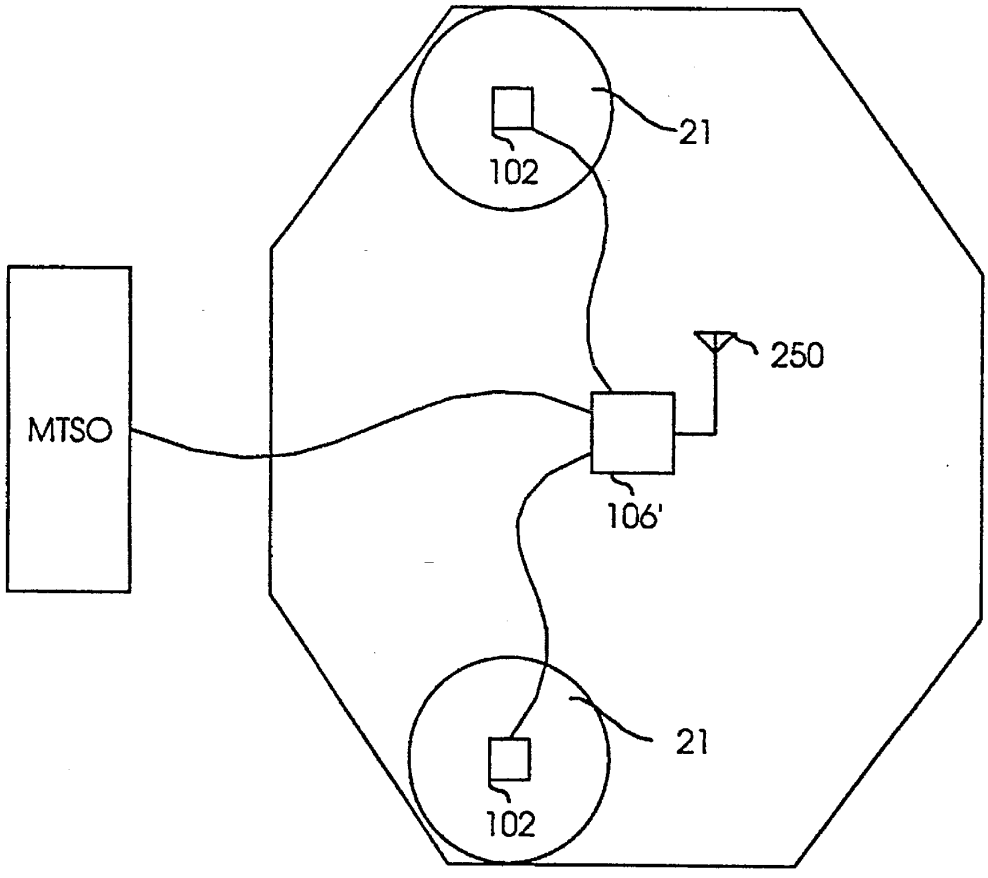
Figure 12



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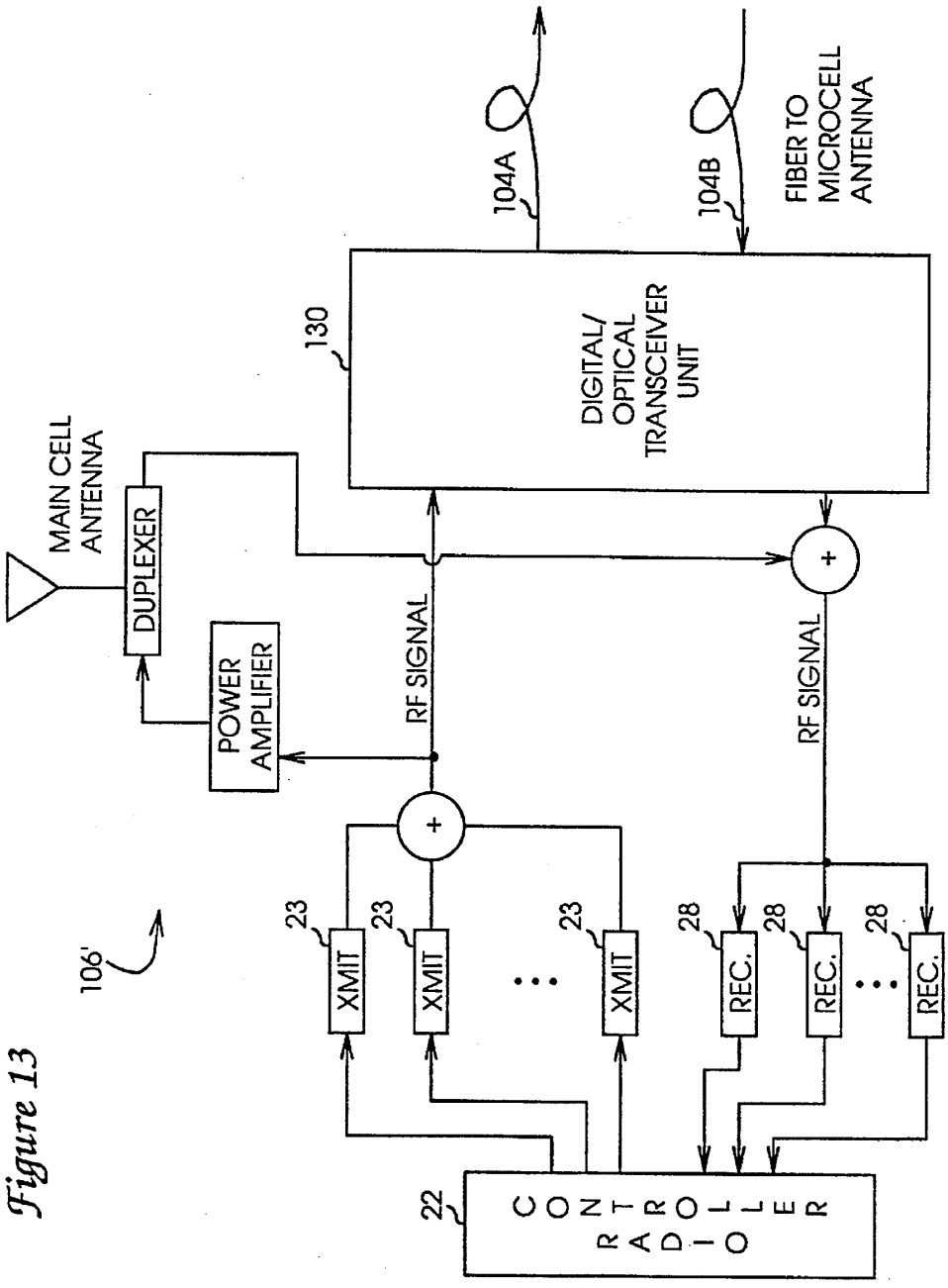

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Figure 14

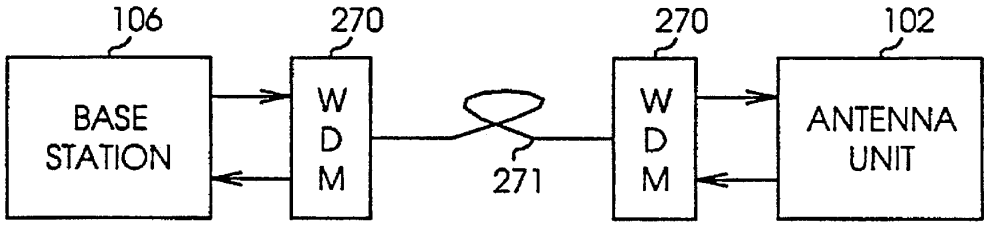

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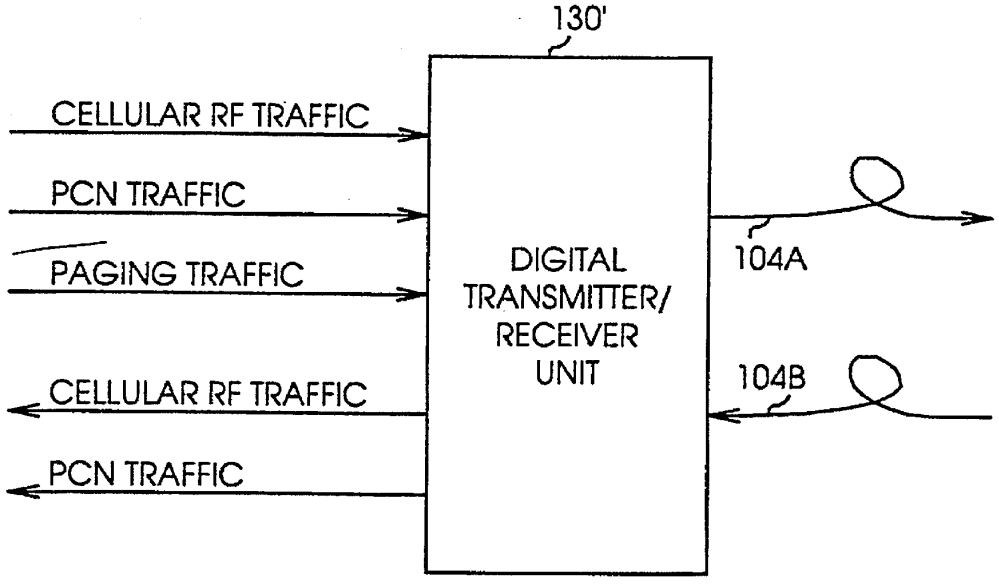
Figure 15



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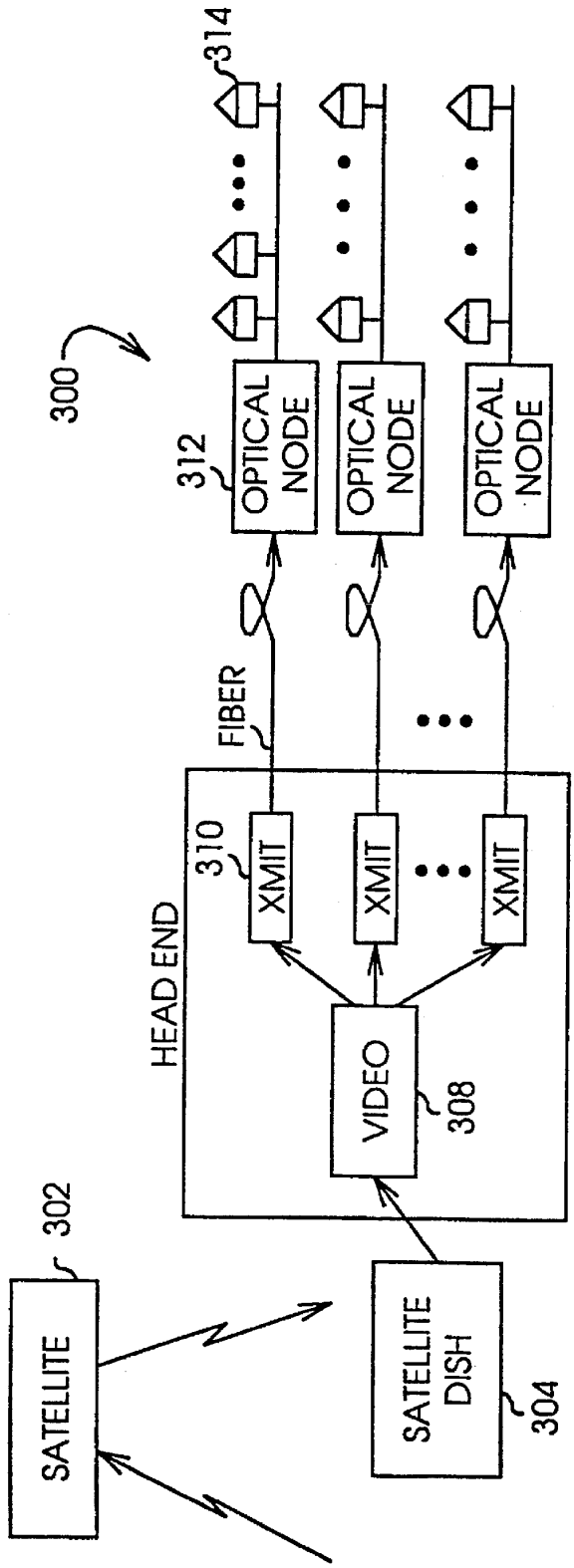

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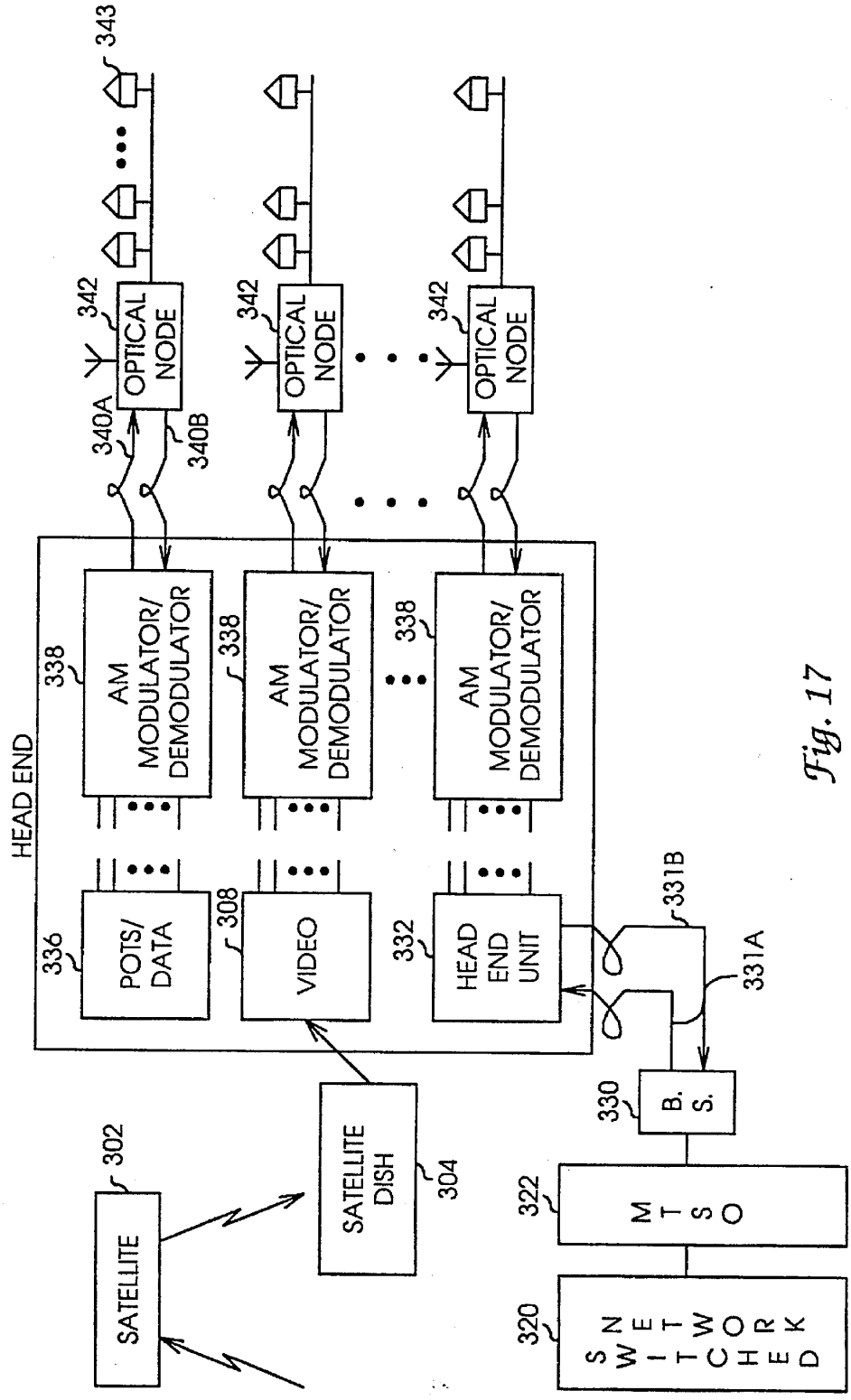

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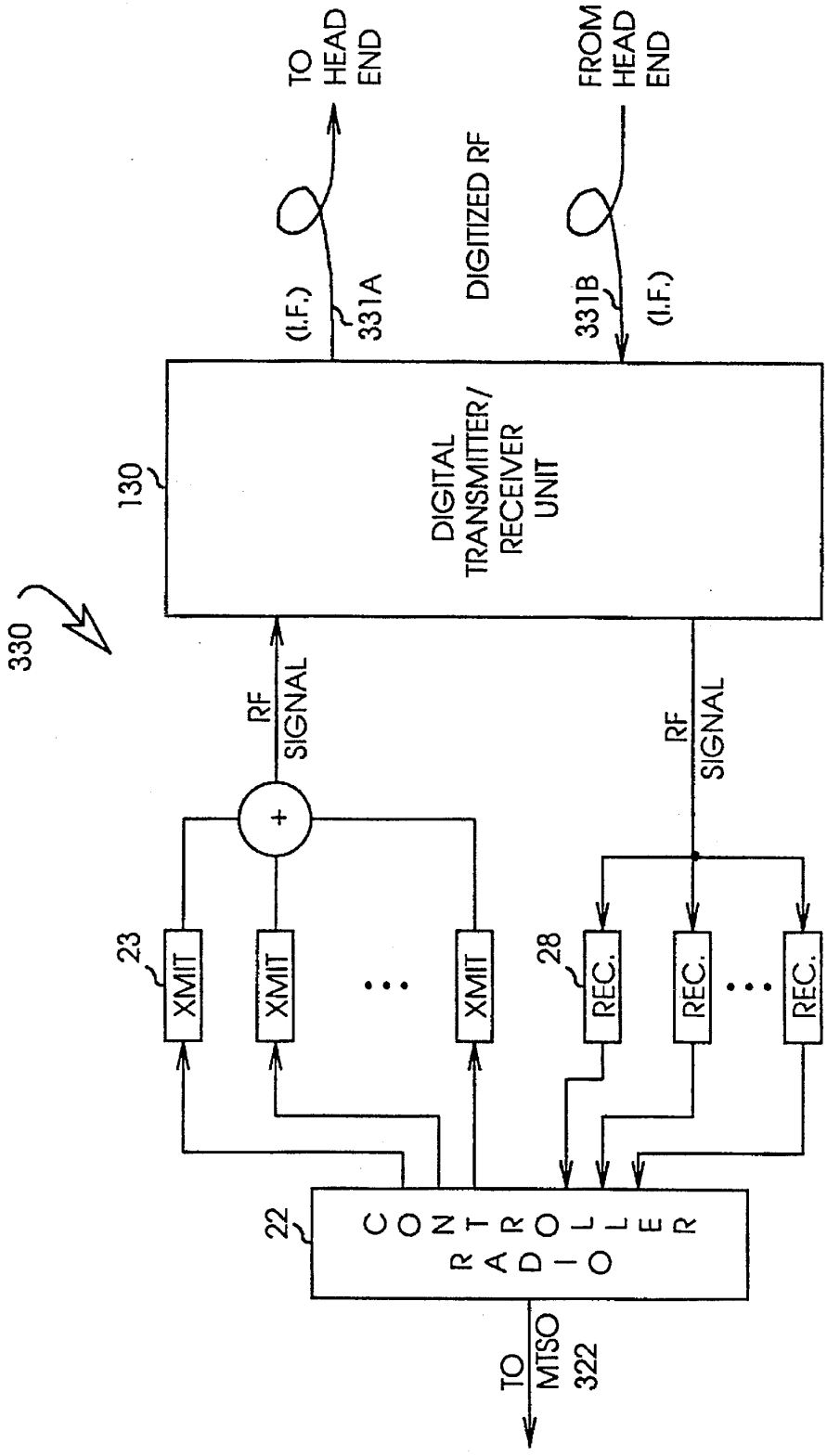

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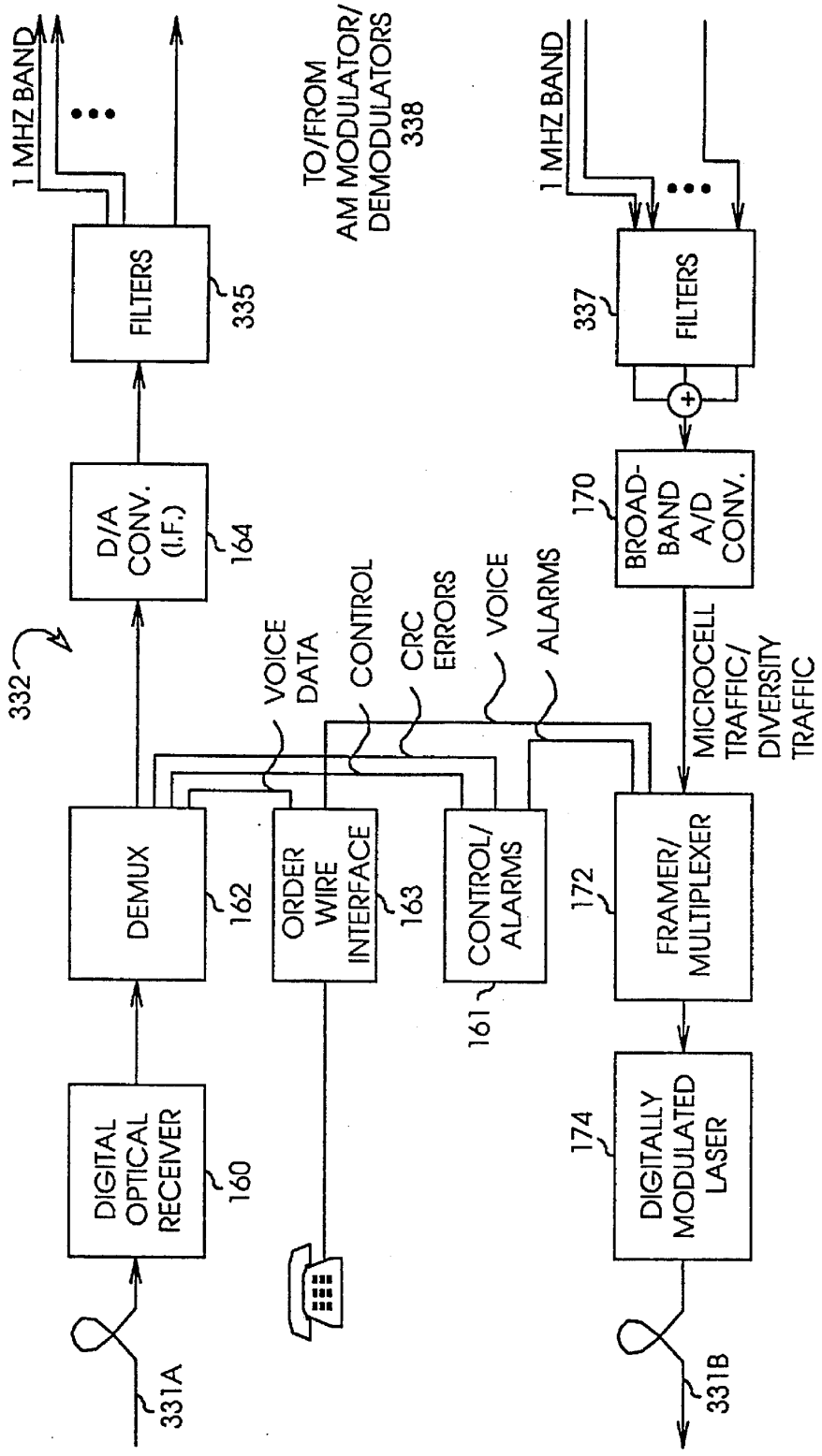

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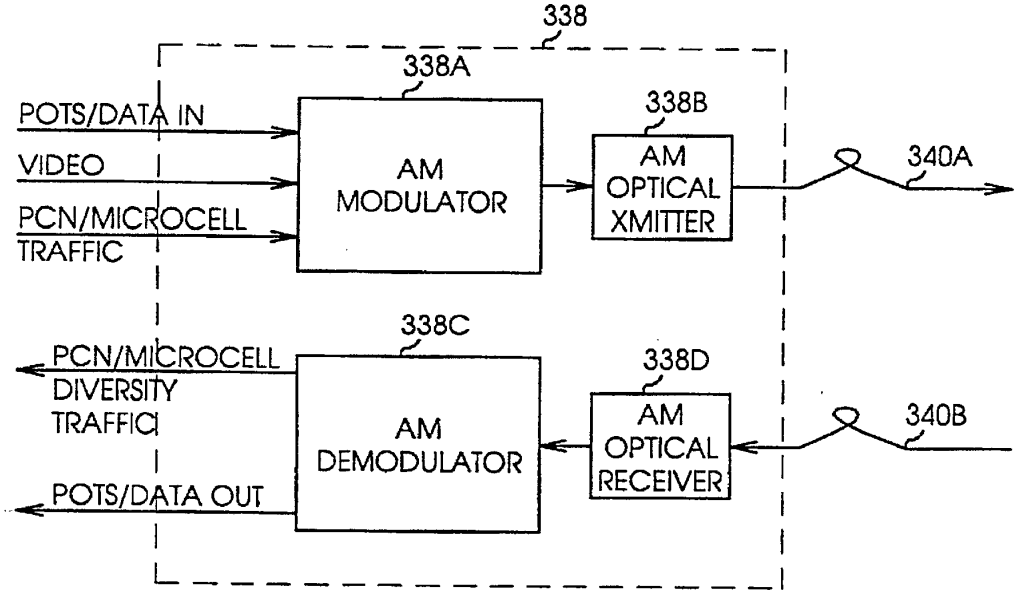

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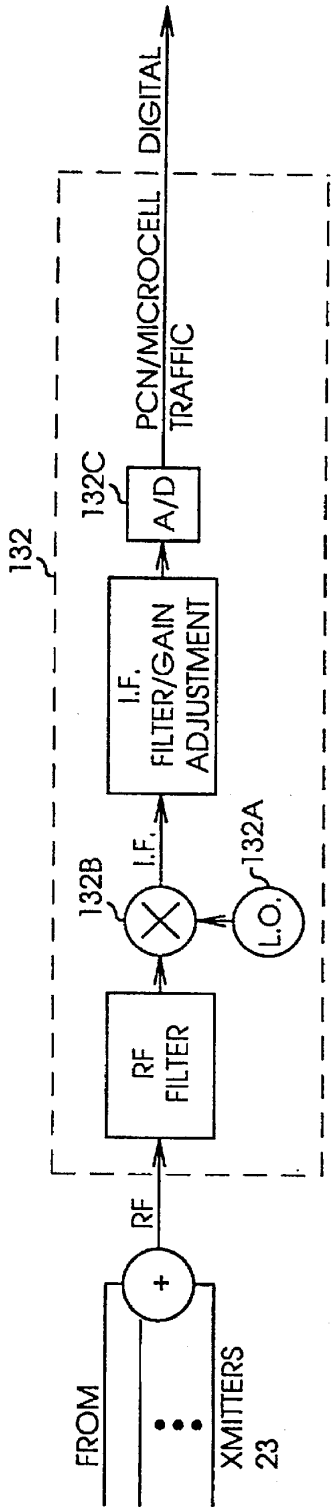

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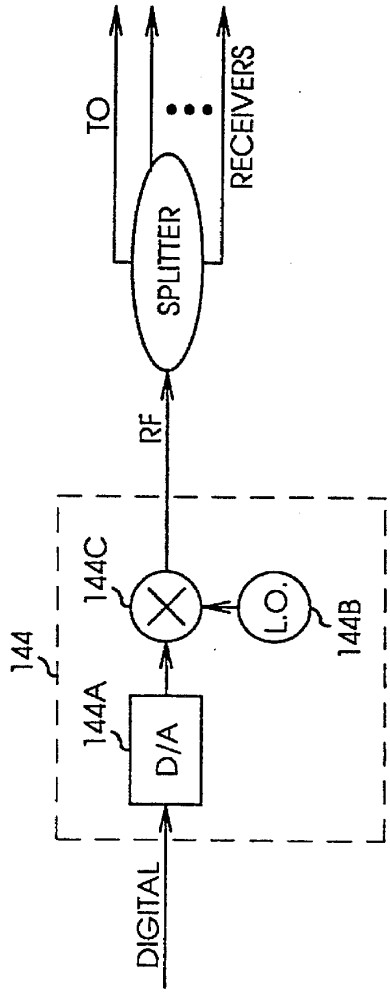

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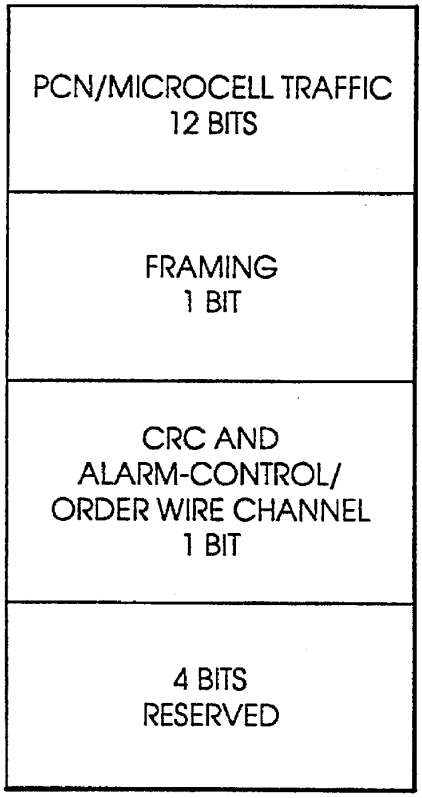

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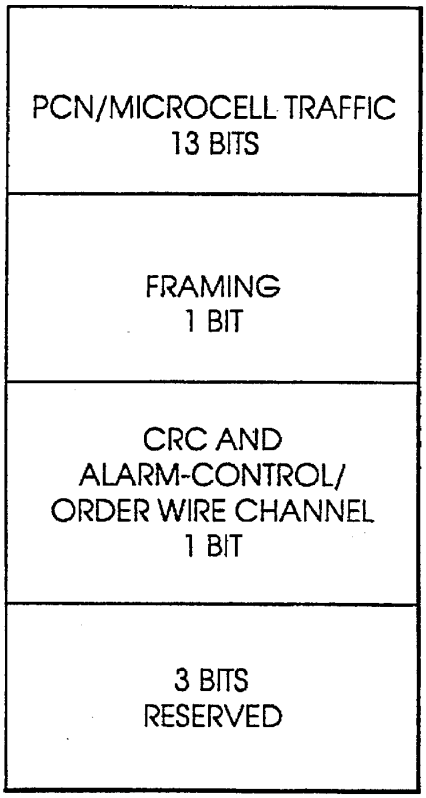

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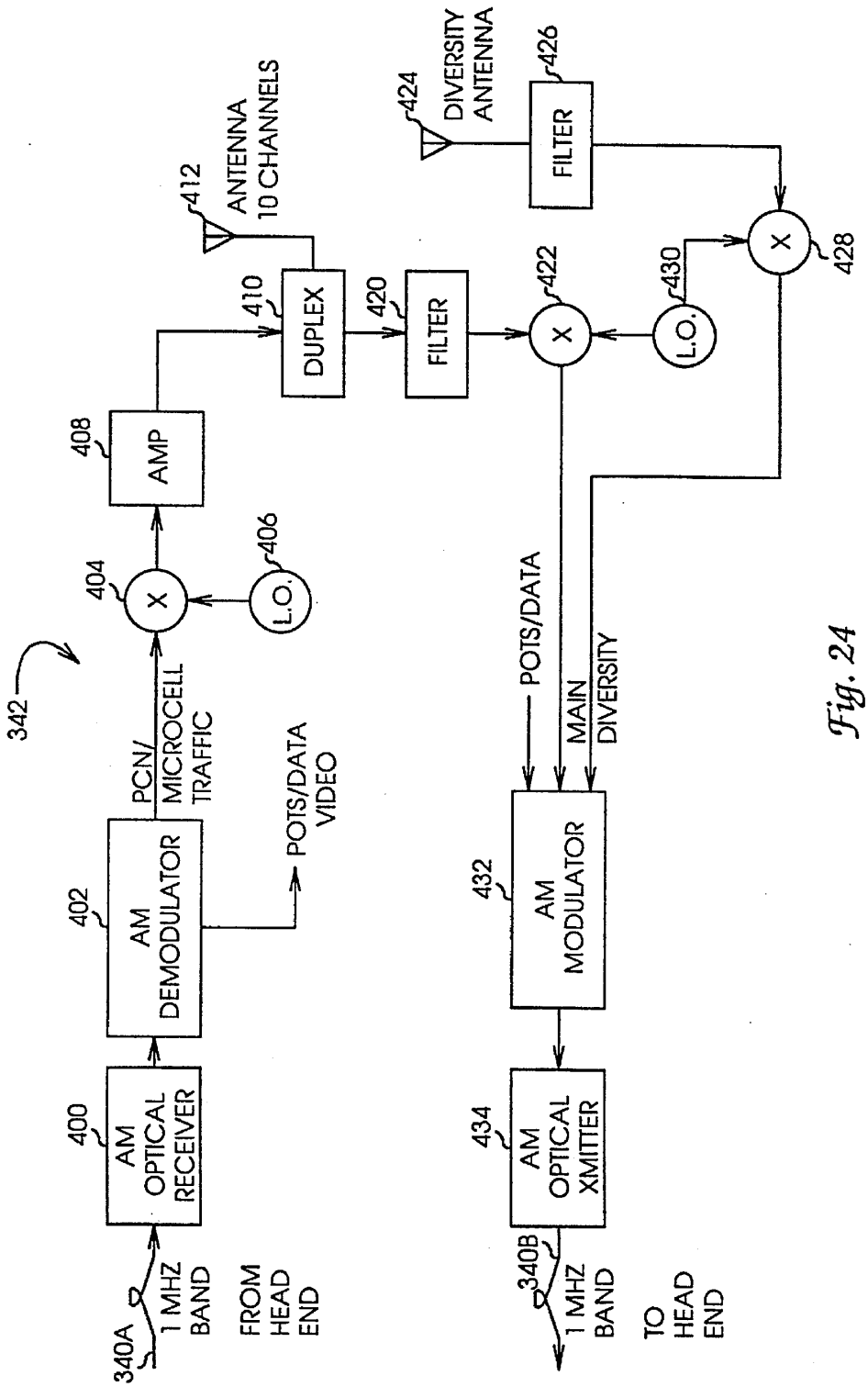

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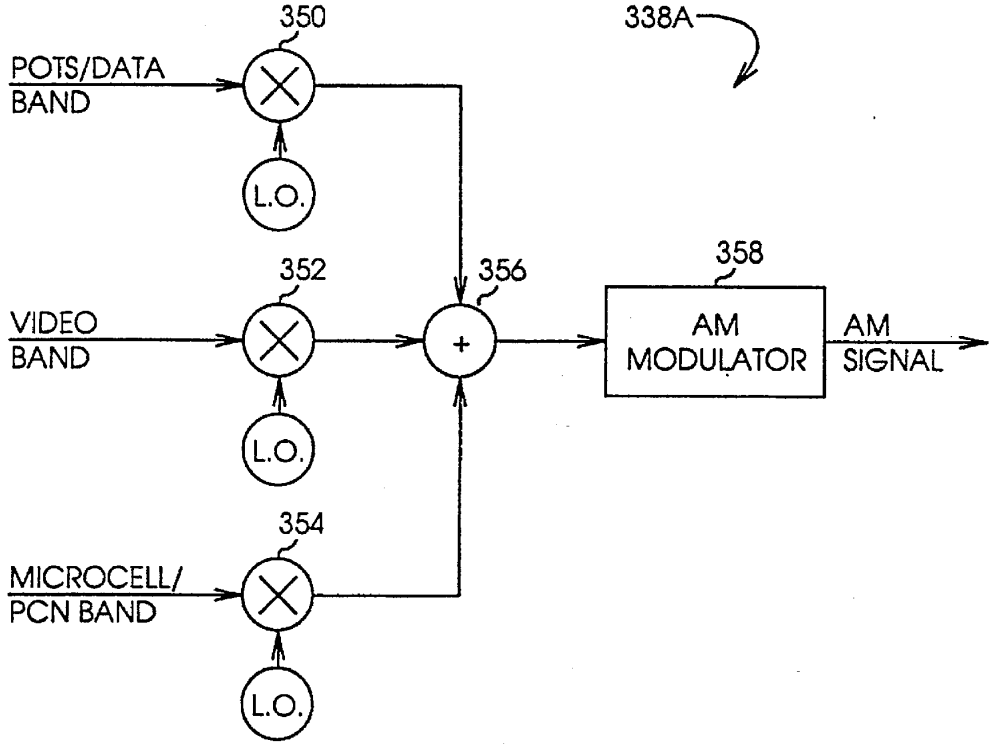

AM Modulator

Fig. 25

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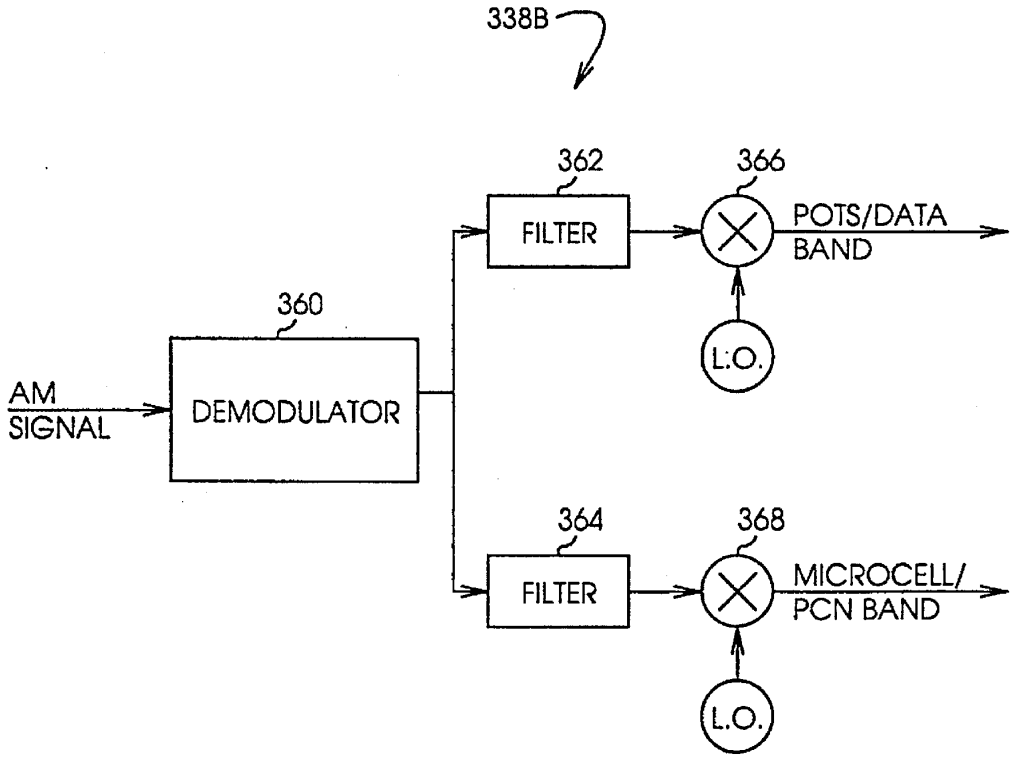

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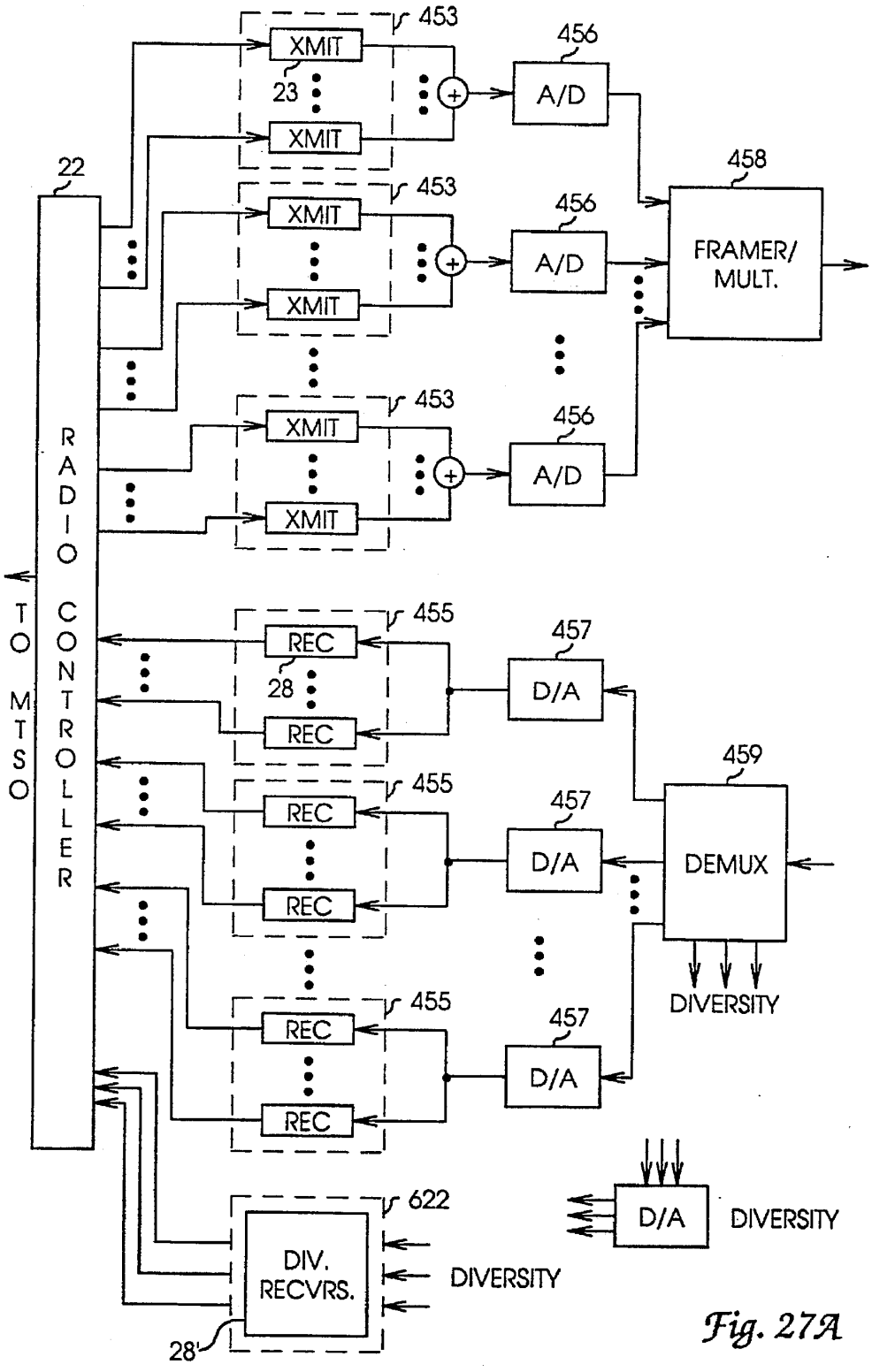

Fig. 27A

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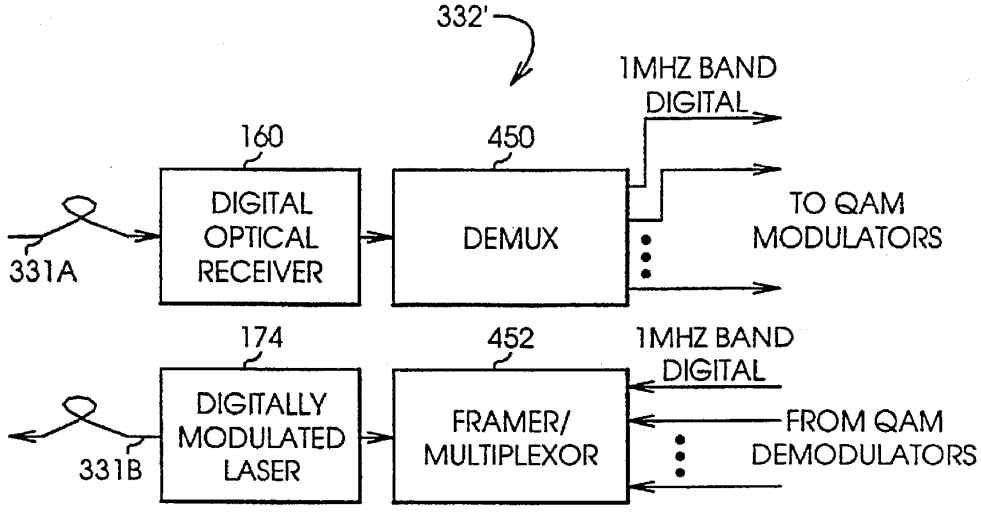

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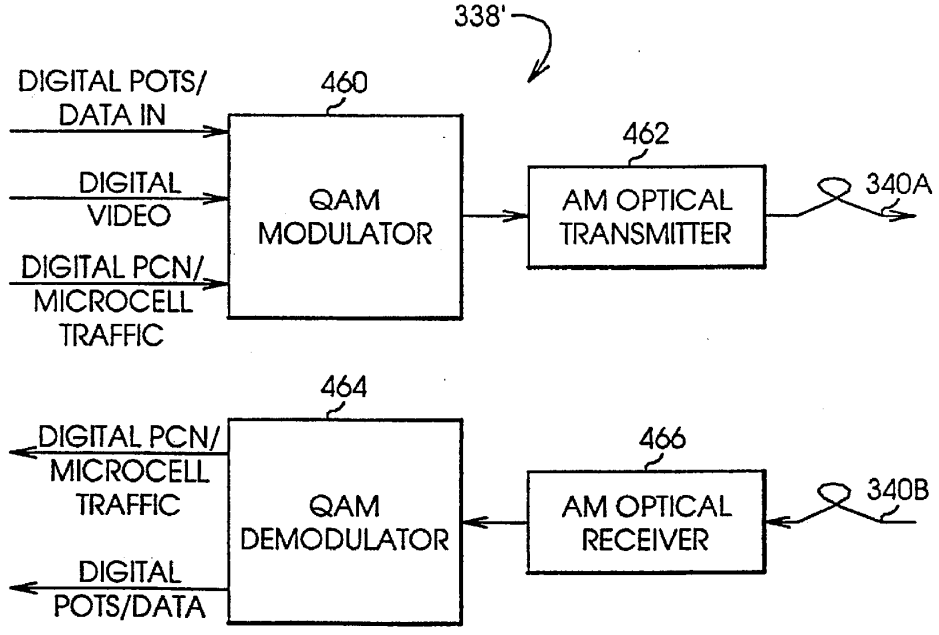

Fig. 28

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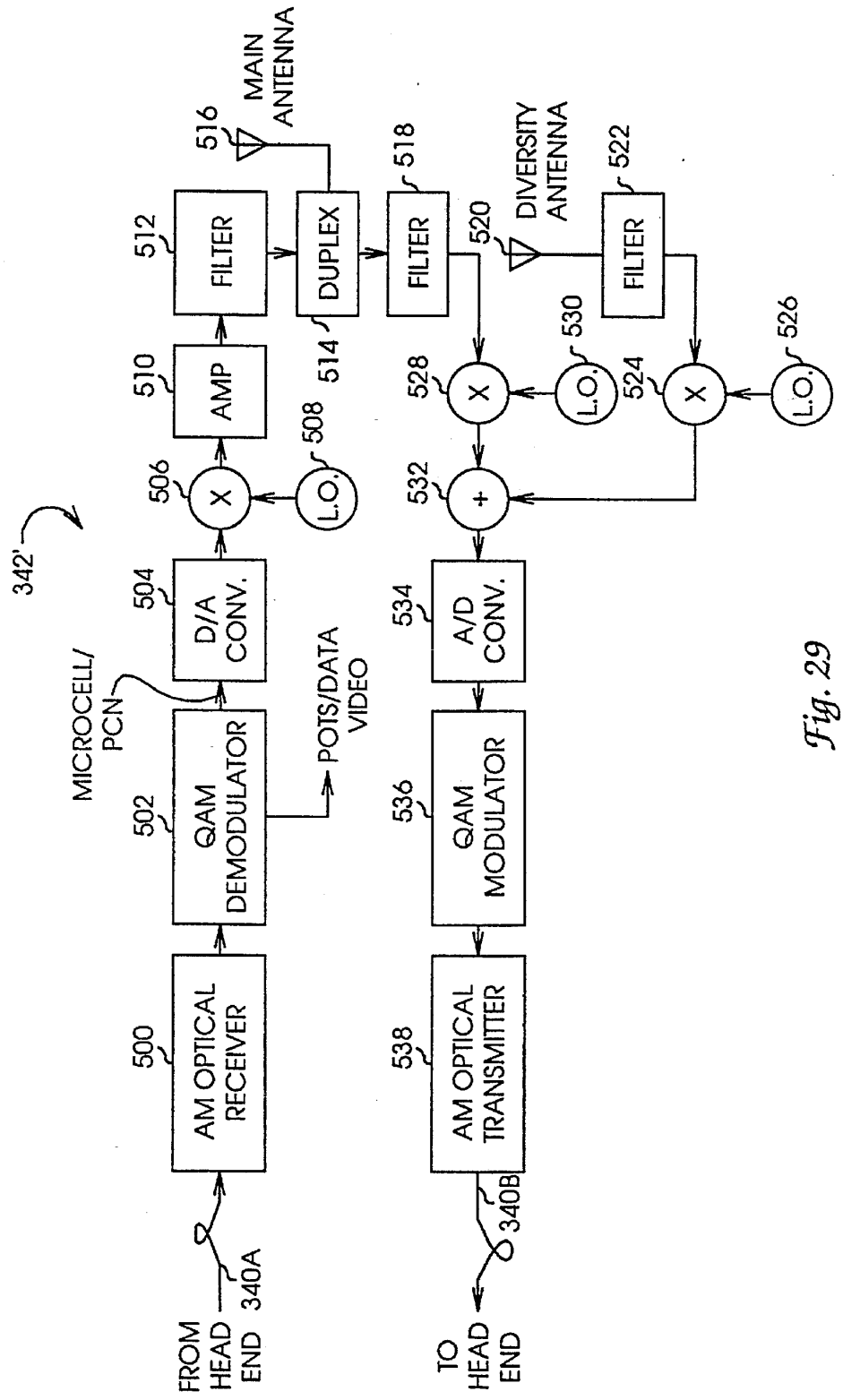

Fig. 29

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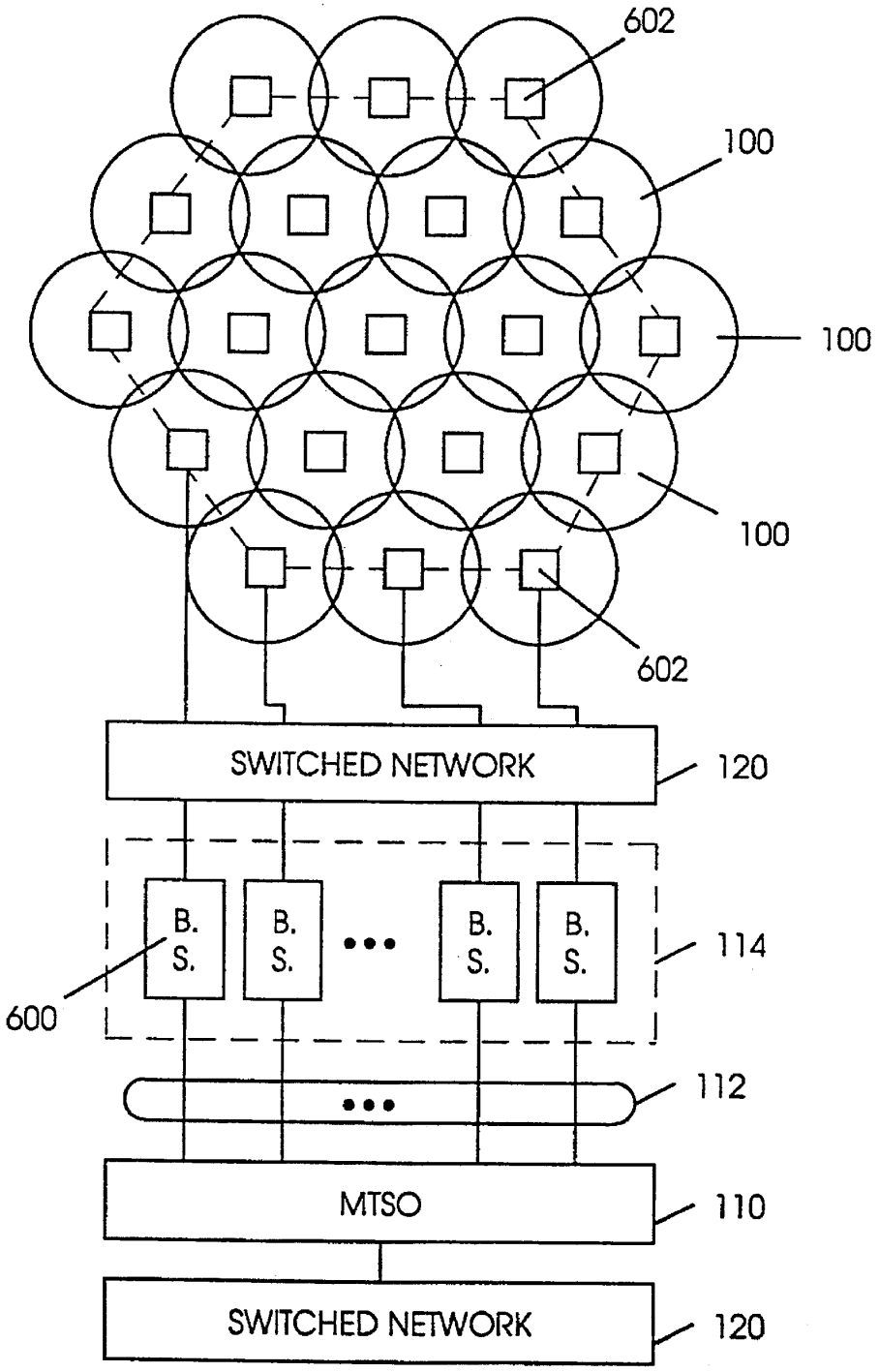
Fig. 30



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T-Mobile Ex. 1043

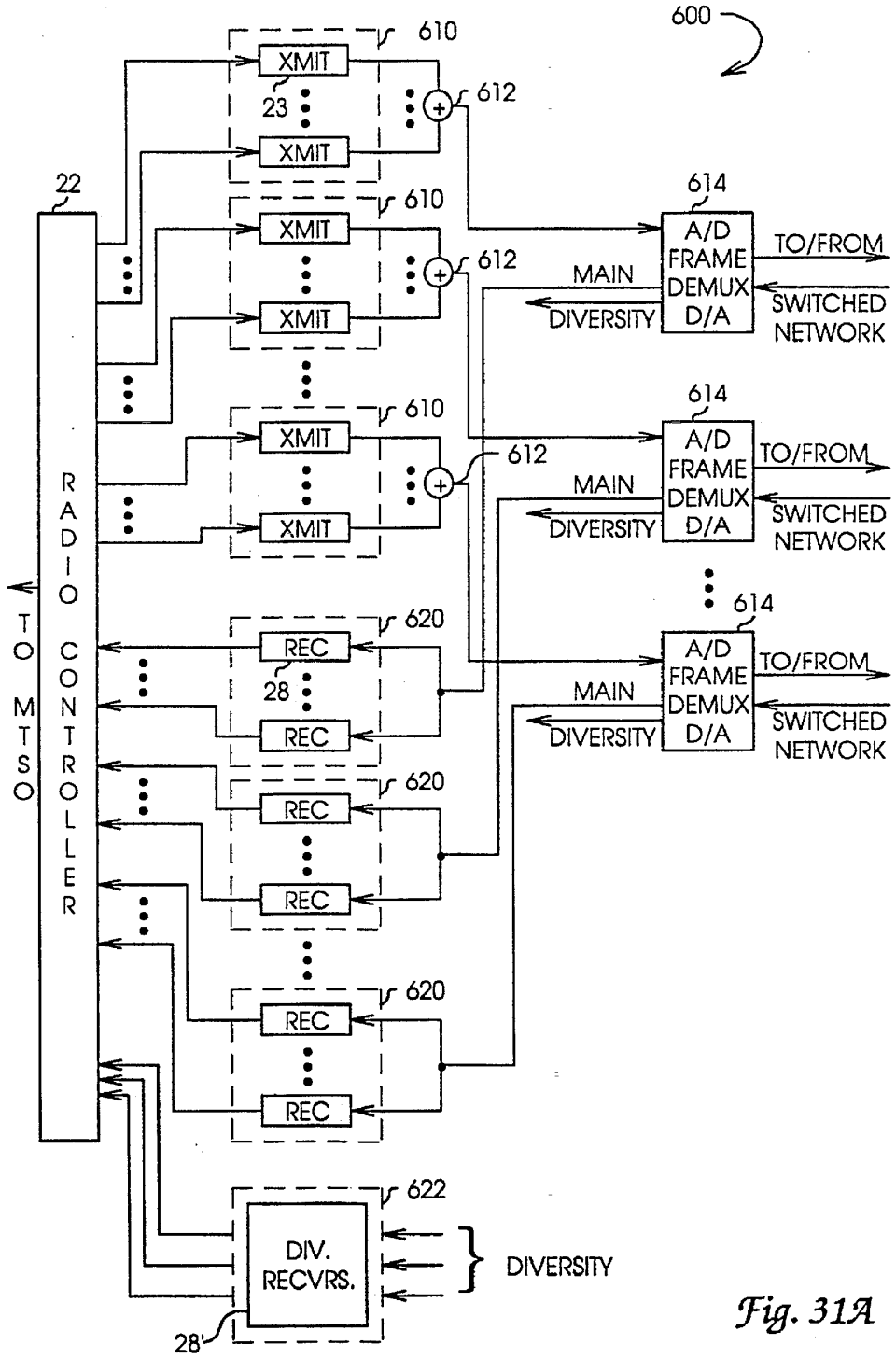

Fig. 31A

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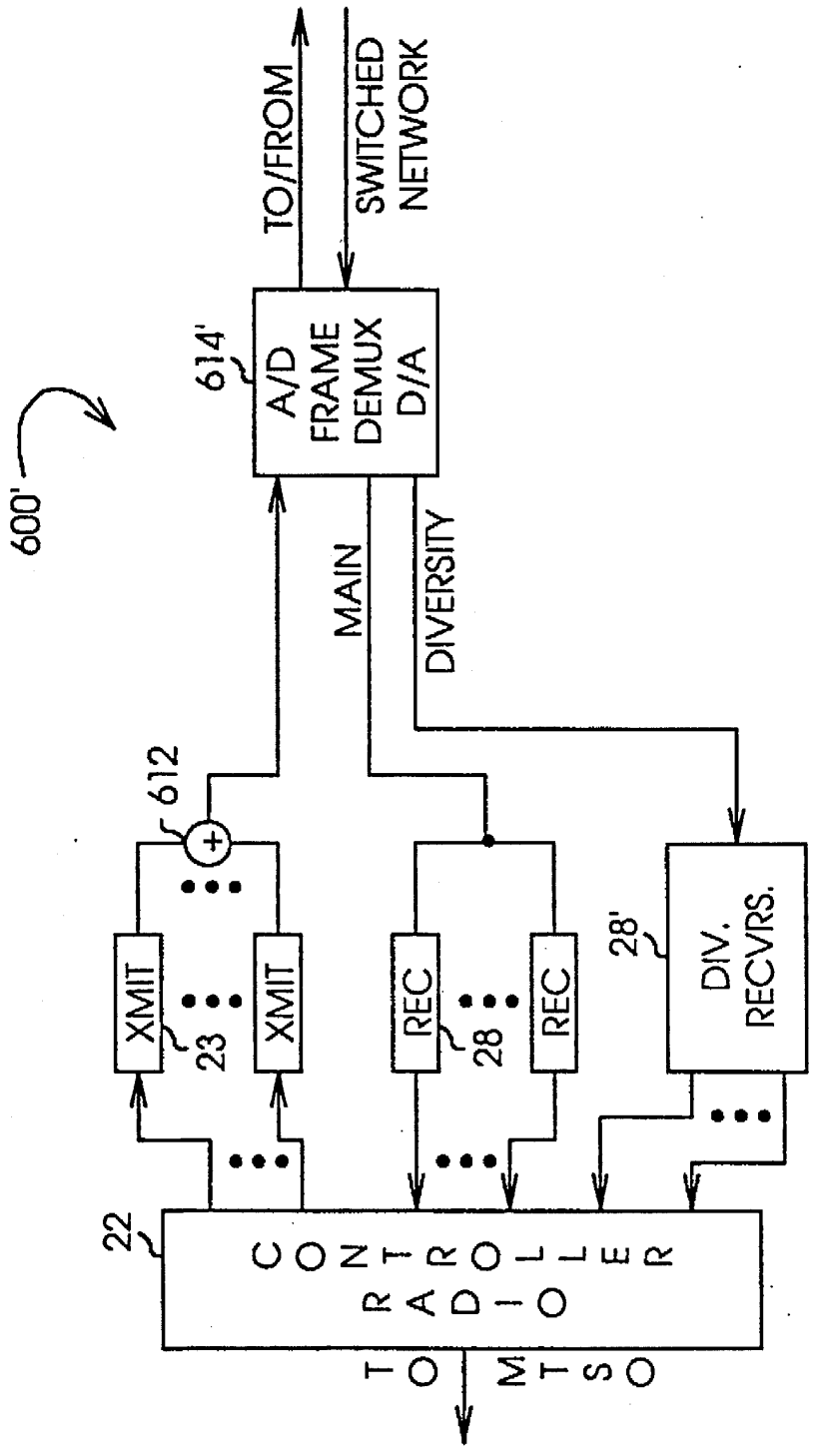

Fig. 31B

T-Mobile v. Dali Wireless Inc.
T-Mobile Ex. 1043

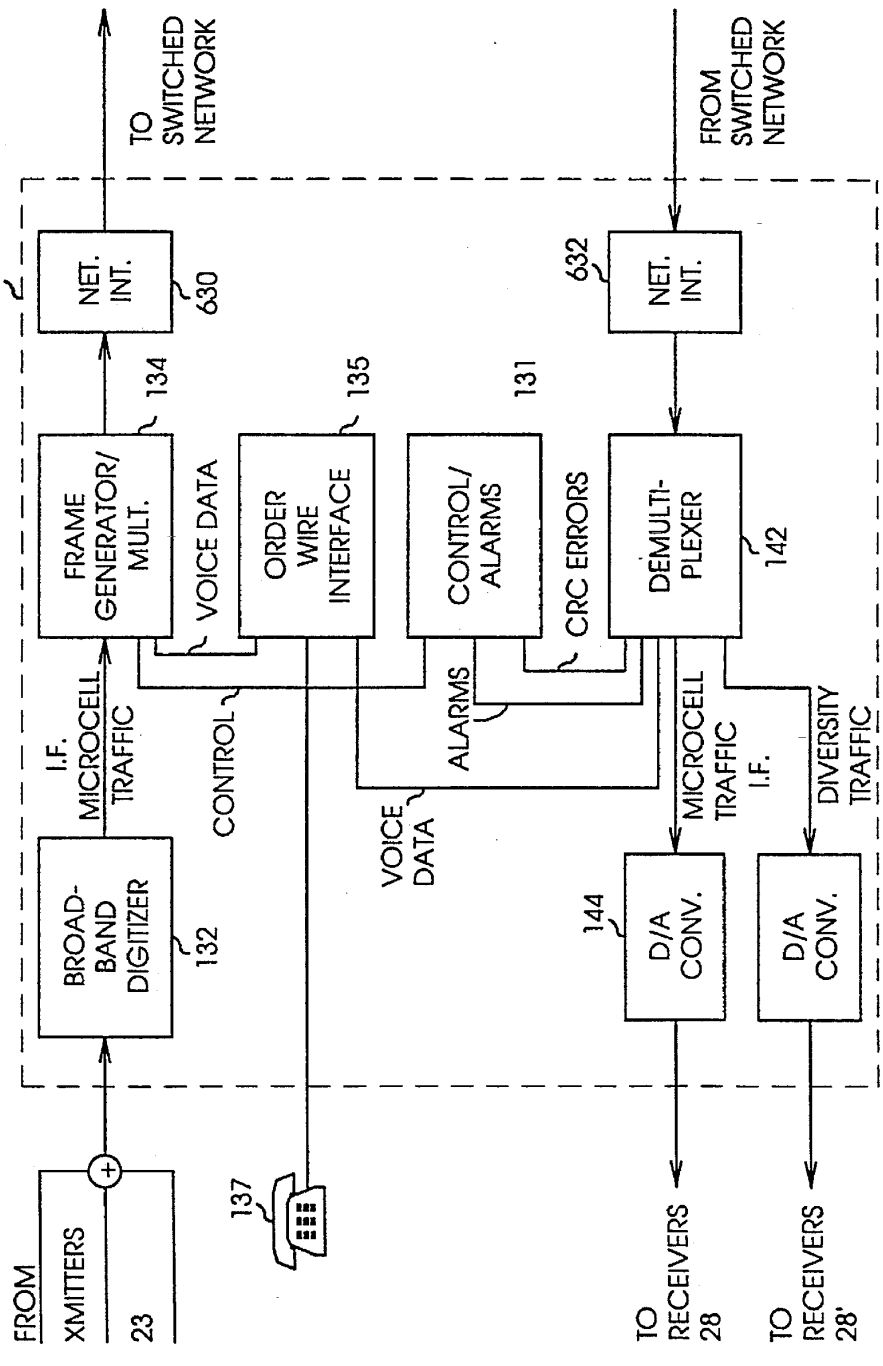

Figure 32A

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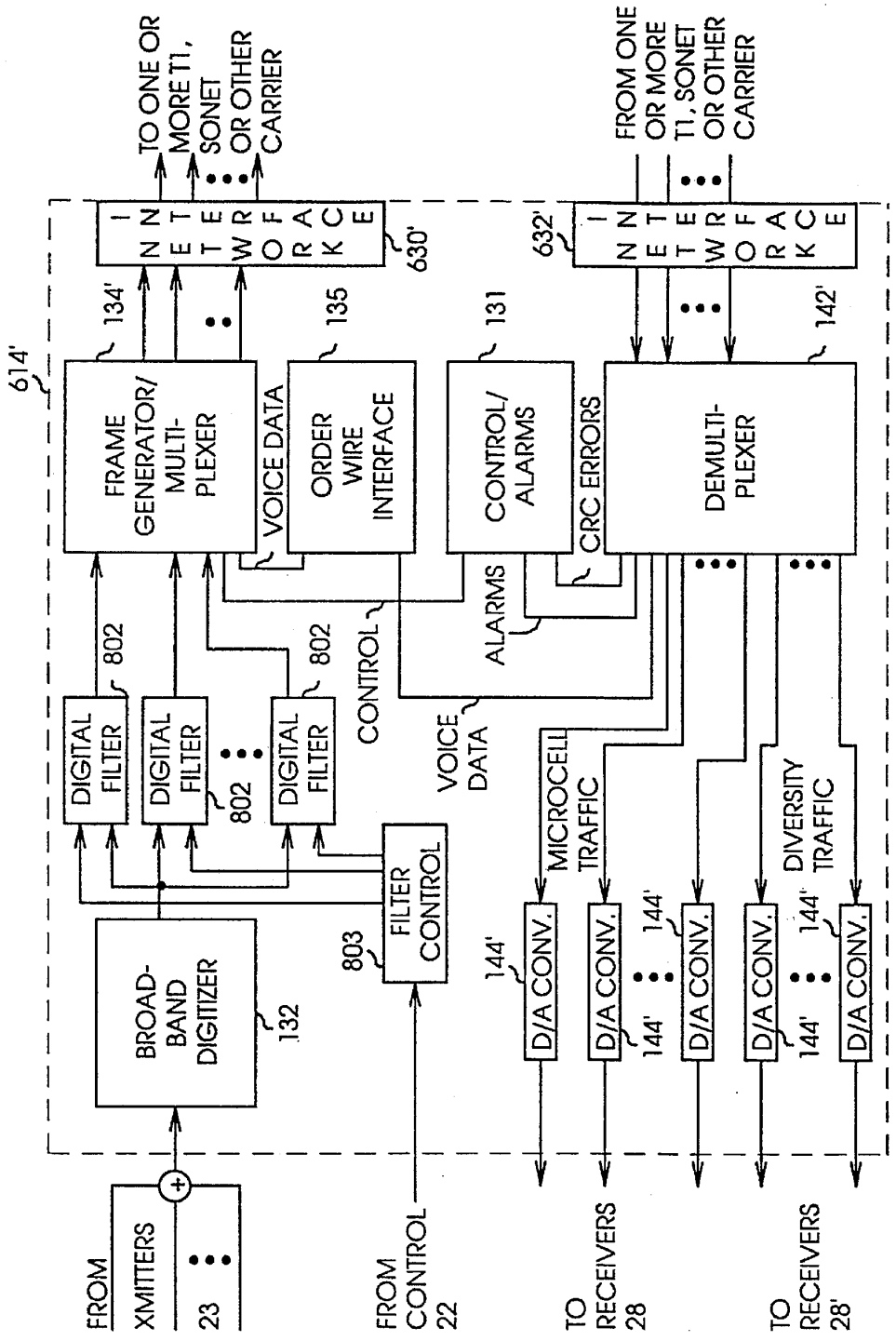

Figure 32B

T-Mobile v. Dali Wireless Inc.
T-Mobile Ex. 1043

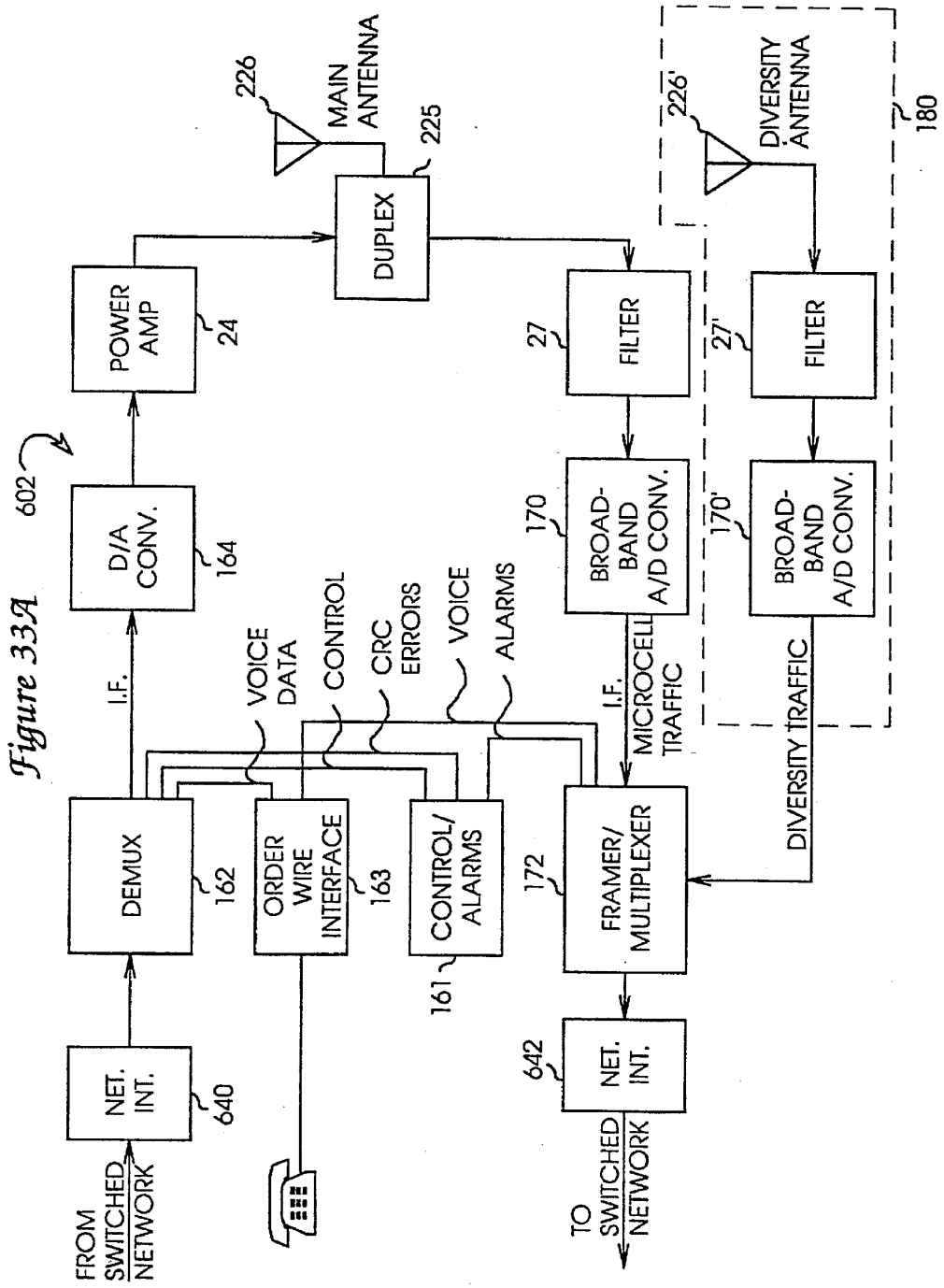

Figure 33A

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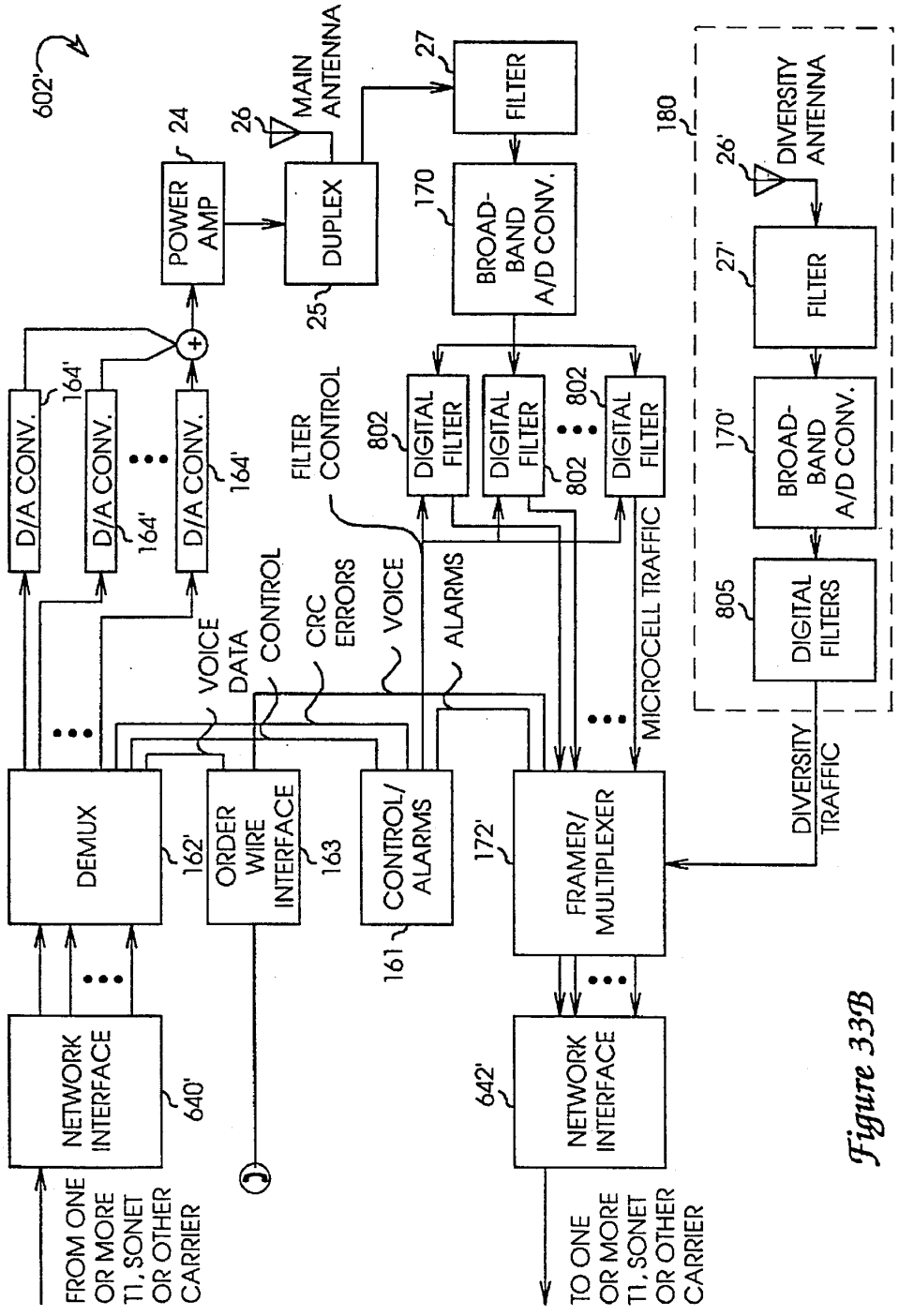

Figure 33B

T-Mobile v. Dali Wireless Inc.
T-Mobile Ex. 1043

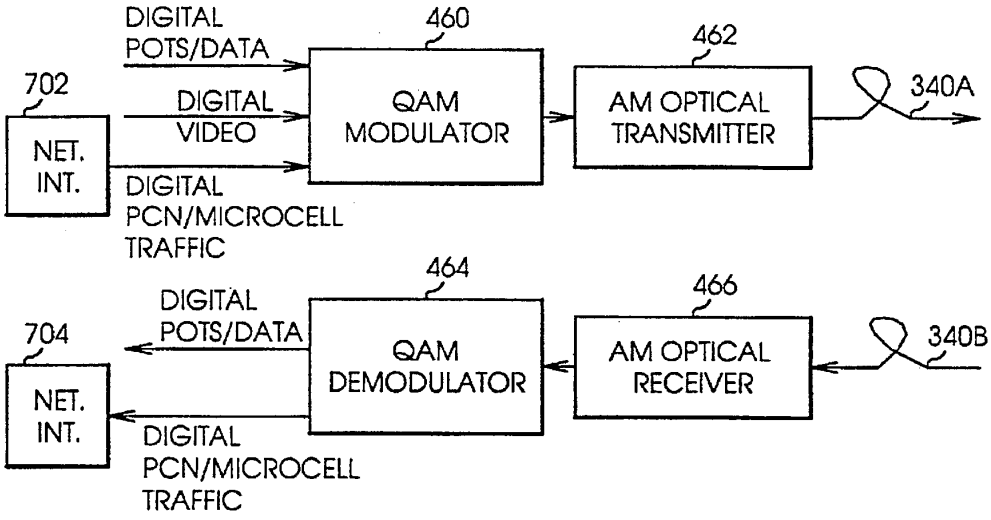

Fig. 34

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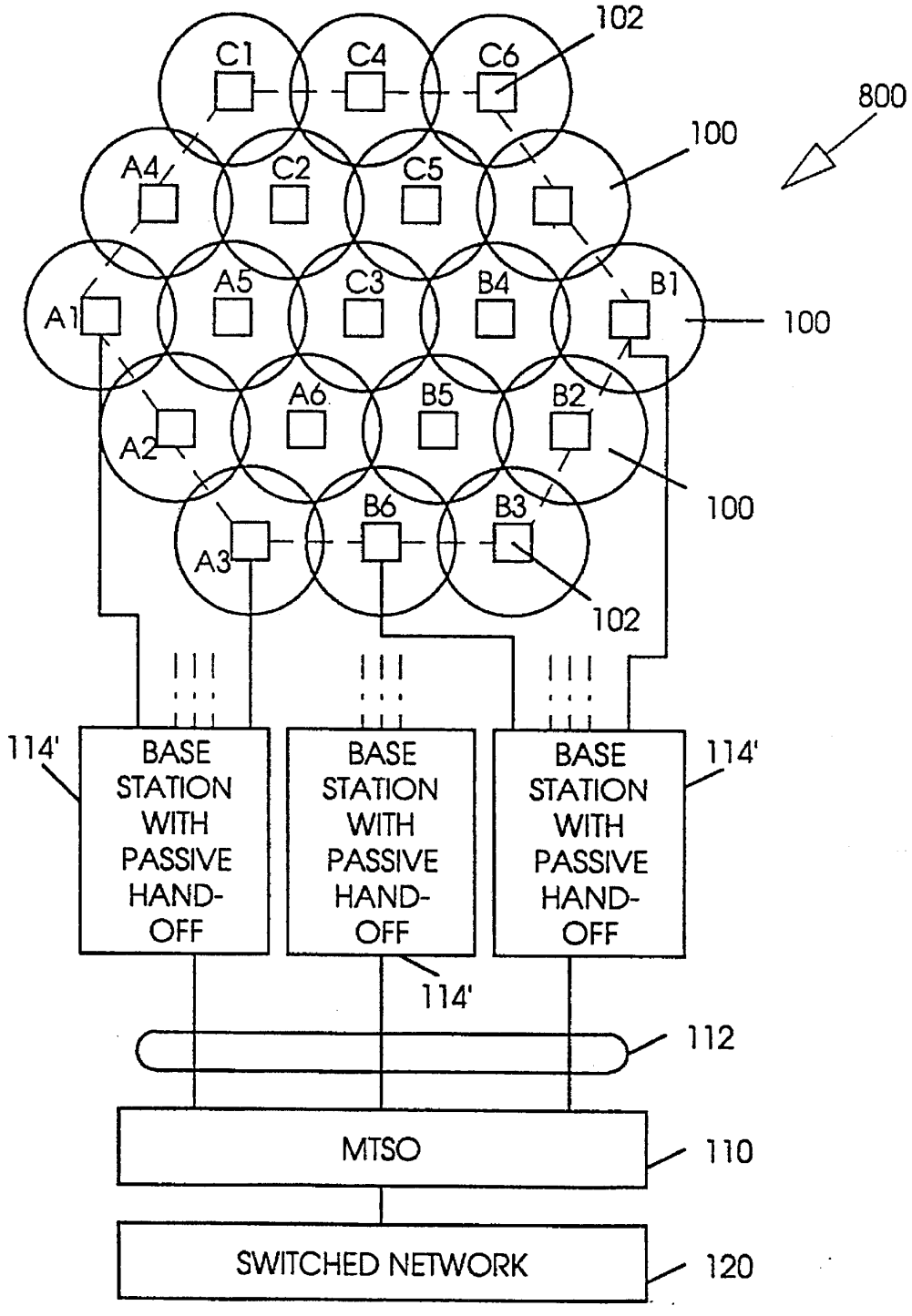
Fig. 35A



T-Mobile v. Dali Wireless Inc.
T-Mobile Ex. 1043

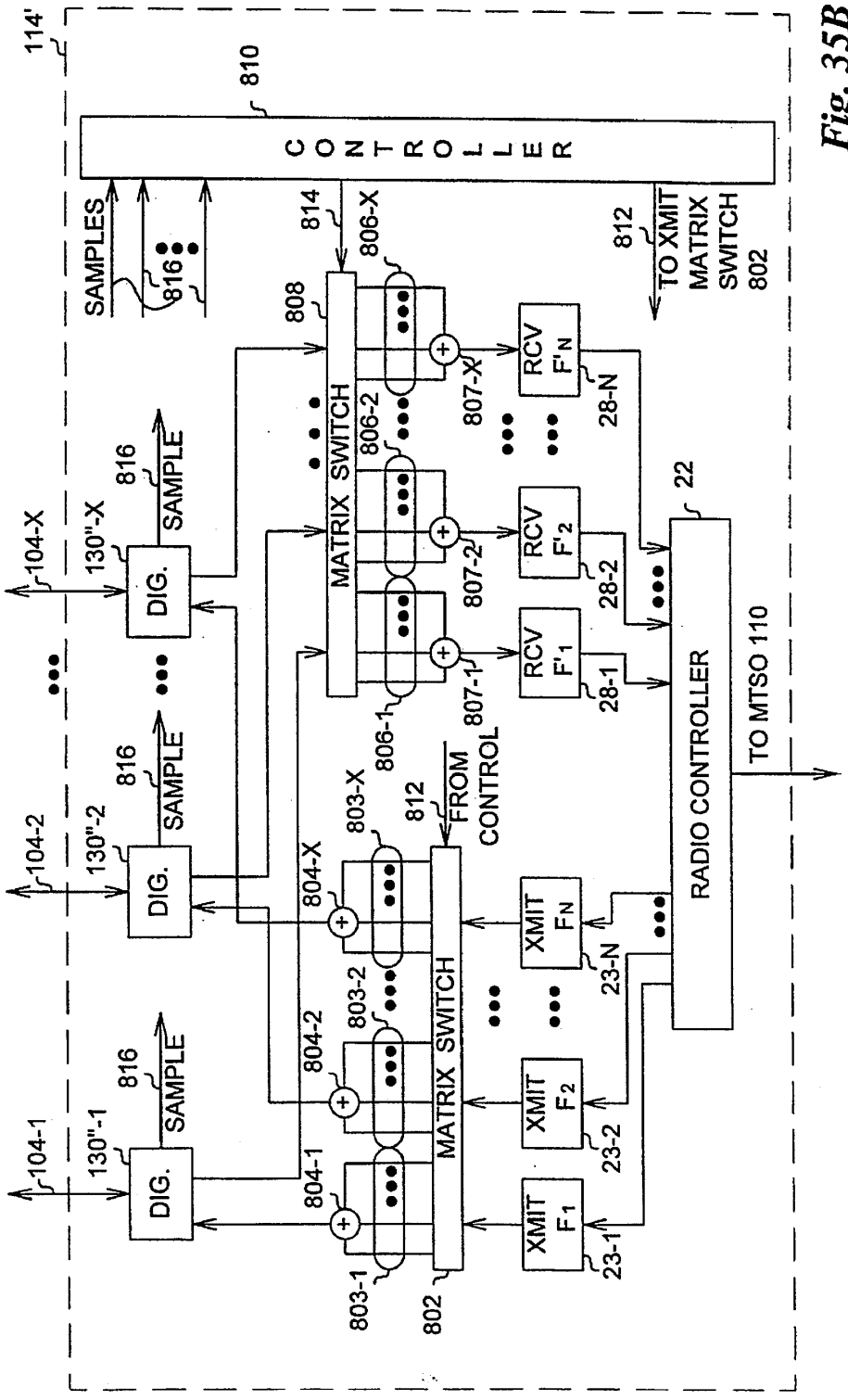


Fig. 35B

T-Mobile v. Dali Wireless Inc.
T-Mobile Ex. 1043

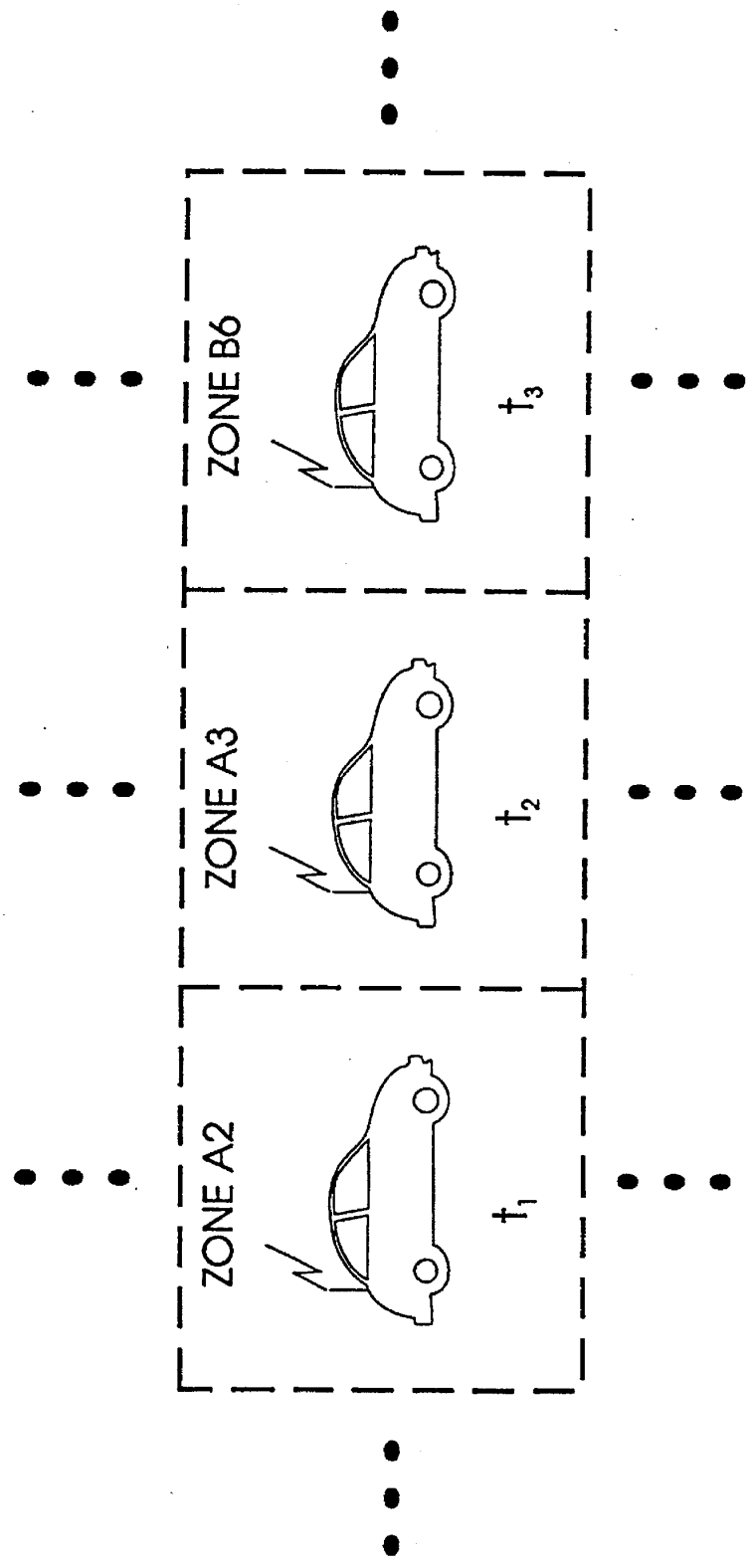


Figure 35C

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T-Mobile Ex. 1043

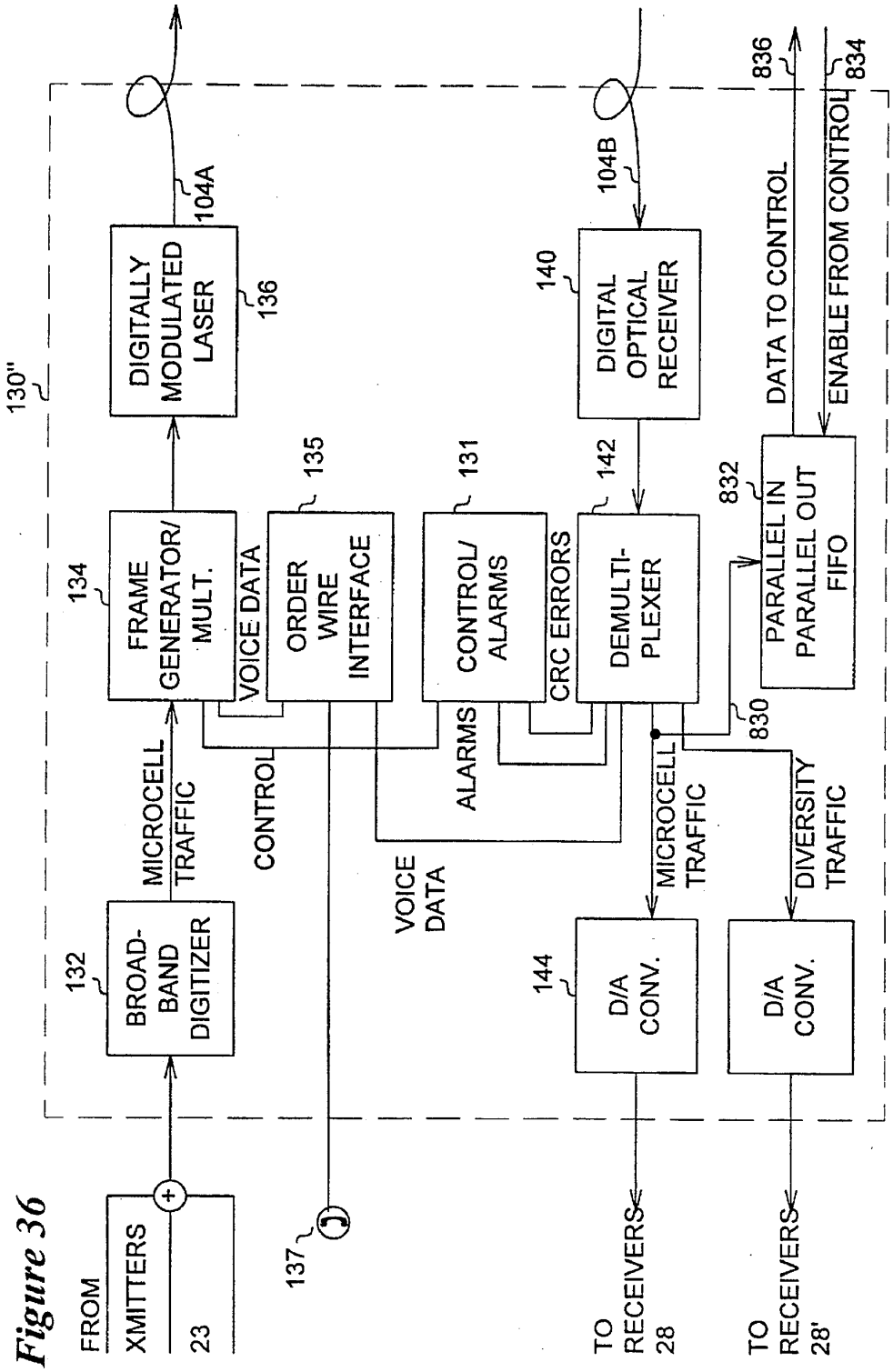

Figure 36

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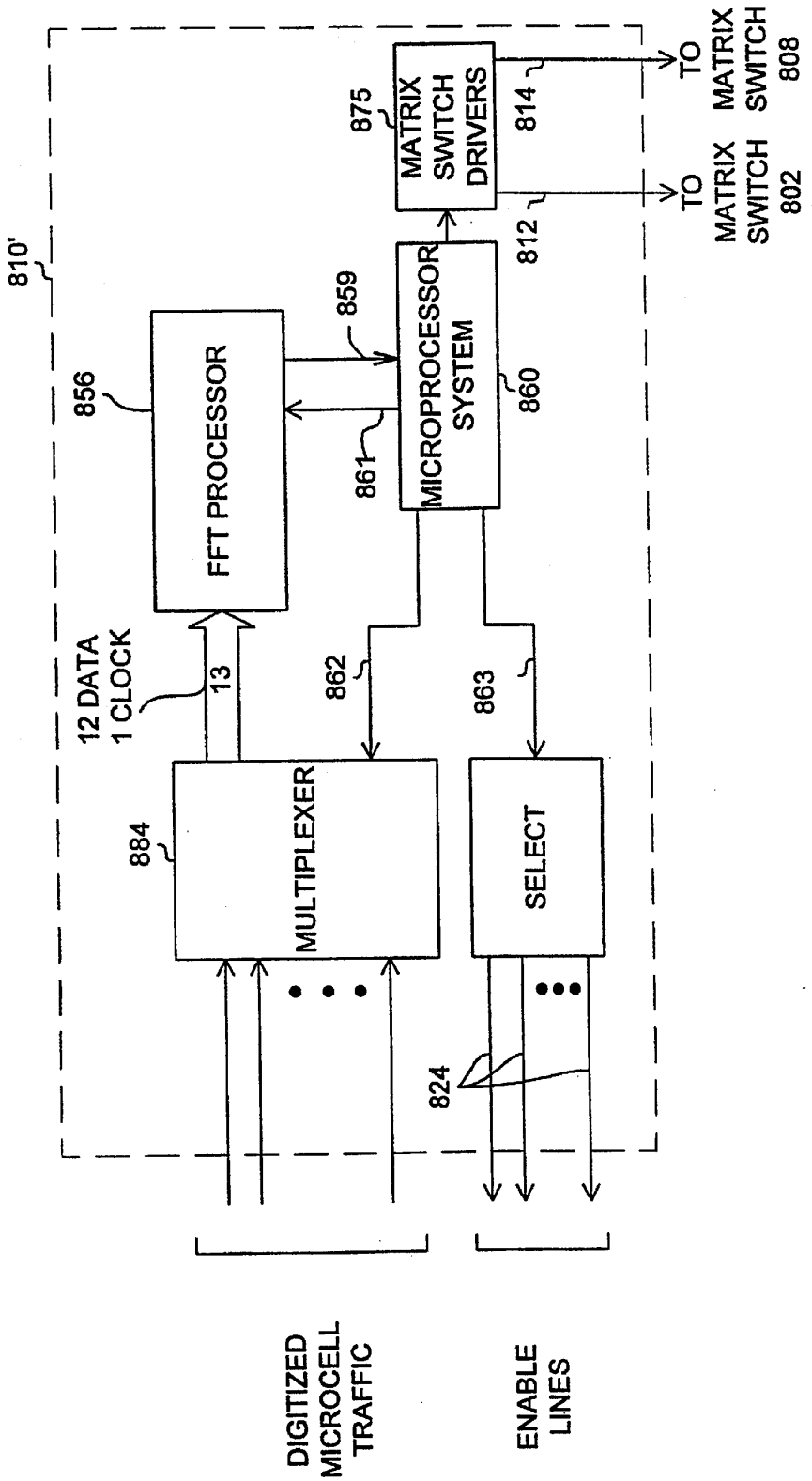

Fig. 37

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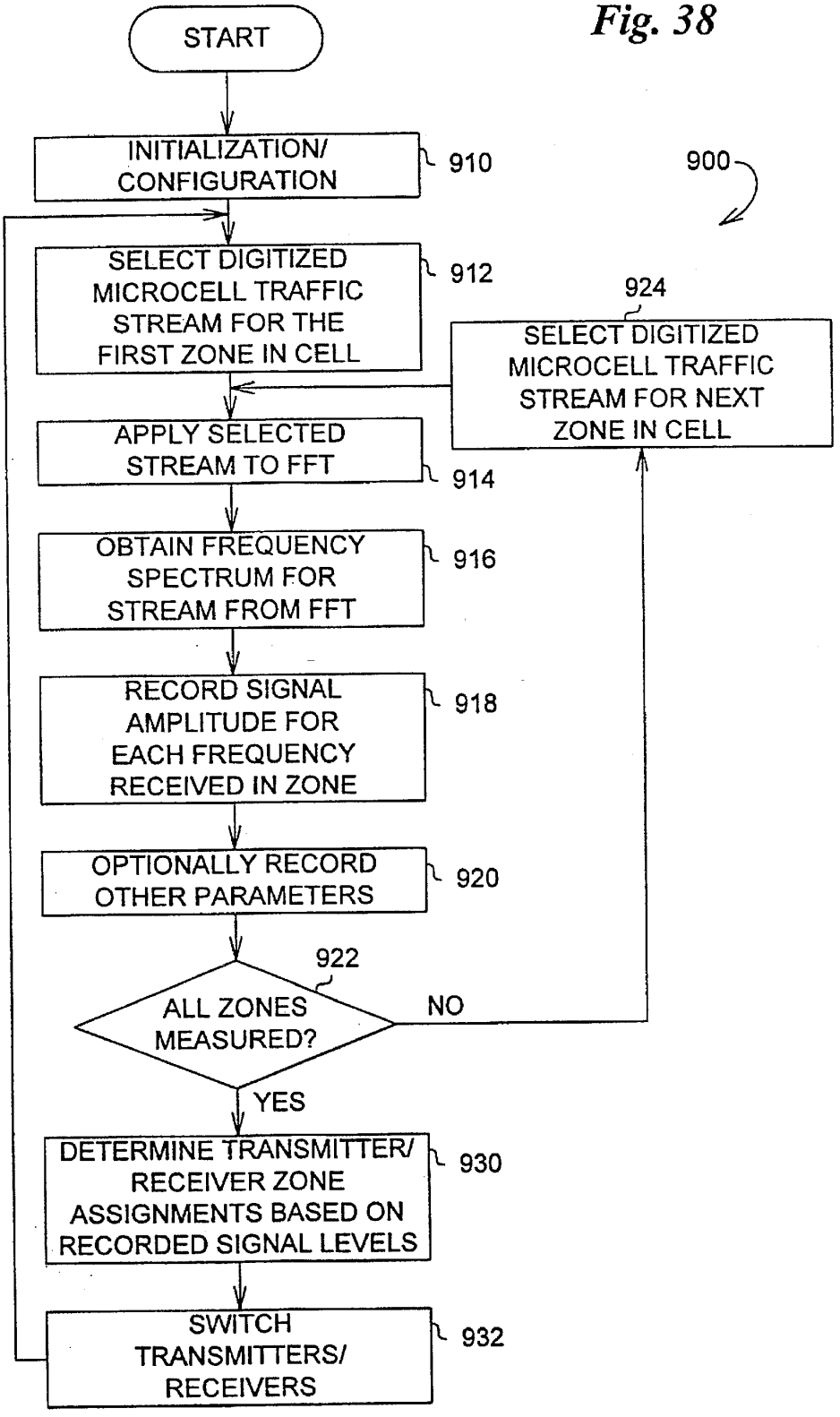
Fig. 38



T-Mobile v. Dali Wireless Inc.
T-Mobile Ex. 1043

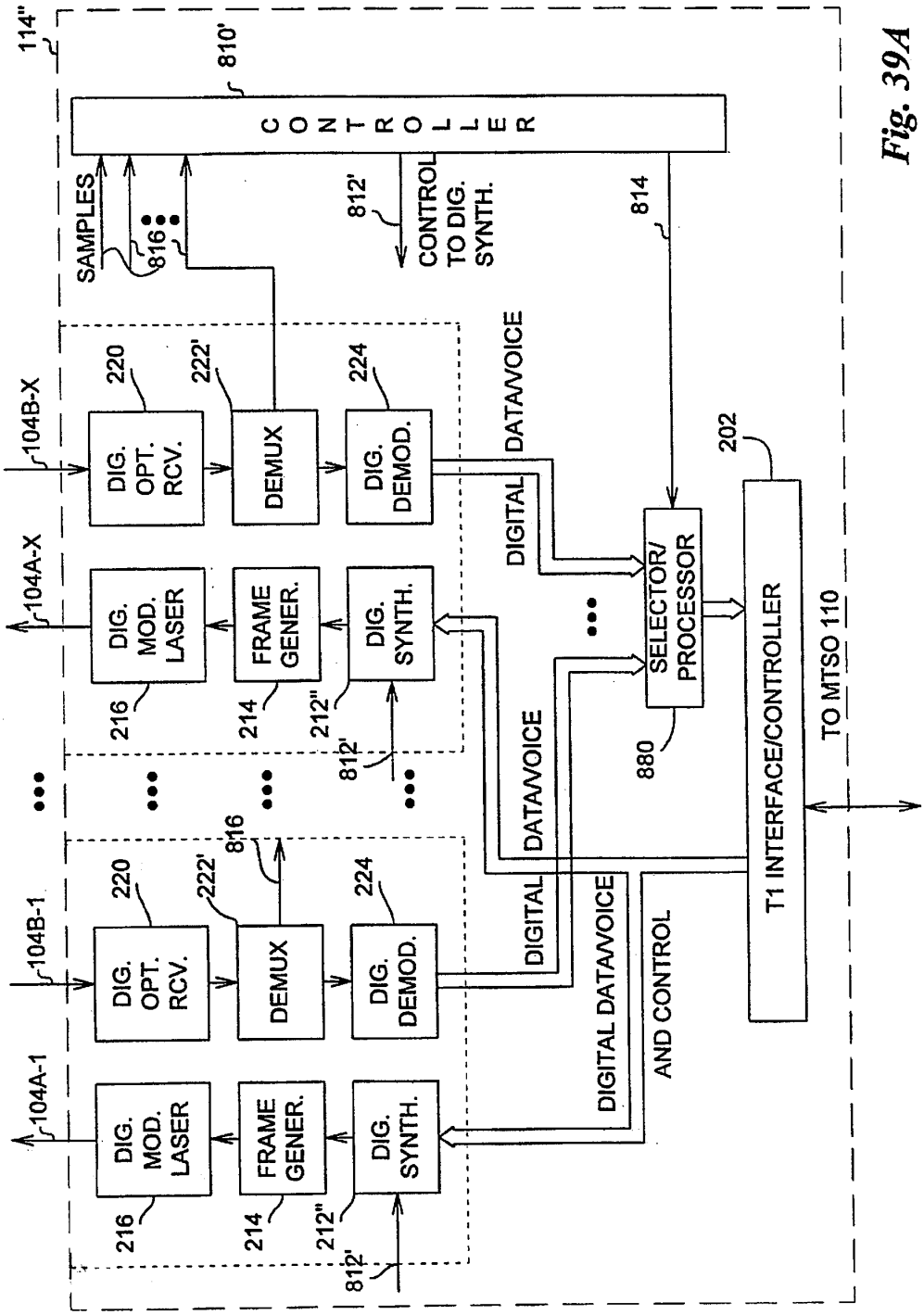


Fig. 39A

T-Mobile v. Dali Wireless Inc.
T-Mobile Ex. 1043

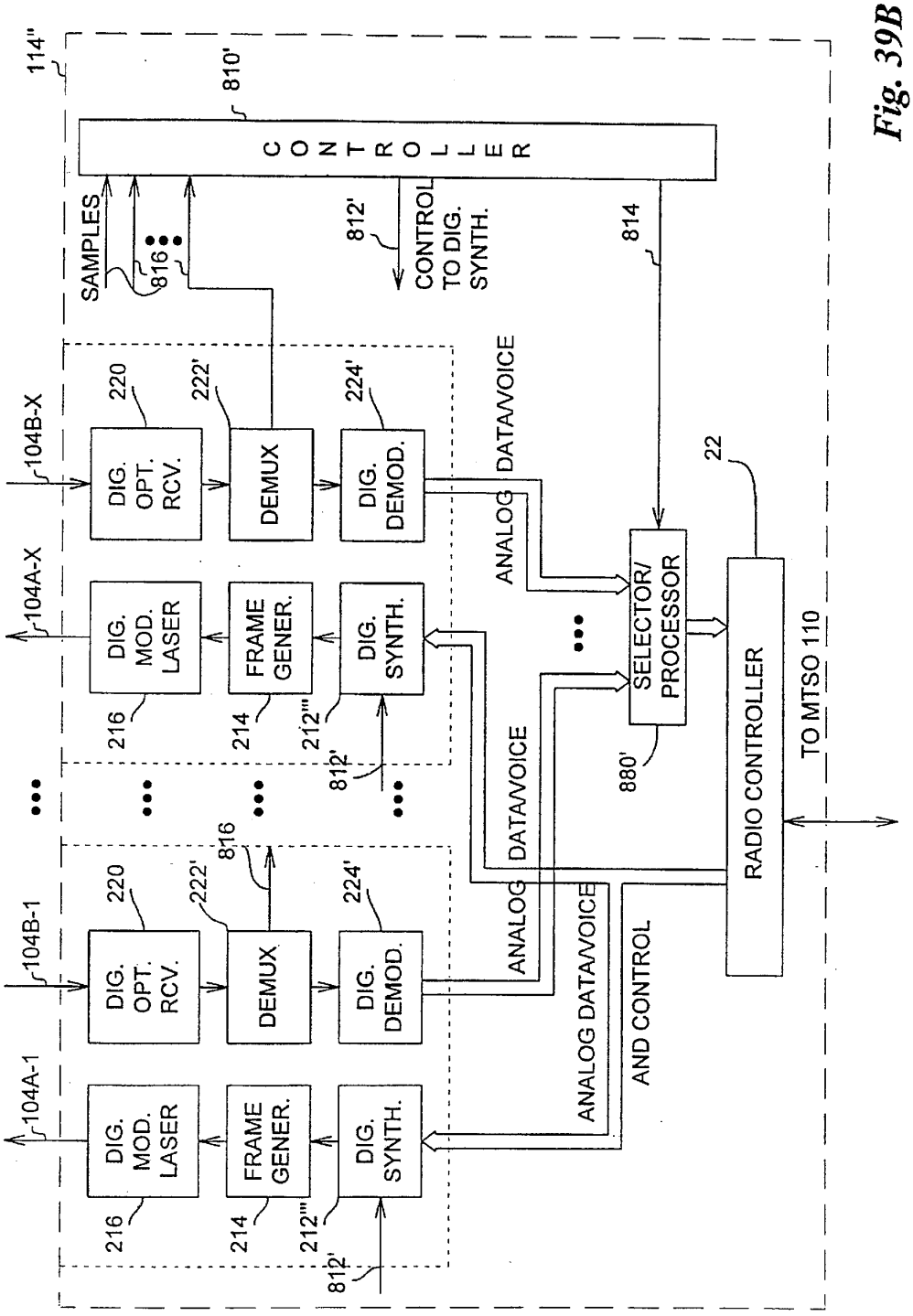


Fig. 39B

T-Mobile v. Dali Wireless Inc.
T-Mobile Ex. 1043

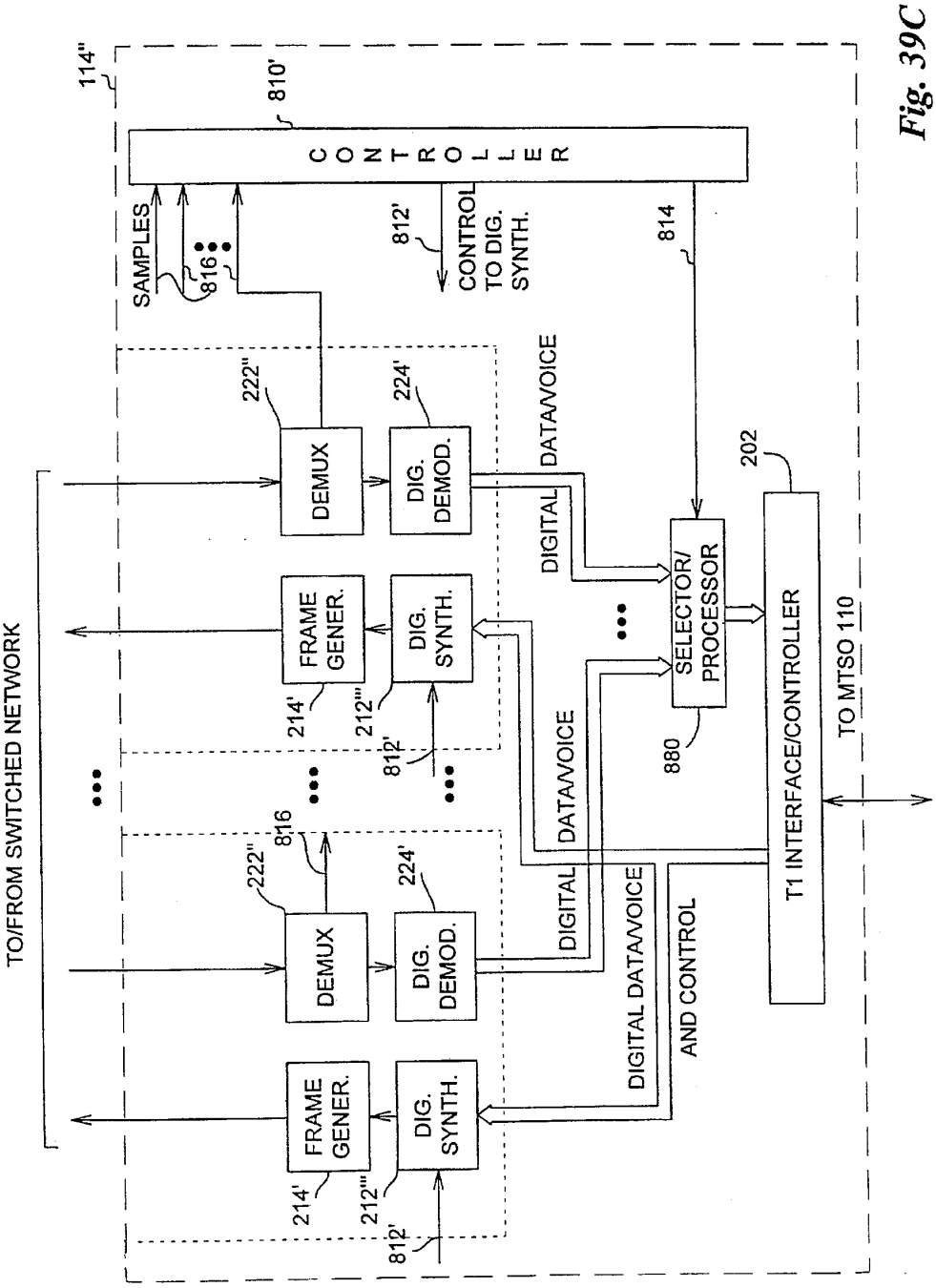


Fig. 39C

T-Mobile v. Dali Wireless Inc.
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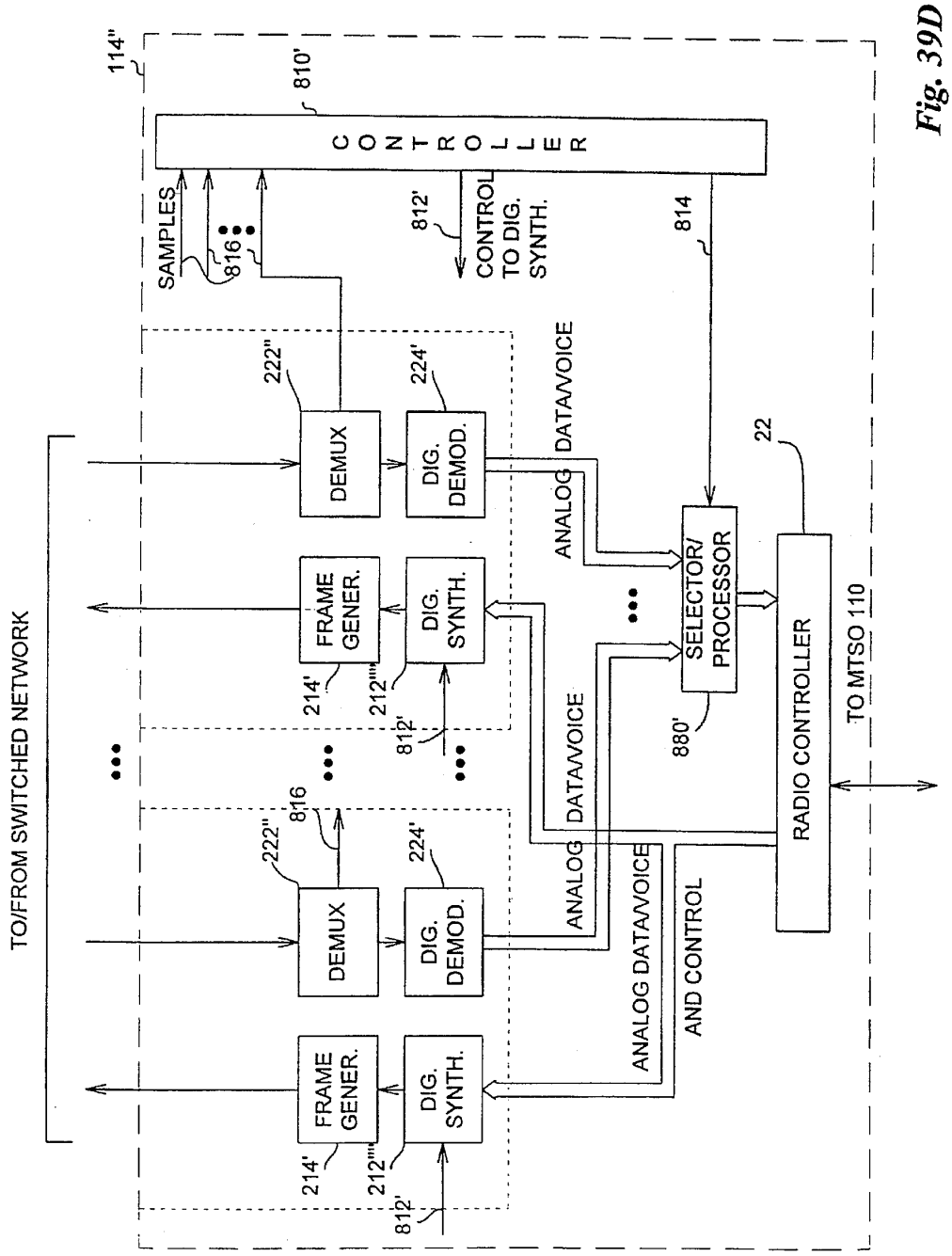

Fig. 39D

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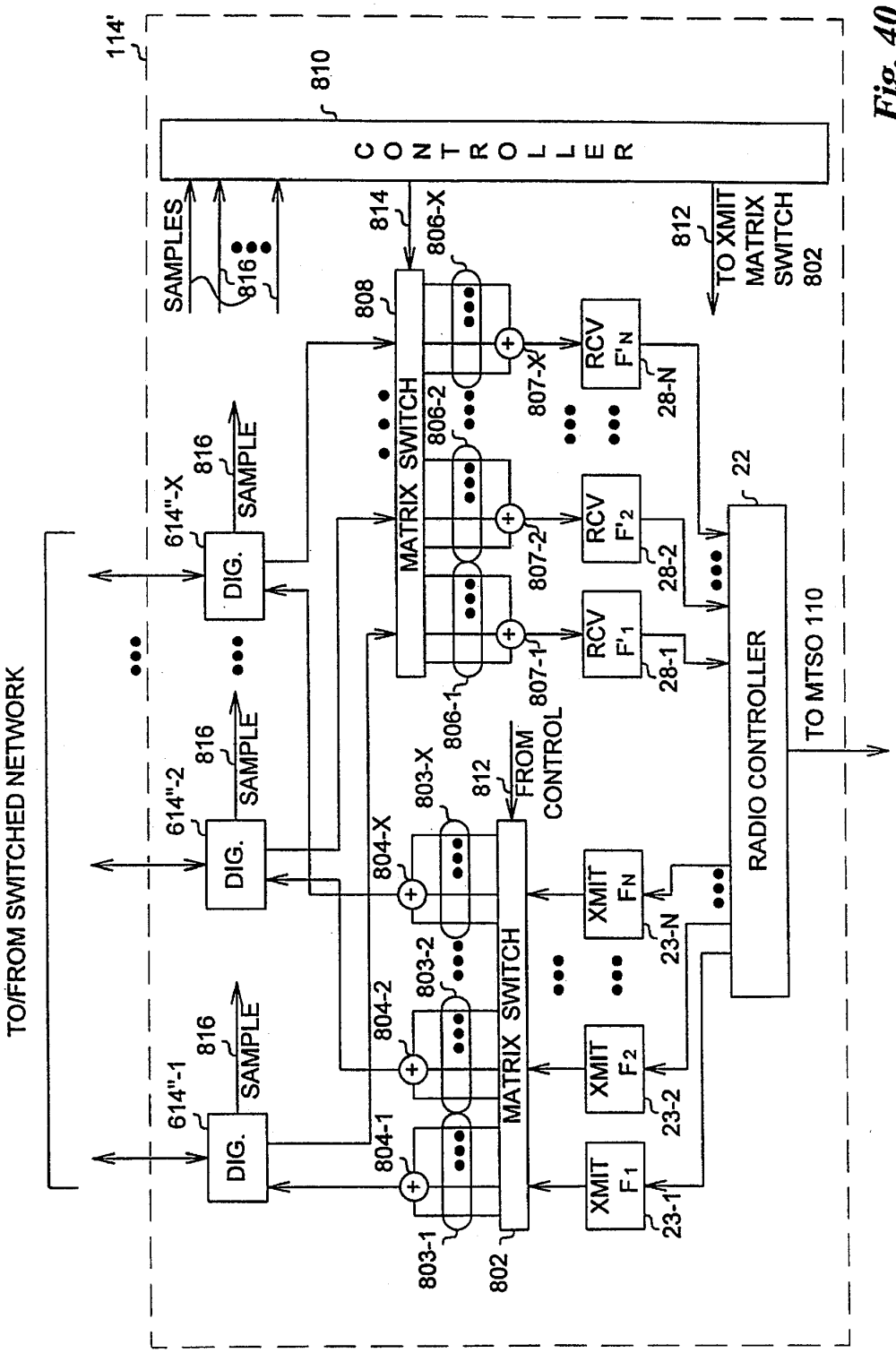

Fig. 40

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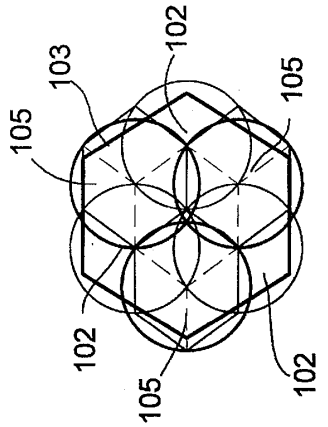

Figure 41A

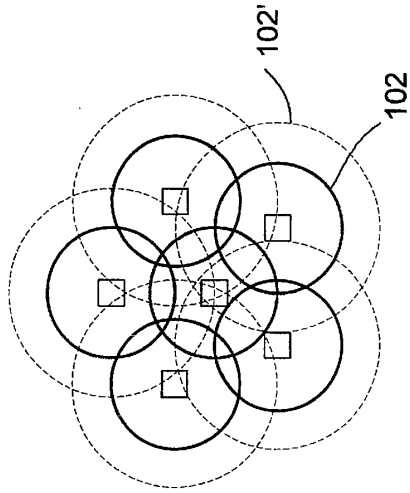

Figure 41C

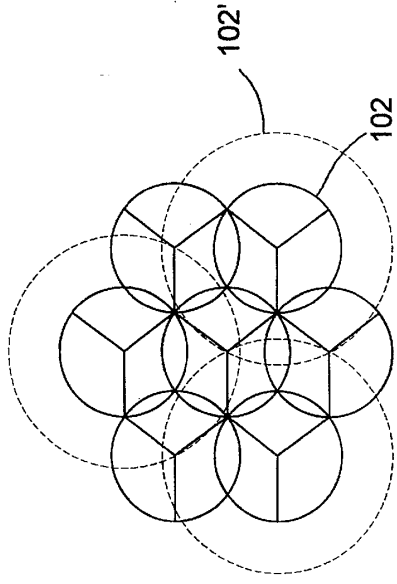

Figure 41B

T-Mobile v. Dali Wireless Inc.
T-Mobile Ex. 1043

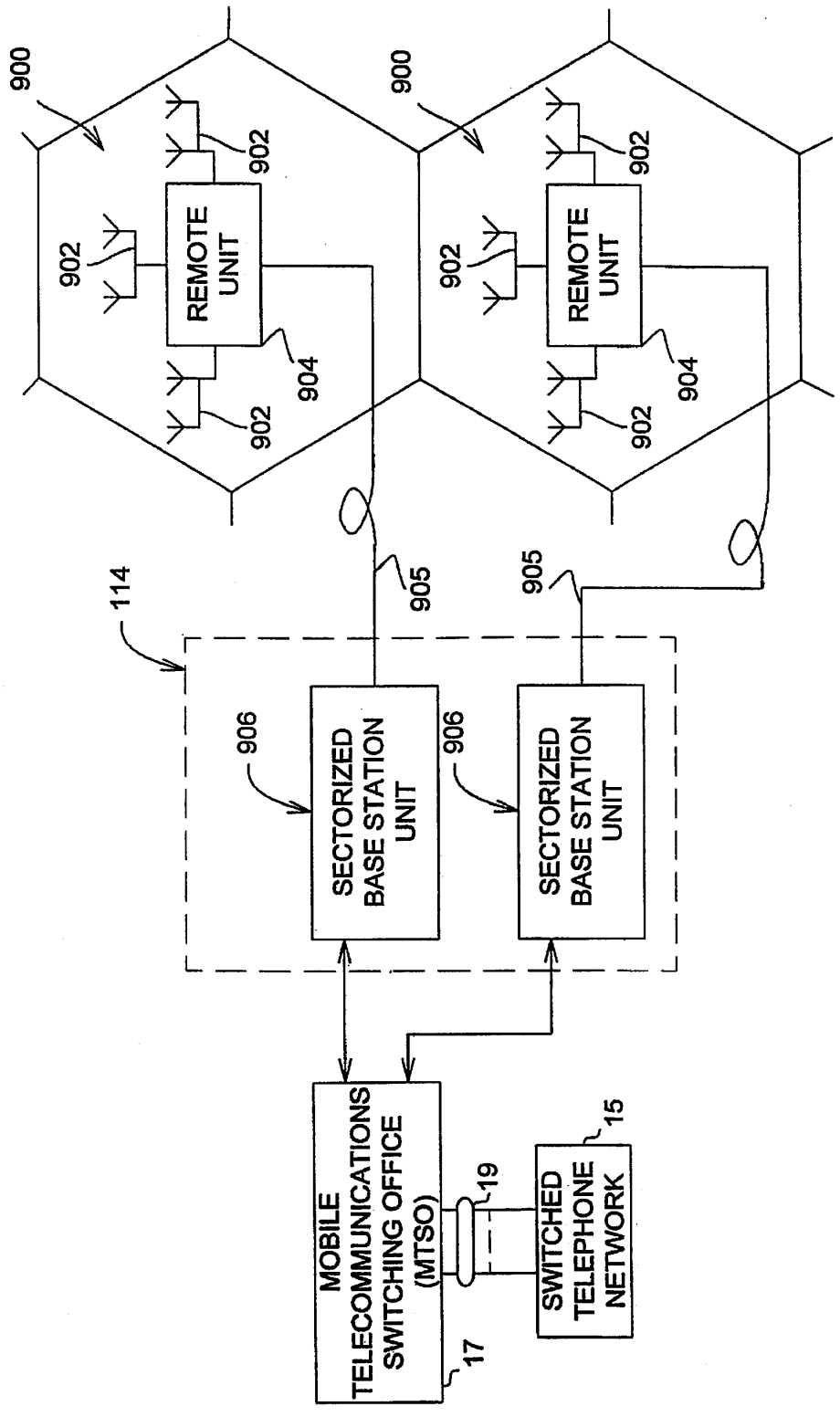

Figure 42

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T-Mobile Ex. 1043

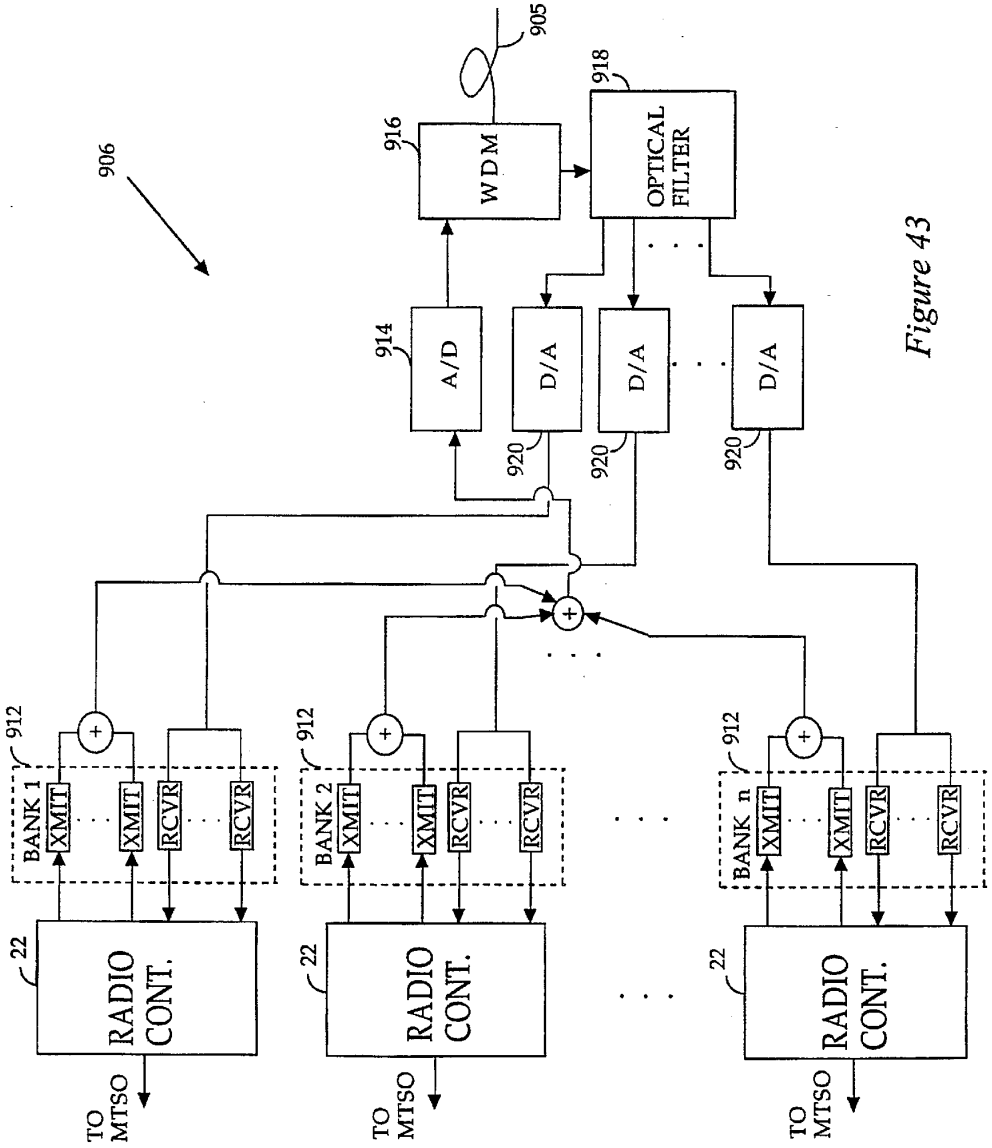

Figure 43

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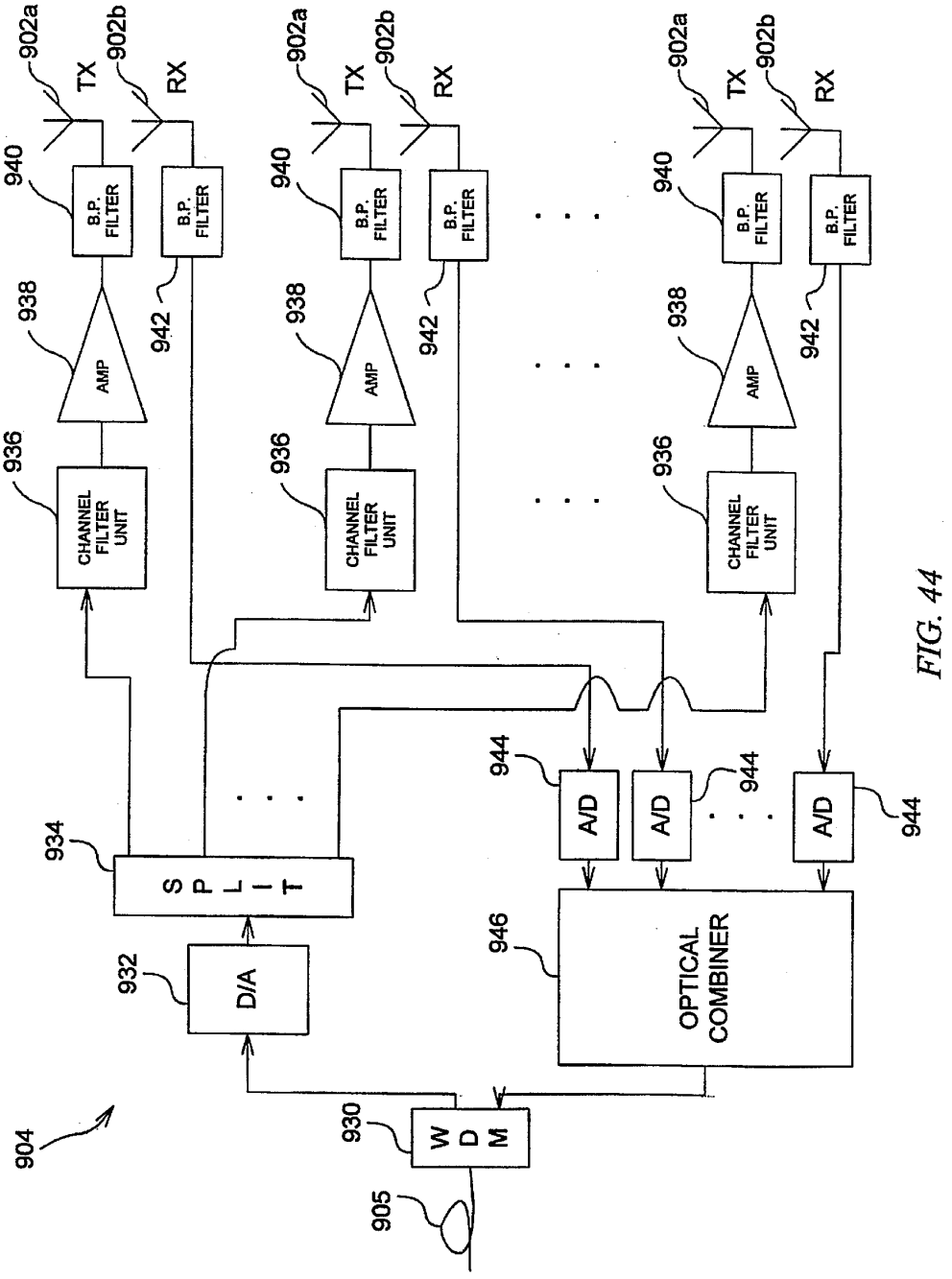

FIG. 44

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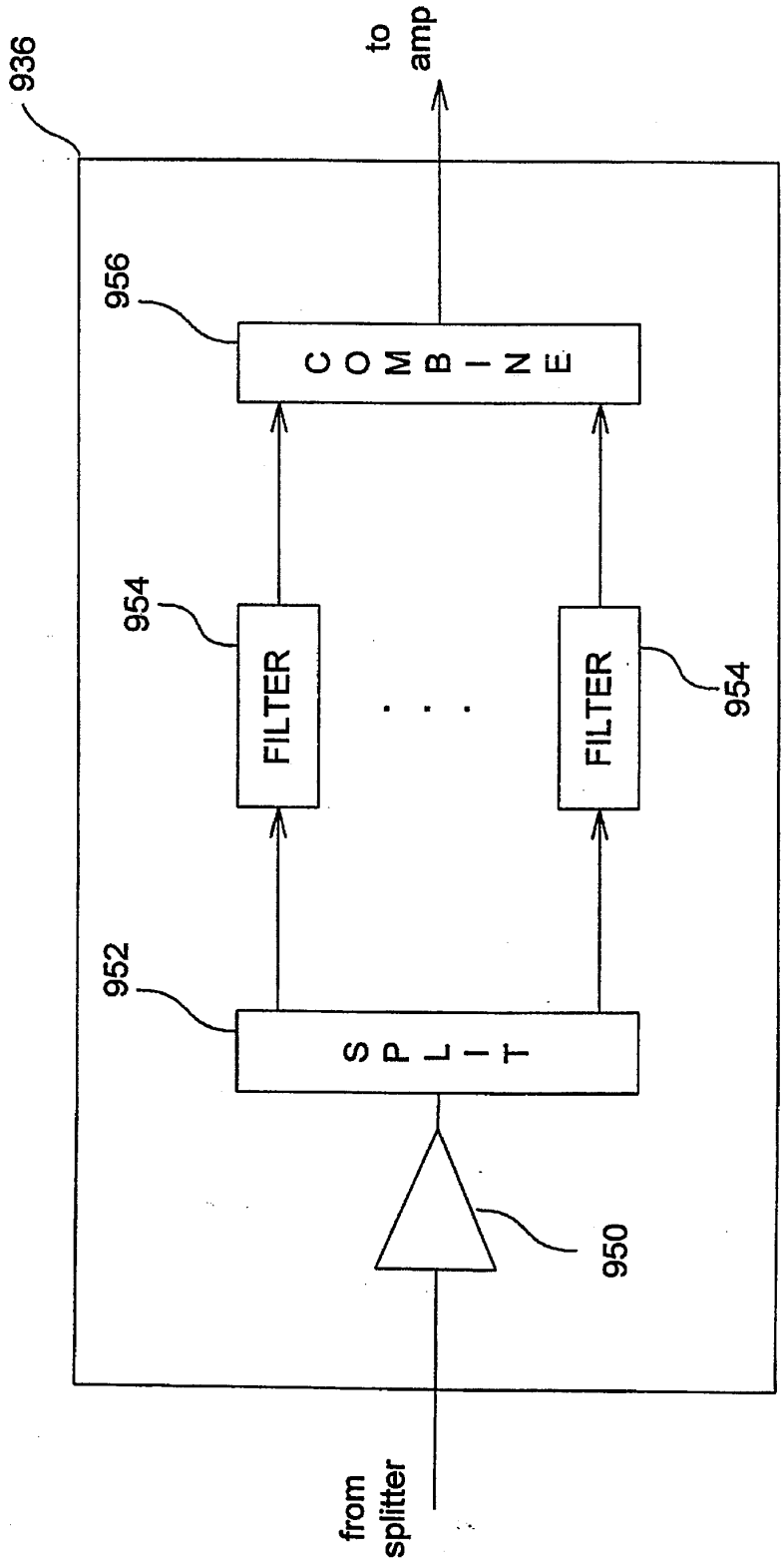

FIG. 45

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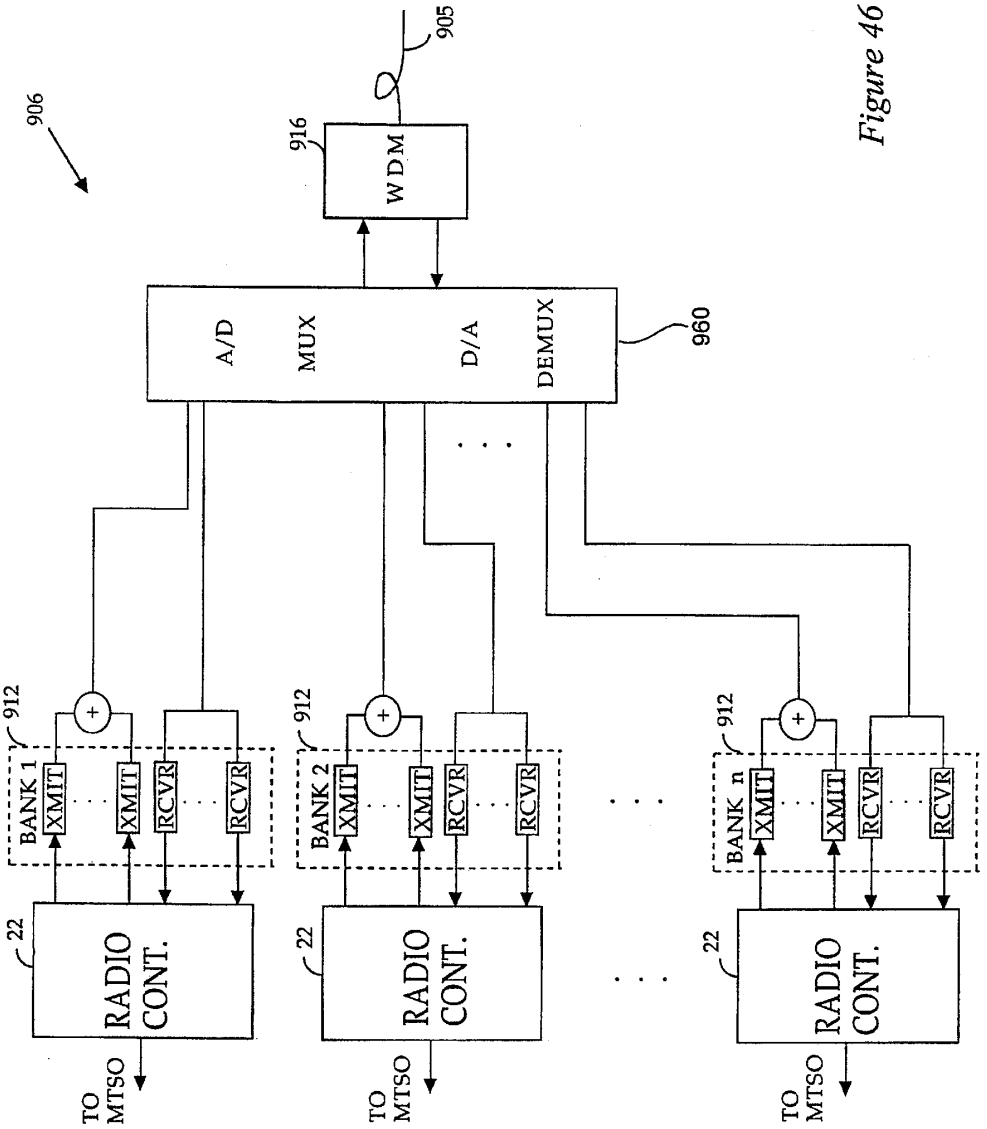

Figure 46

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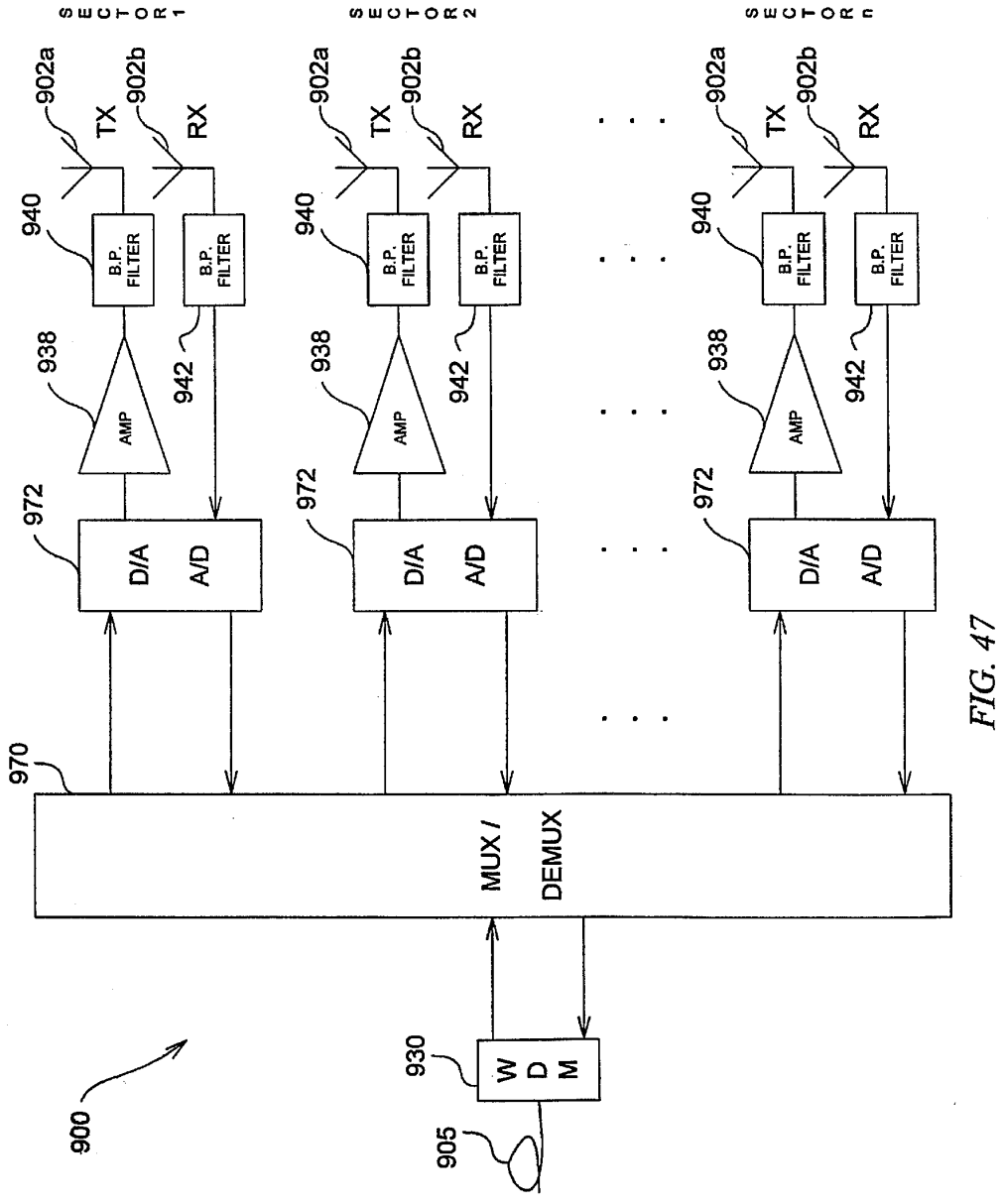

FIG. 47

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CELLULAR COMMUNICATIONS SYSTEM WITH CENTRALIZED BASE STATIONS AND DISTRIBUTED ANTENNA UNITS

This is a division of application Ser. No. 08/204,660, filed Mar. 2, 1994 U.S. Pat. No. 5,627,879, which is a continuation-in-part of U.S. application Ser. No. 08/183,221, filed Jan. 14, 1994, now abandoned, which is a continuation-in-part of U.S. application Ser. No. 08/068,389, filed May 28, 1993, now abandoned, which is a continuation-in-part of U.S. application Ser. Nos. 07/946,402, 07/946,964, 07/946,931, and 07/946,548, all filed Sep. 17, 1992, of which are now abandoned.

FIELD OF THE INVENTION

This invention relates generally to high capacity mobile communications systems, and more particularly to a digital microcellular communication system.

BACKGROUND

A conventional cellular phone system **5** is shown in FIG. **1A**. Such systems are currently in widespread use in the United States. As illustrated in FIG. **1A**, system **5** has a fixed number of channel sets distributed among the base stations **12, 13** serving a plurality of cells **11, 16** arranged in a predetermined reusable pattern. Typical cell areas range from 1 to 300 square miles. The larger cells typically cover rural areas and smaller cells cover urban areas. Cell antenna sites utilizing the same channel sets are spaced by a sufficient distance to assure that co-channel interference is held to an acceptably low level.

A mobile unit **10** in a cell **11** has radio telephone transceiver equipment which communicates with similar equipment in base station sites **12, 13** as the unit moves from cell to cell. Each base station **12, 13** relays telephone signals between mobile units **10** and a mobile telecommunications switching office (MTSO) **17** by way of communication lines **18**. The lines **18** between a cell site and the MTSO **17**, typically **T1** lines, carry separate voice grade circuits for each radio channel equipped at the cell site, and data circuits for switching and other control functions. The MTSO **17** is also connected through paths **19** to a switched telephone network **15** including fixed subscriber telephone stations as well as various telephone switching offices.

MTSO **17** in FIG. **1A** includes a switching network for establishing call connections between the public switched telephone network **15** and mobile units **10** located in cell sites **11, 16**, and for switching call connections from one cell site to another. In addition, the MTSO **17** includes a dual access feeder for use in switching a call connection from one cell site to another. Various handoff criteria are known in the art and utilize features such as phase ranging to indicate the distance of a mobile unit from a receiving cell site, triangulation, and received signal strength to indicate the potential desirability of a handoff. Also included in the MTSO **17** is a central processing unit for processing data received from the cell sites and supervisory signals obtained from the network **15** to control the operation of setting up and taking down call connections.

A conventional base station **12** is illustrated in FIGURE **1B**. A radio controller unit **22** provides the interface between the **T1** lines from the MTSO and the base station radio equipment. Transmitters **23**, one for each channel serviced by the base station, are driven by circuit **22**, which supplies each transmitter with an analog voice signal. Next, the signals are passed to a separate nonlinear power amplifier for each channel, or the signals may be combined and applied to a single linear power amplifier **24** as shown in FIG. **1B**. The output of power amplifier **24** is applied through duplexer **25** to antenna **26**, to be broadcast into the cellular area serviced by the base station.

Signals received in antenna **26** are applied through duplexer **25** to filter **27**. Filter **27** isolates the entire cellular band signal from adjacent bands and applies it to receivers **28**, one for each channel. The analog voice signal outputs of receivers **28** are applied to circuit **22**. Base station **20** may optionally include a diversity antenna **26'** and corresponding diversity filter **27'** and a plurality of diversity receivers **28'**, one for each associated main receiver **28**. Where implemented, the outputs of diversity receivers **28'** are applied to circuit **22**, which would thus include circuitry for selecting the strongest signal as between corresponding receivers **28** and **28'** using known techniques.

In densely populated urban areas, the capacity of a conventional system **5** is severely limited by the relatively small number of channels available in each cell **11, 16**. Moreover, the coverage of urban cellular phone systems is limited by blockage, attenuation and shadowing of the RF signals by high rises and other structures. This can also be a problem with respect to suburban office buildings and complexes.

To increase capacity and coverage, a cell area can be subdivided and assigned frequencies reused in closer proximities at lower power levels. Subdivision can be accomplished by dividing the geographic territory of a cell, or for example by assigning cells to buildings or floors within a building. While such "microcell" systems are a viable solution to capacity and coverage problems, it can be difficult to find space at a reasonable cost to install conventional base station equipment in each microcell, especially in densely populated urban areas. Furthermore, maintaining a large number of base stations spread throughout a densely populated urban area can be time consuming and uneconomical.

AT&T has proposed a system to solve the problem of coverage in urban areas without having to deploy a large number of conventional base stations. The system is shown and described with respect to FIG. **1** of AT&T's European Patent Application No. 0 391 597, published on Oct. 10, 1990. In that system a grid of antennas sites **40** is placed throughout the microcellular system. An optical fiber network **42** interconnects the antennas with the base station **44**. Optical wavelength carriers are analog modulated with RF mobile radio channels for transmission through the optical fiber network **26** to the antennas sites **22**. A detector circuit **27** is provided for each antenna site **22** to receive the modulated carrier and reconstruct an RF signal to be applied to the antenna sites **22**, for transmission into the microcell area **21**. RF signals received at antenna sites **22** from mobile units are likewise modulated onto a fiber and transmitted back through optical fiber network **26** to base station **25**. All of the channels transmitted from base station **25** are distributed to all antenna sites **22**. Also, all the channels transmitted from the base station **25** can be received from the mobile units in any microcell **21** and transmitted via optical fiber to base station **25**.

The above-described AT&T system has certain limitations. The ability to analog modulate and demodulate light, the limitations imposed by line reflections, and path loss on the fiber all introduce significant distortion and errors into an analog modulated signal and therefore limit the dynamic range of the signals which can be effectively carried via an analog system, especially in the uplink direction. These factors limit the distance from the base station to the antenna sites.

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Moreover, in AM systems an out-of-band signal is required to transmit control and alarm information to and from the antenna sites, again adding to the expense of the modulation and demodulation equipment. Moreover, provision of other services such as paging systems, personal communications networks (PCN's) or mobile data services are not easily added to analog AM systems such as that shown in AT&T's European application.

Furthermore, the AT&T system teaches the use of dedicated fiber lines installed for each remote antenna site. It would be desirable if preexisting transmission lines or fiber paths could be utilized so that installation of new fibers could be avoided.

Another approach to increasing coverage is disclosed in U.S. Pat. No. 4,932,049 to Lee. The Lee patent describes a "passive handoff" system wherein a cell is subdivided into several zones, with a directional antenna oriented to cover each zone. All the antenna's in the cell are serviced by the same set of transmitters and receivers. A zone switch is used to selectively connect the transmitters and receivers to the antenna units. In operation, the antenna best able to service a mobile unit on a given channel is connected to the transmitter/receiver pair assigned to the mobile unit by the MTSO, and the other antennas disconnected from that transmitter/receiver pair. To control the switching of transmitters and receivers to the antennas, a scanning receiver continuously polls the strength of signals received at the antenna units on all active channels in the cell. The zone having the best receiver signal strength is selected as the active zone for the associated channel. The system disclosed in the Lee patent thus allows for improving communications with mobile units while at the same time reducing interference with other cells by directionalizing and limiting overall signal strength in a cell.

SUMMARY OF THE INVENTION

The present invention provides improved coverage and increased capacity by assignment of reusable channel sets throughout the microcell system, without the need to deploy independent, conventional base stations in each microcell area. It also provides good dynamic range over extended distances as compared to analog systems such as the AT&T system described above.

According to one exemplary embodiment of the present invention, there is provided a microcell system wherein a plurality of commonly located microcell base station units communicate with a corresponding plurality of microcell antenna units deployed in respective microcell areas. Each base station unit includes conventional RF base station transmitter and receiver pairs, one for each channel assigned to the microcell. Additional receivers are also provided to receive diversity channels. The RF signal outputs from the transmitters are combined and applied to a broadband analog-to-digital converter. The digitized signal is transmitted over optical fiber to a microcell unit. Each microcell unit receives a digitized RF signal and reconstructs the analog RF signal using a digital-to-analog converter. The reconstructed RF signal is applied to a power amplifier, the output of which is fed to an antenna for broadcast into the microcell area.

The antenna units include both a main and a diversity antenna. The antennas each independently receive RF signals from the mobile units. The RF signal from the main antenna is filtered through a first set of filters, one for each channel assigned to the microcell, and the combined filtered main signal applied to an analog-to-digital converter. A second set of filters receives the diversity signal from the diversity antenna. The diversity signal is also applied to an analog-to-digital converter. The digitized main signal and diversity signal are multiplexed and transmitted over the optical fiber back to the microcell base station. The base station in turn includes a pair of digital-to-analog converters which reconstruct the main and diversity analog RF signals for application to the receivers. The strongest signal is selected for use in accordance with conventional diversity technology. Conventional circuitry interfaces the transmitters and receivers to the MTSO.

Thus, the exemplary embodiment outlined above contemplates that the microcell base station/antenna unit pairs are arranged to provide a reusable pattern of channels (as in conventional cellular technology) in the microcell system. The microcell base station units do not normally include an antenna, and can be located in a convenient and preferably low cost location, which may be outside of the microcell system territory if desired.

According to another exemplary embodiment, the invention may be deployed to extend the coverage in a conventional cell. In this embodiment, the base station may include an antenna for transmission and reception of analog RF directly from the transmitters and receivers, while at the same time transmitting and receiving from a microcell antenna unit using the digital carrier over a fiber as described with respect to the first exemplary embodiment.

According to another exemplary embodiment of the invention, the digitized microcell traffic is carried in a frame format to and from the antenna units. Each frame includes a plurality of bits assigned to carry a sample of the digitized microcell traffic, with other bits employed for control and monitoring of equipment, error detection and correction, and end-to-end point-to-point voice traffic between the base station and the antenna unit. Alternate services such as personal communications network traffic, paging services and mobile data services may also be carried using the framing format.

According to yet another exemplary embodiment of the invention, the fiber carrier may be replaced with cable or other carrier medium.

According to still anther exemplary embodiment, the invention can be deployed to distribute a single set of channels to a plurality of microcell areas. In this embodiment, a single base station unit sends the same set of digitized channels to a plurality of microcell antenna units, which in turn return the same set of channel signals to the microcell base station.

Therefore, the invention eliminates the problems associated with analog AM (or FM) systems, such as that illustrated in the above-mentioned AT&T application, by using a digital transport resulting in better signal quality and for greater range between a base station and a microcell antenna unit. As employed in one exemplary embodiment, the invention greatly increases system capacity over existing mobile telephone systems without the requirement of deploying conventional base station equipment in each microcell area, and allows for provision of alternative services such as paging systems, mobile data services or personal communication networks. The present invention also improves the dynamic range of the signal and extends the distance signals may be reliably transported from the base stations to the antenna units. In another exemplary embodiment, the invention provides readily for the transmission of control and monitoring information to and from the microcell antenna unit.

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To provide additional advantages, an exemplary all-digital embodiment of a microcell system is also provided wherein a plurality of commonly located digital microcell base station units communicate with a corresponding plurality of microcell antenna units deployed in respective microcell areas. According to this all digital embodiment, the base stations are fully digital and synthesize a digital signal directly from the T1 carrier received from the MTSO. The digital signal is transmitted over optical fiber to the microcell units. The microcell units receive the digital signal, and construct an analog RF signal using a digital-to-analog converter. The RF signal is applied to a power amplifier, the output of which is fed to an antenna for broadcast into the microcell area. The antenna units receive RF signals from the mobile units. The RF signal is filtered through a set of filters, one for each channel assigned to the microcell, and the filtered signal applied to an analog-to-digital converter. The digitized signal is transmitted over the optical fiber back to the digital microcell base station. The base station in turn directly synthesizes the digital signal onto the T1 carrier back to the MTSO. Conventional circuitry interfaces the transmitters and receivers to the MTSO. Thus, this exemplary embodiment contemplates that the microcell base station units are fully digital and eliminate the need for RF equipment at the base station as well as for analog-to-digital and digital-to-analog converters, thus providing the opportunity to reduce both the cost and volume of equipment required at the base station site, and to reduce maintenance needs on inherently less reliable analog equipment. The digital microcell base station units can be located in a convenient and preferably low cost location, which may be outside of the microcell system territory if desired.

A method which allows for the rapid deployment of a system of the type using analog-type base stations while permitting the easy upgrade of such base stations to all digital technology is also provided. The method's first stage calls for deploying a plurality of microcell base station units as described above, each including conventional RF base station transmitters and receivers, one for each channel assigned to the microcell.

In the second stage of deployment, the analog base stations are replaced with all-digital base stations wherein the base stations are fully digital and synthesize a digital signal directly from the T1 carrier received from the MTSO. The digital signal is transmitted over optical fiber to the microcell antenna units installed in the first stage of deployment. The microcell antenna units receive the digital signal, and construct an analog RF signal using a digital-to-analog converter. The RF signal is applied to a power amplifier, the output of which is fed to an antenna for broadcast into the microcell area. The antenna units also receive RF signals from the mobile units. The RF signal is filtered through a set of filters, one for each channel assigned to the microcell, and the filtered signal applied to an analog- to-digital converter. The digitized signal is transmitted over the optical fiber back to the digital microcell base station. The base station in turn directly synthesizes the digital signal onto the T1 carrier back to the MTSO.

Thus, the exemplary embodiment outlined above contemplates that the antenna units installed in the first stage do not need alteration or replacement when the analog microcell base station units are replaced with all digital microcell base stations. The method thus allows the full benefit of the all-digital base station to be accomplished without the expense of modifying existing installed microcell antenna units.

According to yet another alternate, exemplary embodiment, the digitized RF signal, carrying either microcell or PCN traffic, is framed for transmission over a switched telephone network. In this embodiment, a limited number of digitized microcell or PCN channels are grouped together, in a standard framing format for transmission using a standard DS-3, OC-1, or other protocol.

In yet another alternate, exemplary embodiment, digitized microcell or PCN RF signals are transmitted over the installed fiber infrastructure of a cable system from the head end to the optical nodes, in an amplified modulated (AM) format.

A still further exemplary embodiment contemplates the transmission of the microcell or PCN traffic in digital form over the cable system feeder lines, using QAM modulation or other digital modulation formats.

Thus, according to these embodiments, microcell or PCN channels may be transmitted over an established switched network or using established cable system infrastructure.

According to still another embodiment of the invention, there is provided a passive handoff system using digital signal analysis to rapidly switch transmitters and receivers among different antenna units in different microcell zones of a cell.

According to yet still another embodiment of the invention, there is provided decimation filters for digitally filtering out a selected number of channels from the digital stream output from the analog-to-digital converter, and multiplexing the selected channels onto one or more lower speed carriers, such as a T1 line or SONET carrier.

According to yet still another embodiment of the invention, a passive switching method is described for use in a cellular phone system having a plurality of macrocells including a first macrocell, each macrocell sharing a common set of channels, the method comprising the steps of providing a plurality of primary and secondary microcell antenna units; dividing the first macrocell into a plurality of primary microcells, wherein the step of dividing includes placing the primary microcell antenna units so as to provide coverage over the first macrocell; providing a plurality of secondary microcell antenna units; placing the secondary microcell antenna units to provide macrocell coverage overlapping the primary microcells; at a base station, generating a digitized representation of a telephone signal received from a mobile telephone switching office, selecting a microcell from said plurality of primary and secondary microcells and transmitting the digitized representation to the microcell antenna unit of the selected microcell; receiving, at the selected microcell, the digitized representation, generating a corresponding RF signal by digital-to-analog conversion, and broadcasting the RF signal in the selected microcell; receiving RF signals in each of the plurality of primary and secondary microcells for the set of channels, and converting the RF signals received to corresponding digitized RF signal representations for transmission back to the base station; at the base receiving the digitized RF signal representations from the primary and secondary microcells; and monitoring the digitized RF signal representations from each of the primary and secondary microcells and based on the energy level of each channel in each zone, selectively controlling the channels broadcast into each of the primary and secondary microcells and selectively choosing the microcell from the plurality of primary and secondary microcell in which a received channel is received so that passive switching may be accomplished.

According to yet still another embodiment of the invention, a method of sectorizing coverage over a particular cellular communications area is described, the method com-

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prising the steps of providing a remote unit having a plurality of microcell antenna units, including a first and a second microcell antenna unit, wherein each microcell antenna unit comprises an antenna configured to cover a particular sector and a channel filter unit used to filter channels assigned to the particular sector; connecting the remote unit to a sectorized base station unit, wherein the step of connecting comprises providing a unique sector frequency associated with each antenna unit sector; connecting the sectorized base station unit to a mobile telecommunications switching office; generating, at the sectorized base station unit, a digitized representation of a telephone signal received from the mobile telephone switching office; transmitting the digitized representation to the microcell antenna unit for a particular sector; receiving, at the first microcell antenna unit, a first RF signal, digitizing the first RF signal and converting the digitized first RF signal to a first sector frequency; receiving, at the second microcell antenna unit, a second RF signal, digitizing the second RF signal and converting the digitized second RF signal to a second sector frequency; and multiplexing the digitized first RF signal at the first sector frequency and the digitized second RF signal at the second sector frequency and transmitting the multiplexed signal to the sectorized base station.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the invention and its various features, objects and advantages may be obtained from a consideration of the following detailed description, the appended claims, and the attached drawings in which:

FIG. **1A** is a functional block diagram of a first prior art mobile communications system;

FIG. **1B** is a functional block diagram of a prior art base station;

FIG. **1C** is a functional block diagram of a prior art microcell mobile communications system;

FIG. **2** is a simplified block diagram of an exemplary embodiment of the microcell communications system of the present invention;

FIG. **3** is a more detailed block diagram of the base station embodiment shown in FIG. **2**;

FIG. **4** is a more detailed block diagram of the base station shown in FIG. **3**;

FIG. **5** is a more detailed block diagram of the frame generator/multiplexer **134** shown in FIG. **4**;

FIG. **6** is a simplified diagram of the structure of one exemplary data frame;

FIG. **7** is a diagram of the structure of another exemplary data frame;

FIG. **8** is a functional block diagram of a microcell antenna unit according to the exemplary embodiment shown in FIG. **2**;

FIG. **9** is a functional block diagram of the demultiplexer **142** and associated interfaces of FIG. **4**;

FIG. **10** is a functional block diagram of an all-digital exemplary embodiment of the invention;

FIG. **11A** is a more detailed block diagram of the system illustrated in FIG. **10**;

FIG. **11B** is an alternative embodiment of the system illustrated in FIG. **11A**;

FIG. **11C** is yet another alternate embodiment of the system illustrated in FIG. **11A**;

FIG. **11D** is still another alternative embodiment of the system illustrated in FIG. **11A**;

FIG. **12** is a simplified illustration of an alternate embodiment of the microcell communication system according to the present invention;

FIG. **13** is a functional block design of the alternate embodiment **106'** of the system of FIG. **12**;

FIG. **14** is another alternate exemplary embodiment of the microcell communication system of the present invention;

FIG. **15** illustrates yet another alternate exemplary embodiment of the invention wherein alternate services, such as personal communication network (PCN) traffic and paging traffic is multiplexed with cellular system traffic;

FIG. **16** is a simplified illustration of a prior art cable television system infrastructure;

FIG. **17** is a simplified block diagram of an alternate exemplary embodiment of the invention, wherein cable system infrastructure is used to transmit digitized RF to and from a microcell location;

FIG. **18** is a block diagram of a base station unit of the exemplary embodiment of FIG. **17**;

FIG. **19** illustrates the head end unit located at the head end of the cable system of the exemplary embodiment of FIG. **17**;

FIG. **20** is a more detailed block diagram of the AM modulator/demodulator, located in the head end of the cable system of the exemplary embodiment of FIG. **17**;

FIG. **21A** is a more detailed block diagram of analog-to-digital converter **132**, as used throughout the various embodiments in the invention;

FIG. **21B** is a more detailed block diagram of digital-to-analog converter **144** as used throughout the various embodiments of the invention;

FIG. **22** is an alternate preferred framing structure for the embodiment of FIG. **2** of the present invention;

FIG. **23** is yet another alternate preferred framing structure for the embodiment of FIG. **2** of the present invention;

FIG. **24** is a more detailed block diagram of the microcell remote unit to be positioned at the optical node in the cable system embodiment of FIG. **17**;

FIG. **25** is an illustration of the amplitude modulator as used in the embodiment of FIG. **17**;

FIG. **26** is a more detailed illustration of the amplitude demodulator, as used in the embodiment of FIG. **17**;

FIG. **27A** is an illustration of a base station of an alternate exemplary embodiment of the system illustrated in FIG. **17**, wherein the RF microcell or PCN signal is digitally modulated;

FIG. **27B** is an illustration of an alternate embodiment of the system illustrated in FIG. **17**, wherein the RF microcell or PCN signal is digitally modulated;

FIG. **28** is a further illustration of the alternate embodiment using digital modulation;

FIG. **29** further illustrates the construction of the optical node in the digital modulation embodiment;

FIG. **30** is an overview diagram of yet another exemplary embodiment wherein digitized microcell or PCN RF traffic is framed and transmitted over a switched telephone network;

FIG. **31A** is a more detailed block diagram of the base station units of the embodiment of FIG. **30**;

FIG. **31B** is an alternate exemplary embodiment of the base station units of the embodiment of FIG. **30**;

FIG. **32A** is a more detailed block diagram of the analog-to-digital converter and framing circuits of the base station units illustrated in FIG. **31A**;

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FIG. **32**B is a more detailed block diagram of the analog-to-digital converter and framing circuits of an alternate exemplary embodiment of the base station units illustrated in FIG. **31**B;

FIG. **33**A is a more detailed block diagram of the remote antenna units of the system illustrated in FIG. **30**;

FIG. **33**B is a more detailed block diagram of an alternate exemplary embodiment of the remote antenna units of the system illustrated in FIG. **30**;

FIG. **34** illustrates yet another exemplary embodiment of the invention wherein digitized RF signals are transmitted over a switched telephone network and a cable system; and

FIG. **35**A is an overview functional block diagram of an exemplary embodiment of a microcell communications system, having passive handoff capability according to the present invention;

FIG. **35**B is a more detailed block diagram of an exemplary base station unit **114'** of the system of **35**A according to the present invention;

FIG. **35**C is a schematic illustration of the movement of a mobile unit from one zone to another;

FIG. **36** shows an exemplary embodiment of digital transmitting/receiving unit **130"** of the system of FIG. **35**A;

FIG. **37** illustrates an exemplary embodiment of controller **810** of the system of FIG. **35**A;

FIG. **38** is a simplified block diagram of the operation of controller **810** of the system of FIG. **35**A;

FIGS. **39**A, **39**B, **39**C and **39**D are still other alternate exemplary embodiments of passive handoff systems with all-digital base station units;

FIG. **40** is an alternate embodiment of the system of FIG. **35**B;

FIGS. **41**A, **41**B and **41**C are exemplary embodiments of redundant microcell coverage;

FIG. **42** is a simplified block diagram of an exemplary embodiment of a sectorized microcell communications system according to the present invention;

FIG. **43** is a more detailed block diagram of the base station embodiment shown in FIG. **42**;

FIG. **44** is a more detailed block diagram of the remote unit embodiment shown in FIG. **42**;

FIG. **45** is a more detailed block diagram of one example of a channel filter unit which can be used in the remote unit shown in FIG. **44**;

FIG. **46** is an alternate embodiment of the base station embodiment shown in FIG. **42**; and

FIG. **47** is an alternate embodiment of the remote unit embodiment shown in FIG. **42**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the following detailed description of exemplary embodiments of the invention, reference is made to the accompanying drawings which form a part hereof, in which like numerals refer to like elements throughout the several views, and which is shown by way of illustration only, specific embodiments in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present invention.

The general configuration of one exemplary embodiment of the present invention is shown in FIG. **2**. The microcell system includes a plurality of microcell areas **100**. Deployed within each microcell area **100** is a microcell remote antenna unit **102**. Such units may be deployed on the roof of a building or within a building, or on or in other structures. For example, a microcell antenna unit **102** may be deployed on each floor of a building on or adjacent an antenna tower, or along a highway corridor.

Remote antenna units **102** are connected through fiber **104** (or optionally another high bandwidth carrier) to respective base station units **106**. Base station units **106** are interfaced to MTSO **110** over T1 lines **112**. MTSO **110** is interfaced with a switched telephone network **120**, as in a conventional cellular phone system. Microcell base station units **106** are preferably located in a single location **114**. Such location may be inside or outside of the area serviced by the microcell system, but in any event is preferably conveniently located for maintenance purposes.

Referring now to FIG. **3** there is shown a simplified diagram of a microcell base station **106** according to one exemplary embodiment of the present invention. Base station **106** includes conventional transmitters and receivers **23** and **28**, respectively, and conventional radio controller or interface circuitry **22** to the MTSO **110**. A digital transmitter/receiver unit **130** receives the combined RF signal from transmitters **23**, digitizes the combined signal and transmits it in digital format over fiber **104**A connected to a remote antenna unit **102**. Unit **130** also receives a digitized RF signal over fiber **104**B from a remote antenna unit **102**, reconstructs the corresponding analog RF signal, and applies it to receivers **28**. Accordingly, conventional equipment may be used on the downstream (MTSO) side of digital transmitting/receiving unit **130**.

Referring now to FIG. **4**, there is shown digital transmitting/receiving unit **130** in greater detail. Unit **130** includes a broadband digitizer **132** receiving the combined RF signal from transmitters **23**. Digitizer **132** provides a digitized microcell traffic stream, consisting of a series of samples of the incoming analog RF signal. Frame generator/multiplexer **134** frames the digitized microcell traffic data, together with control, voice and error checking data, and applies it to a digitally modulated laser **136**. The voice data channel, also termed the order wire channel, originates from order wire interface **135**, which has an input for a handset **137** or a two-wire phone line. Order wire interface **135** provides for two-way point-to-point voice grade communications. Typically a handset is used at the remote site to connect with a handset at the base site. Control signals originate from control/alarm circuit **131**, which generates control information for the remote antenna unit **102** to monitor error and alarm information.

The laser signal from digitally modulated laser **136** is applied to fiber **104**A for transmission to the corresponding remote antenna unit **102**. According to one possible embodiment, digitizer **132** preferably provides a 24 bit wide word (parallel structure sample) running at 30.72 MegaSamples/second (MSamples/s). The frame generator/multiplexer **134** converts the 30.72 MSamples/s word to a single serial bit stream running at 819.2 MegaBits/second (Mb/s).

The digitizer **132** conditions the broadband RF signal by providing bandpass filtering sufficient to eliminate out of band signals, and sufficient gain adjustment to prevent overloading of the analog-to-digital converter. The analog-to-digital converter converts the conditioned broadband RF signal into a parallel bit stream, either by direct sampling at RF, or by sampling following down-conversion to baseband or to an intermediate frequency band. In the preferred

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embodiment, the digitizer is obtained from Steinbrecher Corporation of Woburn, Mass., with sampling performed on a 12.5 MHz wide signal down-converted to either the first or second Nyquist zone, with 12 bit sampling occurring at a rate of 30.72 MSamples/s.

Unit **130** further includes a digital optical receiver **140**. Receiver **140** outputs an electronic digital signal, which is applied to demultiplexer **142**, which extracts the digitized microcell traffic data generated at the remote antenna unit **102**, as will be explained further below. Demultiplexer **142** further extracts alarm (monitoring) and voice information framed with the microcell traffic data. The digitized microcell traffic signal is applied to digital-to-analog converter **144**, which reconstructs the analog RF signal, to be applied to receivers **28**.

The digital-to-analog converter **144** operates on the microcell traffic parallel bit stream extracted by demultiplexer **142**, reconstructing a baseband replica of the broadband RF signal digitized by digitizer **132**. The baseband replica is then up-converted to its original radio frequency by mixing with a local oscillator and filtering to remove image frequencies. In the preferred embodiment, the digital-to-analog converter is obtained from Steinbrecher Corporation of Woburn, Mass., and operates at the preferred sample rate of 30.72 MSamples/s.

Referring now to FIG. **21**A, there is illustrated in more detail the broadband digitizer or analog-to-digital converter circuit **132** in FIG. **4** and **170** in FIG. **8**. Analog-to-digital converter circuit **132** preferably includes a local oscillator **132**A, which applies its output to mixer **132**B, which receives the combined output from the transmitters **23**. Mixer **132**B reduces the high frequency microcell signal (approximately 850 MHz in the case of conventional cellular phone service or approximately 1.8 GHz in the case of PCN traffic), to an intermediate (or baseband) frequency of approximately 1 to 15 MHz (such that the 12.5 MHz frequency fits between these limits) prior to application to analog-to-digital converter **132**C.

Illustrated in FIG. **21**B is the digital-to-analog converter **144** and **164**, of FIGS. **4** and **8**, respectively, which performs the reverse operation of analog-to-digital converters **132** and **170**. Digital-to-analog converter **144** includes a digital-to-analog converter **144**A, which outputs an intermediate frequency signal, which is up-converted with mixer **144**B, using the local oscillator **144**C. Up-conversion restores the operating frequency of the RF to the broadcast frequencies of the cellular or PCN systems.

Referring now to FIG. **5**, there is shown in greater detail the frame generator/multiplexer circuit **134** according to the exemplary embodiment of the invention shown in FIG. **4**. Circuit **134** includes a cyclic redundancy check (CRC) generator **155**, which receives microcell traffic data from digitizer **132** and outputs a CRC code.

According to one exemplary embodiment, framer/multiplexer **154** multiplexes the CRC channel, microcell traffic, order wire (voice) channel and control (alarm) channel into the frame structure illustrated in FIG. **6**. Each frame includes a 12-bit microcell traffic word, a one bit CRC channel, a one bit control-alarm/order wire channel and a six bit framing word. The control-alarm and order wire data are multiplexed together in a single channel.

FIG. **7** shows an alternate frame structure having 12 bits for the main antenna channel, 12 bits for 12.5 MHz coverage of alternate service or diversity channel, a one or two bit CRC channel, 1 bit control-alarm channel and 6 bit frame word. Other possible framing structures could involve a total of 48 information bits for full band coverage and diversity capability, or for carrying additional services. It shall be understood that the present invention is not limited to these or any other particular framing format, but rather that any format could be used without departing from the scope of the present invention.

To achieve synchronization with the parallel transfer word, the frame signal shown in FIGS. **6** and **7** runs at 819.2 Mb/s (i.e. $32 \times 25.6 \times 10^6$ bits/second=819.2×10^6 bit/second). (The bit rate and sampling rate for 40 MHz/48 bit or other frame structure would change accordingly.) Synchronization is achieved at the receiving demultiplexer **142** (**162** in FIG. **8** described below) by searching for the frame pattern. Thirty-two individual frames are grouped into a superframe. One of the 32 frames has a bit sequence different from the other 31 frames. Each frame byte is a balanced code having an equal number of ones and zeros. The frame search is initiated by the demultiplexer **142** to find consecutive patterns, followed by a search for the unique bit sequence in one of the 32 frames. When the frame and superframe are found by the demultiplexer **142** (or **162**), valid traffic pattern or data patterns result. Framing methods of this type are well known in the telecommunications arts, and those of skill in the art will recognize that various alternate framing methodologies may also be used. Preferably, frame generator/multiplexer **134** includes circuitry for scrambling the outgoing data to provide for the balanced line code preferred for fiber optic transmission.

Referring now to FIGS. **22** and **23**, there are shown the alternate preferred framing structures of the embodiment of FIG **2**. As shown in FIG. **22**, the framing structure includes 12 bits of PCN/microcell traffic, one framing bit, one bit of CRC and an alarm-control/order wire channel, and four reserve bits. The framing structure in FIG. **23** is identical, except for 13 bits have been allocated to the PCN/microcell traffic. Neither of these framing structures is designed to accommodate diversity traffic, however, they could be so expanded. The framing structures of FIGS. **22** and **23** assumes a 12 bit sampling at 30.72 Mb/s. The basic framing structure is 18 bits, which, when run at 30.72 Mb/s, results in a rate of 552.96 Mb/s serial rate. As shown in FIG. **22**, one bit is dedicated to framing. Another bit is multiplexed between CRC, alarm-control, and the order wire function. These two bits achieve framing and multiplexing by virtue of the following sequence:

Framing Bit	CRC, Etc.
00	Frame 1
01	Frame 2
10	Frame 3
10	Frame 4
1C	Frame 5
1D	Frame 6

As illustrated above, the framing structure of this embodiment contemplates that six frames make up a "super frame." The first four frames of each super frame include the 00, 01, 10, 10 sequence. In the fifth frame, the framing bit is a 1, and the other bit represents one bit of CRC code. In the sixth frame, the framing bit is a 1 and the other bit is an alarm-control/order wire channel bit.

Preferably, the CRC code is 32 bits wide, so that 32 frames must be received in order to accumulate the entire CRC code. Accordingly, errors are checked every 32 words of data. As in the case of the previously described framing structure, a balanced line code is provided.

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Referring now to FIG. **8**, there is shown a block diagram of the remote antenna unit **102**, according to the first exemplary embodiment of the present invention. A digital optical receiver **160** receives the optical digital data stream transmitted from the microcell base station on fiber **104**A. Receiver **160** converts the optical data stream to a corresponding series of electrical pulses, which are applied to demultiplexer **162**. Demultiplexer **162** extracts the microcell traffic and applies the 12-bit (or 13-bit) samples to digital-to-analog converter **164**. Converter **164** reconstructs the analog RF signal and applies it to linear power amplifier **24**. Converter **164** is preferably the same as digital-to-analog converter **144** described and shown above with respect to FIG. **4**. Amplifier **24** is connected to the main antenna **26** through a duplexer **25**. Accordingly, radio frequency signals originating from transmitters **23** in the microcell base station are transmitted from main antenna **26**. Demultiplexer **162** also extracts control signals for application to a control/alarm circuit **161**. Order wire data is also extracted and applied to order wire interface **163** to provide two-way, point-to-point voice grade communication.

RF signals received at main antenna **26** are passed through duplexer **25** to filter **27**. Power amplifier **24**, duplexer **25**, main antenna **26** and filter **27** are conventional base station components, as are described with reference to FIG. **1**B. The output of filter **27** is combined and applied to a broadband analog-to-digital converter **170** (of the same type as **144** described above with respect to FIG. **4**), which digitizes the analog RF signal and applies it to a frame generator/multiplexer circuit **172**. The output of circuit **172** is applied to digitally modulated laser **174**, which applies the corresponding optical digital stream to fiber **104**B. Frame generator/multiplexer **172** is of substantially the same design as framer/multiplexer **34**. It receives an alarm (or monitoring) signal data stream from control/alarm circuit **161**, and an order wire data stream signal from order wire interface **163**.

Optionally, remote antenna unit **102** may include a diversity antenna system **180**. System **180** includes a diversity antenna **26'**, which applies its output to filter **27'** and in turn to broadband analog-to-digital converter **170'**, which operate in the same manner as main antenna **26**, filter **27** and broadband analog-to-digital converter **170**, respectively. The output of analog digital converter **170'** is applied to circuit **172**, which multiplexes the digitized RF signal from the diversity antenna into the data stream applied to fiber **104**B. In such a case, the framing scheme includes diversity traffic capacity.

Referring now to FIG. **9**, there is shown in greater detail demultiplexer circuit **142** (and correspondingly **162**) shown in FIG. **4** and FIG. **8**. Circuit **142** (**162**) includes a demultiplexer **190**, which receives the digital data stream from digital optical receiver **140**. Demultiplexer **190** extracts the control/alarm channel, order wire channel, CRC channel and microcell traffic channel from the digital data stream. Optionally, where the diversity function is provided, the diversity CRC channel and diversity microcell channel are also extracted. The main CRC channel and microcell traffic channel are applied to CRC checking circuit **192**, which provides an error signal to the control/alarm circuit **131**. Circuit **131** monitors the error rate of data and alarms occurring at the remote antenna unit **102**. The order wire channel is applied to order wire interface **163**, to provide two-way point-to-point communication.

Where diversity is optionally included, a second CRC checking circuit **192'** receives the diversity CRC channel and diversity microcell channel and produces an error signal which is applied to control/alarm circuit **131**.

ALL-DIGITAL EMBODIMENT

Referring now to FIG. **10**, there is shown an alternate exemplary embodiment **200** of the present invention. Alternate embodiment **200** includes a remote antenna unit **102** as described with respect to FIG. **8**. Remote antenna unit **102** is connected to an all-digital microcell base station **210** through fibers **104**A and **104**B. Microcell base station **210** is connected to an MTSO.

All-digital microcell base station **210** is shown in more detail in FIG. **11**A. Circuit **210** includes a T1 interface **202**, which extracts digitized voice channels carried by a T1 line or other carrier from an MTSO and applies those channels in digital form to digital synthesizer **212**. Digital synthesizer **212** replaces transmitters **23** and the analog-to-digital converter **132** of the embodiment shown in FIG. **4**. Digital synthesizer **212** constructs, with digital logic or software, an equivalent to the digitized output of broadband digitizer **132** for application to frame generator/multiplexer **214**. Synthesis may be accomplished, for instance, by electronic or software simulation of the generation of the analog telephone signal and the modulation of the transmittal signal therewith. The simulated signal transmitter output signal can then be directly represented in digital form that can be processed to emulate the output of the A/D converter.

An alternate embodiment of the system of FIG. **11**A is shown in FIG. **11**B. In the system of FIG. **11**B, the synthesizer **212'** receives an analog input from radio controller **22**, and converts the analog output signals (corresponding to analog telephone signals) from the radio controller **22** into a corresponding digitized traffic stream. In this process, for example, synthesizer **212'** can first digitize the individual analog input signals, and then process them digitally to produce the digitized signal for delivery to units **106**. On the return path, digital demodulator **224'** produces a plurality of analog telephone signals compatible with the input to the radio controller **22**. Multiplexer **214** operates in the same fashion as described with respect to frame generator/multiplexer **134** described above with respect to FIGS. **4** and **5**. The output of frame generator multiplexer **214** is applied to digitally modulated laser **216**, which outputs the optical data stream on fiber **104**A. Digital optical receiver **220** receives the optical data stream from fiber **104**B and applies it to demultiplexer **222**, which operates in the same fashion as demultiplexer **142** of FIG. **4**. The output of demultiplexer **222** is applied to digital demodulator or receiver circuit **224**, which extracts the microcell channels and applies them to T1 interface **202** for transmission to the MTSO.

Yet another alternate embodiment of the all digital base station is shown in FIG. **11**C. In FIG. **11**C, the frame generation/multiplexer **211'** is modified to apply its output directly to the switched telephone network, in a format compatible with network protocols, for example DS1, DS3 or SONET. The switched network is then used to connect the base station with each antenna unit **106**. According to this embodiment, the modified synthesizer **212"** generates a separate digitized output (for example as shown below with respect to FIG. **32**B) for each channel being used (as opposed to all channels in the cellular band), such that only the digitized form of the channels used for each antenna unit **106** are actually transported thereto, thus greatly reducing the bandwidth required for this purpose. Similarly, demultiplexer **222'** is configured to receive the individually packaged digitized channels from the switched network, and demodulator **224"** is modified to receive and extract the individual channels. The embodiment of FIG. **11**B can also be modified in this manner, as is illustrated in FIG. **11**D.

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Thus, all-digital base station **210** synthesizes the effect of digitizing the transmitter data stream, providing for an all-digital conversion from circuit **202** to the data stream applied to fiber **104**A. The synthesized signal is received at the remote antenna unit **102**, which constructs the radio frequency signal, using digital-to-analog converter **164**, thus eliminating the need for transmitters **23**. Similarly, digital demodulator or receiver circuit **224** eliminates the need for receivers **28**, by converting the demultiplexed digitized RF data stream directly into digital phone channels for application to circuit **202** and transport to the MTSO.

Yet another exemplary alternative embodiment of the invention is shown in FIG. **12**. The alternate embodiment shown in FIG. **12** includes a base station **106'**, having an antenna **250** for broadcasting and receiving RF signals into a cellular area. In addition, **106'** includes one or more remote antenna units **102** used to reach shadowed areas. This embodiment is not for the purpose of extending capacity, but rather to improve coverage.

Referring to FIG. **13**, base station embodiment **106'** is shown in more detail. The configuration of FIG. **13** is the same as FIG. **3**, except the RF signals are connected simultaneously to a main cell site antenna through a duplexer and power amplifier.

Referring now to FIG. **14**, there is illustrated an alternate preferred embodiment of base station units **106** and antenna unit **102**. According to this alternate preferred embodiment shown in FIG. **14**, there are provided wave division multiplexers **270** at the base station **106** and remote antenna unit **102**. Wave division multiplexers **270** provide that a single optical fiber **271** can be used in place of a pair of optical fibers **104**A and **104**B, as shown with respect to the exemplary embodiment of FIG. **4**. Preferably, the wavelengths of operation for wave division multiplexers 270 are 1310 nm±20 nm, and 1550 nm±20 nm.

Yet another alternate exemplary embodiment of the invention is shown in FIG. **15**. In FIG. **15**, alternate service traffic (personal communication network (PCN) traffic and/or paging traffic as shown in FIG. **15**, for example) are multiplexed into the digital carrier and conveyed to the remote antenna unit **102** for transmission as part of a broadband signal reconstructed by the digital-to-analog converter. The remote antenna unit is modified to include separate analog-to-digital converter, digital-to-analog converter, filter, duplexer, linear power amplifier and antenna for the alternate service. The optical transceiver and fiber being shared with the microcell traffic. PCN transmissions are received at the remote antenna unit **102** and conveyed on the digital carrier back to the base station **106**. The additional services are carried over the same fiber simply by adding more bits per frame. Therefore, the embodiment of FIG. **15** can carry the traffic associated with several different alternate services and cellular traffic simultaneously, with minimal cost over straight cellular traffic. It is contemplated that yet other services can be carried, and the invention is in no way limited to microcellular, paging, PCN or mobile data service traffic.

Method of Installing and Upgrading the Microcell System

For ease of implementation of the present all-digital embodiment, two-stage deployment is contemplated. In the first stage, microcell base station units **106**, of the design shown in FIG. **3**, are deployed. These units may be readily constructed with conventional transmitter and receiver technology in the base station unit, and conventional interface circuitry to the MTSO. In the second stage, units **106** may be replaced or upgraded to all digital microcell base station units **210**, wherein the analog transmit and receive circuits are eliminated. This upgrade may be accomplished without changing remote antenna units **102**, and therefore may be done conveniently and expeditiously. This method of installation thus allows the initial units **106** to be constructed readily and at relatively low cost, and thus providing for rapid deployment, while allowing for upgrade to more reliable all-digital base station equipment without change to the remote antenna units **102**.

Thus, as described above, the present invention provides not only improved coverage, but also for increased capacity by assignment of reusable channel sets throughout the microcell system, without the need to deploy independent, conventional base stations in each microcell area. Also, by virtue of digital transmission, it also provides good dynamic range over extended distances as compared to analog systems.

The exemplary configuration illustrated with respect to base station **106** and remote antenna unit **102** provides control/alarm/monitoring and two-way point-to-point voice channels to be readily multiplexed on the digital carrier, providing advantages over analog systems such as that disclosed by AT&T. Furthermore, a diversity channel can also be multiplexed into the data stream to provide the diversity function without the need for additional fiber paths.

The invention also permits ready adaptation to carry alternate services such as PCN, mobile data and paging services together with microcellular traffic.

Another advantage of the invention is its ready adaptation to all digital base station technology, wherein microcell traffic data received from an MTSO in digital form can be digitally converted to a synthesized stream of data samples for application to the digital-to-analog converter in the remote antenna unit **102**.

It shall be understood that other control or monitoring type channels between the base station and antenna units are also possible, and that the invention is not limited to the particular channels illustrated in the exemplary embodiments.

Transmission of Microcell and PCN Traffic Over Cable System Fiber Feeders

A conventional cable system is illustrated in FIG. **16**. System **300** includes one or more satellite dishes **304** receiving satellite television signals from satellite **302**. In addition, the head end may receive video feeds from local sources or over other media such as fiber, coaxial cable or line of sight microwave link. Video unit **308** provides video signal splitting, and provides a video signal to AM transmitters **310**, which apply an amplitude modulated signal, typically down-converted prior to transmission, for application to a fiber feeder. The fiber optic feeder transmits the video signal to a optical node **312**, which processes the received signal for delivery to a plurality of homes **314**, typically over copper coax cable, or in state of the art installations, over a fiber link. In a typical suburban installation of the type most adaptable to the benefits of this exemplary embodiment, an optical node **312** preferably provides service to approximately 250 homes, covering a geographic area of approximately 1–2 square miles.

An exemplary embodiment of the present invention, wherein the cable system **300** is utilized to transmit microcell or PCN traffic to microcell areas will now be explained with reference to FIG. **17**. The system of FIG. **17** provides the advantage of using the installed infrastructure of a cable television system to transport microcell and PCN traffic. As shown in FIG. **17**, the head end of the cable system includes a head end microcell/PCN unit **332**, video multiplexer **308**, and a plain old telephone service (POTS) and data source

336. Although the provision of POTS and data service is included in this exemplary embodiment, it is not necessary to the delivery of cellular/PCN service, and may be omitted from the system. Preferably, the POTS/data are carried on a plurality of subcarriers within a certain band. A separate subcarrier would be assigned to each subscriber in the system. Similarly, the video channels are also contained on a plurality of subcarriers in a specified band. In addition, the microcell/PCN channels are also carried on separate subcarries in a defined band. The head end unit **332** is interfaced with a base station unit **330**, through a pair of fibers **331**A and **331**B. Base station unit **330** is interfaced to the switched telephone network **320** through a mobile telephone switching office (MTSO) **322**.

The head end further includes a plurality of AM modulator/demodulators **338**, which are coupled to microcell optical nodes **342** through fibers **340**A and **340**B. Optical nodes **342** each include an antenna for the transmission and reception of microcell or PCN traffic and are interfaced to a plurality of subscriber homes **343**. POTS/data source **336**, multiplexer **308** and head end **332** are each connected to the respective AM modulator/demodulators **338**, as more fully illustrated in FIG. **20**, to be explained further below.

Base station unit **330** is shown in more detail in FIG. **18**. Unit **330** functions identically to unit **106** as described above with reference to FIG. **3**. The base station unit **330** may be positioned, as in the embodiment of FIG. **2**, in a convenient location, remote from the head end. Alternatively, base station **330** could be located at the head end, with the elimination of the fiber link and other unnecessary components, such that the RF signal output of the transmitters may be filtered and applied directly to the AM modulator/demodulators **338** and in return the output of the AM modulators/demodulators **338** filtered and applied directly to the receivers **28**. Digital transmitter/receiver **130** of base station **330** is configured as illustrated in FIG. **4**.

As shown in FIG. **19**, head end unit **332** is configured substantially the same as unit **102** from the embodiment of FIG. **2**. RF digitization and framing for communication between the head end unit **332** and base station **330** is performed substantially the same as described above with regard to units **102** and **106**. However, the output of digital-to-analog converter **164** is applied to filters **335**, which filter the RF signal into a plurality of bands, each to be delivered to a particular microcell associated with a optical node **342**. In the exemplary illustrative embodiment illustrated herein, the channels of the microcell or PCN system are divided into a plurality of 1 MHz bands, each containing a plurality of channels of microcell or PCN traffic (for example ten 100 KHz channels or approximately thirty 30 KHz standard channels). Each of the AM modulator/demodulators **338** (shown in detail in FIG. **20**) receives a 1 MHz band of channels and conveys it to the microcell optical node **342** over the fiber **340**A and **340**B by AM modulation. In the reverse path, 1 MHz bands are received back from the microcell optical nodes **342** (over fiber **340**B), demodulated in an AM modulator/demodulator **338**, filtered by filters **337** and combined before application to broadband analog-to-digital converter **170**, on a return path to the base station unit **330**.

Referring now to FIG. **20**, there is illustrated in more detail a modulator/demodulator **338**. Each unit **338** includes an AM modulator **338**A, which receives a POTS/data input signal, a video input signal, and a PCN/microcell traffic input signal. AM modulator **338**A combines the signal inputs and produces an AM modulated signal for application to AM optical transmitter **338**B, which in turn applies its optical wavelength output to fiber **348**. On the return path, AM demodulator **338**C receives an input from AM optical receiver **338**D, and provides an output of PCN/microcell and diversity traffic, together with a POTS/data output signal.

Referring now to FIG. **24**, the microcell optical node unit **342** is shown in more detail. Unit **342** includes an AM optical receiver **400**, which receives the AM modulated signal from an AM modulator/demodulator **338**. The output of optical receiver **400** is applied to an AM demodulator **402**, which outputs a POTS/data signal and a video signal. The POTS/data is to be delivered to subscriber homes over the optical node to home data transmission medium. The video signal is also supplied to subscriber homes over the transmission medium (usually coaxial cable, or possibly fiber). The PCN/microcell traffic is separately outputted from AM demodulator **402** and applied to an up-converter comprising mixer **404** and local oscillator **406**, where it is restored to its operating frequency. The signal is amplified with amplifier **408** and applied through duplexer **410** for transmission into the microcell area via a main antenna **412**. According to the exemplary embodiment disclosed herein, the channels carried in the 1 MHz band, are transmitted from the antenna unit at the optical node. RF signals received at antenna **412** are fed through duplexer **410** and are applied to filter **420**. Diversity antenna **424** may optionally be provided with its output applied through filter **426** to a mixer **428**. A local oscillator provides an input to mixer **422** and mixer **428**, effecting a down-conversion of the received PCN or microcell traffic before application to AM modulator **432**, together with return POTS/data traffic. AM modulator **432** combines the main channel, diversity channel and POTS/data signals and modulates them onto fiber **340**B through AM optical transmitter **434**.

The AM modulators (**338**A, **432**) and demodulators (**338**C, **402**) are illustrated in more detail in FIGS. **25** and **26**. Referring now to FIG. **25**, there are shown in more detail AM modulator **338**A. The POTS/data, video channel and microcell/PCN channel signal sources are applied to respective mixers **350**, **352** and **354**, where they are frequency shifted to a desired frequency for combination at combining circuit **356**. The combined signals applied to a conventional modulator AM modulator **358**.

As shown in FIG. **26**, on the return path, the AM signal is applied to a conventional AM demodulator **360**, the output of which is filtered by filters **362** and **364** for application to respective mixers **366** and **368**, where the bands are restored to their desired carrier frequency.

Thus, as described above, the alternate embodiment illustrated generally in FIG. **17** provides that microcell or PCN traffic may be carried over the installed fiber distribution system of an existing cable TV system. In addition, the system illustrates the provision of POTS/data service utilizing the same system. However, the additional provision of POTS/data service is in no way essential for the invention.

Alternate Digital Modulation/Demodulation

In the above-described system, the digitized RF signal is converted to an analog form prior to being transported to the remote optical node unit **342**. According to the alternate exemplary embodiment now to be described, the digitized form of the RF signal may be maintained through to the remote optical node units **342** by use of digital modulation such as QAM modulation. In the alternate exemplary embodiment of FIG. **27**A, groups **453** of transmitters apply a combined output to the input of corresponding analog-to-digital converters **456** (including down-conversion to an intermediate or baseband frequency), and the framer/

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multiplexer **458** frames the digitized transmitter group signals so that these groups may be extracted from the framing structure at the other end of the link. Similarly, a demultiplexer **459** demultiplexes a received signal and applies a corresponding digitized signal to each of analog-to-digital converters **457** (including up-conversion) for application to respective receiver groups **455**. Diversity output is also optionally provided. The transmitter groups may, for example, contain up to ten transmitters, so that the combined digitized bandwidth is approximately 1 MHz, consisting of approximately 300 KHz of spectrum digitized at a 2+X rate, plus framing and control bits. The alternate digital modulation embodiment of the head end unit **332'** is illustrated in FIG. **27B**. Although this embodiment shall be described with respect to QAM modulation, it shall be understood that other forms of digital modulation are also within the scope of the present invention. According to this embodiment, the digitized RF received at the head end unit **332'** is demultiplexed in demultiplexer **450**, output group by group, and applied in digital form to a plurality of QAM modulators/demodulators **338'**, as illustrated in FIG. **28**. The return traffic from a QAM demodulator **464** is applied to a framer/multiplexer unit **452**, which in turn applies the digital signal back to fiber **331B** through digitally modulated laser **174**.

As illustrated in FIG. **28**, QAM modulator **460** receives a digital POTS/data input signal, a digital video signal and a digital PCN/microcell traffic signal. QAM modulator **460** multiplexes the input signals and produces a QAM modulated output signal for application to AM optical transmitter **462**, which is in turn applied to fiber **340A**. On a return path, AM optical receiver **466** receives a QAM modulated signal from optical fiber **340B** and applies an input to QAM demodulator **464**. Demodulator **464** demultiplexes the received signal and in turn produces a digital microcell/PCN signal and a digital POTS/data signal.

Referring now to FIG. **29** there is shown the alternate QAM embodiment of microcell optical node **342'**. Alternate optical node **342'** includes an AM optical receiver **500** receiving its input from fiber **340A**. QAM demodulator **502** receives an output from AM optical receiver **500** and demultiplexes and demodulates the signal for application to digital-to-analog converter **504**. Converter **504** outputs an intermediate or baseband frequency signal which is up-converted with mixer **506** and local oscillator **508** to the transmission frequency. The signal is applied to amplifier **510**, filtered with filter **512**, passed through duplexer **514** and transmitted from the main antenna unit **516**. On the return path, the RF signal is received at the main antenna unit **516**, passed through duplexer **514**, filtered at filter **518** and applied to a down-converter, comprising mixer **528** and local oscillator **530**. A diversity antenna **520** is optionally provided together with filter **522** and a down-converter comprising a local oscillator **526** and mixer **524**. The main antenna signal and diversity antenna signals are combined using combining circuit **532** and applied to analog-to-digital converter **534**. The output of analog-to-digital converter **534** is applied to QAM modulator **536**, which applies its output to AM optical transmitter **538**, which in turn applies its output to fiber **340B** for transmission to the head end.

Thus, as described above, this alternate exemplary embodiment provides a system for maintaining the RF or PCN signal in digital format all the way to the optical node unit **342**. It thus can advantageously provide a higher quality signal than might otherwise be obtained with AM modulation schemes.

Transmission of Digitized RF Over Switched Telephone Network

Yet another alternate exemplary embodiment of the present invention is shown in FIG. **30**. In FIG. **30**, base station units **600** are connected to the remote antenna units **602** through a switched telephone network **120**, as illustrated in more detail in FIGS. **31A**, **32A**, **33A** and **34**. As illustrated in FIG. **31A**, each base station unit **600** includes radio controller and T1 interface circuitry **22** receiving a plurality of PCN or microcell channels from the MTSO. The output of each of a plurality of groups **610** of transmitters **23** are combined at combining circuit **612** for application to an analog-to-digital and digital-to-analog converter/framing/demultiplexing circuits **614**. Groups **620** of receivers **28** receive an analog signal output from circuits **614**. Each of circuits **614** also produces an analog diversity signal, which is applied to a group **622** of diversity receivers **28'**.

Each of circuits **614** functions to convert the analog RF (after suitable down-conversion) to a digital signal which is framed and applied to the switched telephone network. In addition, each of circuits **614** receives a signal from the switched network, which it demultiplexes and converts back to a corresponding analog RF signal, for application to a respective receiver group **620** or diversity receiver **622**.

In the exemplary embodiment illustrated herein, it is contemplated that approximately ten 30 KHz, PCN or AMPS cellular channels (given current 7 channel spacing requirements) may be digitized into a respective 1.05 or 1.25 MHz bandwidth which may be formatted as a 44.736 Mb/s DS-3 or OC-1 signal for application to the switched telephone network through a T1 line or optical fiber link, with bits available for control and error detection. AMPS, or Advanced Mobile Phone Service, is the original and standard format for cellular service consisting of frequency modulated (FM) channels at 30 KHz spacings. However, the system could carry 15 to 18 time division multiple access (TDMA) signals, or a combination of AMPS and TDMA signals could be carried. As is well known to those of skill in the art, TDMA is an alternative modulation technique for cellular which replaces each AMPS channel with three time-multiplexed digital signals. Hence 5 to 6 AMPS channels are 15 to 18 TDMA channels.

Referring now to FIG. **32A**, there is illustrated in more detail circuit **614**. Circuit **614** is essentially identical to circuit **130**, as illustrated with regard to FIG. **4**, but includes a network interface circuit **630** and **632** in place of digitally modulated laser **136** and digital optical receiver **140**, respectively. Interface circuits **630** and **632** provide the necessary T1 interface or interface to an optical path.

The remote antenna units **602** are illustrated in more detail in FIG. **33A**. Antenna units **602** are essentially identical in construction to the remote antenna units **102** as illustrated with respect to FIG. **8**. However, in place of the digital optical receiver **160** and digitally modulated laser **174**, there are provided network interfaces **640** and **642** for interfacing to the switched network **120**.

The same framing structure illustrated above with respect to FIGS. **6**,**7**,**22** and **23** are applicable to this exemplary embodiment of the invention, except at lower speeds as necessary. In the case where the diversity function is provided, the return path would include additional DS-3 or OC-1 signals, requiring additional T1 or SONET line capacity on the return path.

Referring now to FIGS. **31B**, **32B** and **33B**, there is shown an alternate exemplary embodiment **600'** of the base station **600** illustrated in FIG. **30**. Alternate embodiment **600'** provides that all the transmitters **23** in the base station are

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applied to unit **614'**, which is illustrated in FIG. **32B**. Similarly, unit **614'** services all of the receivers **28** and **28'** in the base station. Thus, the embodiment of FIG. **31B** differs from the embodiment of FIG. **31A** in that a single unit **614'** is provided for the base station, and the transmitters and receivers are ungrouped.

Referring now to FIG. **32B**, there is illustrated analog-to digital and digital-to-analog converter/framing/demultiplexing unit **614'**. Unit **614'** receives the combined input from all the transmitters **23** in the base station **600'**. A broadband digitizer **132** digitizes the combined signal. The output of broadband digitizer **132** is applied to the plurality of digital filters **802**. Digital filters **802** each preferably include a decimation filter and a finite impulse response (FIR) filter. Decimation filter **802**A receives the 30.72 MSamples/s (12-bit wide) data stream and produces a digitized data stream corresponding to the output of one of the transmitters **23** (i.e. one of the channels) consisting of an approximately 80 KSamples/s data stream, with 12-bit samples. The 80 KSamples/s rate corresponds to a sampling rate of 2.4×, of a 30 KHz signal (the channel width). However, any rate of at least 2× satisfying the Nyquist criterion can be used.

Decimation filter **802** is preferably, for example, a decimating digital filter, Part Number HSP 43220, available from Harris Semiconductor, Inc. of Melbourne Fla. Another vendor of such filters may be ESL, a division of TRW, Inc. Referring back to FIG. **32B**, each digital filter **802** is programmed to filter out of the broadband signal from digitizer **132** a channel corresponding to one of transmitters **23**. Accordingly, a base station installation with twenty transmitters would require twenty digital filters **802**, to extract the digitized data stream corresponding to each transmitter. Broadband digitizer **132** digitizes the entire microcell traffic spectrum, which is, in the case of the original AMPS system, 12.5 MHz wide. In the case of twenty channels, the bandwidth to be transported can thus be greatly reduced to 600 KHz, from 12.5 MHz. Thus, digital filters **802** greatly reduce the amount of data to be transmitted over the switched network.

A frame generator/multiplexer of generally the same design as generator multiplexer **134'**, is provided to multiplex the data stream from each digital filter **802** onto one or more **T1**, SONET or other carriers. For instance, a single channel of 72 KSamples/s, with 12-bit samples, constitutes an 864 Kb/s serial data stream. Adding framing and control bits, as, for example, illustrate in FIGS. **22** or **23** (with, for example, a 1-bit CRC channel, a 1-bit alarm-control/under wire channel and a frame word of 6 bits) produces a serial data stream of approximately 1.54 mb/s (20 bits×72 KHz).

Frame generator/multiplexer **134'** can thus multiplex the output of one of digital filters **802** into a DS1 format on a T1 carrier with a capacity of 1.55 mb/s, or can combine multiple outputs of digital filters **802** on a 44.736 Mb/s DS-3 or OC-1 signal for application of the switched telephone network.

A filter control circuit **803** is also provided in unit **614'**, and has an input to each of digital filters **802**. Filter control **803** allows digital filters **802** to be programmed, so that their filtering characteristics (and channel selection) may be selectively changed, if desired. Filter control **803** further includes an input from radio controller **22**, which may provide control input, in order to specify the channels to be extracted from the data stream. A network interface circuit **630'**, interfaces frame generator/multiplexer **134'** to the switched telephone network.

Referring now to FIG. **33B**, there is shown alternate embodiment **602'**, which operates in conjunction with alternate embodiment **614'**. A network interface circuit **640'** receives one or more T1, SONET or other carriers from the switched telephone network, carrying digitized microcell traffic produced by frame generator/multiplexer **134'**. The digitized data stream(s) are applied to demultiplexer **162'**, of generally the same design as demultiplexer **162**, which extracts the digitized stream from each carrier, channel by channel, and applies each individual extracted channel to a separate one of digital-to-analog converters **164'**. The outputs of converters **164'** are combined, and applied to power amplifier **24**, to be broadcast through antenna **26**. Each of digital-to-analog converters **164'** may be of the same design as digital-to-analog converter **164** of FIG. **21B**. However, unlike digital-to-analog converters **164**, digital-to-analog converters **164'** need only handle a single channel, and thus may possibly be of less exacting design.

Alternate embodiment of remote unit **602'** further includes a plurality of digital filters **802**, which operate in the same manner as digital filters **802** of base station unit **614'** to extract selected microcell digitized channels from the output of the broadband digitized signal from the output of broadband analog-to-digital converter **170**. Framer/multiplexer **172'**, of generally the same design as multiplexer **172**, operates in a manner similar to frame generator/multiplexer **134'** to multiplex the extracted channels onto one or more T1, SONET or other carriers, applied to the switched telephone network through network interface **642'**.

Referring again to FIG. **32B**, demultiplexer **142'**, of generally the same design as demultiplexer **142**, receives the multiplexed signals from remote unit **602'** through network interface **632'**. Unit **142'** demultiplexes each of the channels and applies a single channel to each of digital-to-analog converters **144'**, which may be of similar design to digital-to-analog converters **164'**. The output of digital analog converters **144'** may be applied to receivers **28**.

As illustrated in FIG. **33B**, remote unit **602'** may also include a diversity path with digital filters **805** provided to extract the diversity channels from the digitized diversity signal. The extracted channels may be multiplexed through framer multiplexer **172'** onto the switched telephone network. In base station unit **614'**, a diversity path is provided from demultiplexer **142'**, whereby extracted diversity channels may be applied to diversity receivers **28'**. Thus, as described above, the alternative embodiment illustrated in FIGS. **31B**, **32B** and **33B** provides digital filters to extract selected microcell channels from the broadband digitized signal travelling to and from the remote units **602'**. The extraction of selected channels provides that a much more limited bandwidth capacity is required to carry the signals from transmitters **23** to the remote units and return the received channels from the remote units to the base station.

In yet another alternate embodiment, the system of FIG. **11** is modified to transport the digitized signals over the switched telephone network, as for example illustrated herein above.

Network Interface to Cable System

FIG. **34** illustrates yet another alternate exemplary embodiment of the present invention, wherein the transmission of digitized RF over the switched telephone network is combined with the transmission of the RF signal over the cable system. More specifically, as shown in FIG. **34**, a network interface **702** is provided at the head end unit to receive digital PCN/microcell traffic off the switched telephone network. That traffic is applied to QAM modulator **460** and AM optical transmitter **462** (see FIG. **28**). Similarly, network interface circuitry **704** provides for application of digital PCN or microcell traffic to the switched network, as

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it is received from QAM demodulator **464**. Thus, signals originating from a base station **600** can be carried through the switched network to the cable system and back again.

Thus, as described above, this alternate exemplary embodiment of the invention provides that PCN or microcell traffic may be conveniently carried over a switched telephone network. This operation has obvious advantages, permitting rapid installation of additional capacity, rather than the necessity of installing additional transmission lines.

Thus, these alternate exemplary embodiments provide for an ability to transmit radio frequency microcell or PCN traffic through a switched network and through a cable system installation.

Various modifications and alternate configurations of the embodiments of FIGS. **17** through **34** are contemplated. An all digital configuration (similar to the embodiment of FIG. **10**) of the embodiment of FIG. **17** or FIG. **27**A eliminates the transmitters, receivers and analog-to-digital and reverse conversion in the base station **330**. An all digital configuration for the embodiment of FIG. **30** eliminates these analog components from the base stations **600**. The method of installing and upgrading from the analog embodiments to the all digital embodiments can be carried out substantially as described above with regard to the embodiments of FIGS. **2–15**. Other modifications to the embodiments of FIGS. **17** through **35** include wave division multiplexing so that the fiber pairs may be replace with a single fiber.

Passive Handoff System

Referring now to FIG. **35**A there is illustrated an exemplary embodiment of a passive handoff microcell telecommunications system **800**. The system shown in FIG. **35**A is of like construction to that of FIG. **2** with the exception of base station units **114'**, which are constructed as shown in FIG. **35**B to provide passive handoff switching.

For the purposes of describing system **800**, microcell areas **100** are referred to as "microcell zones," which zones are labeled for the purposes of one exemplary embodiment as **A1–A6**, **B1–B6** and **C1–C6**. Each zone includes an independent antenna for transmitting to and receiving from mobile units. Zones **A1–A6** collectively comprise "Cell A," zones **B1–B6** collectively comprise "cell B," and zones **C1–C6** collectively comprise "cell C." Each cell A, B and C has a set of reusable frequencies to be used within the cell, according to conventional cellular system design. Passive handoff system **800** provides that a transmission frequency or channel assigned to a mobile unit in a given cell may be broadcast from the remote unit **182** in any one of microcell zones **100** under the control of a unit **114'** without interaction with or control from MTSO **110**. A channel can thus follow a mobile telephone unit from one microcell zone to another within a given cell. Accordingly, multiple microcell zones may be served by the same set of channels (i.e. transmission frequencies) allowing the signal transmission power level within each zone to be minimized, and thereby avoiding undesirable interference with adjoining microcell zones or cells. The system also reduces the switching load on MTSO **110**. However, when a mobile unit travels from one cell to another, MTSO **110** switches the unit to a new channel (and corresponding pair of transmit and receive frequencies) in the newly entered cell, in a conventional manner.

Referring now to FIG. **35**B, there is shown in more detail a base station unit **114'** according to the present invention. Unit **114'** includes a radio controller **22** providing an interface between the T1 lines from the MTSO **110** and the base station radio equipment. Transmitters **23-1** to **23-N** (where N is a positive integer) are connected to a matrix switch **802**, the outputs of which are in turn connected to a plurality of combining circuits **804-1** to **804-X** (where X is a positive integer), which are in turn connected respectively to a plurality of digital transmitting/receiving units **130"-1** to **130"-X**. Units **130"-1** to **130"-X** are connected to the microcell areas **102** over respective transmission paths **104-1** to **104-X**, as illustrated in FIG. **35**A.

The respective outputs of transmitter/receiver digitizing units **130"** carrying the analog microcell traffic, are each applied to matrix switch **808**. Matrix switch **808** selectively connects any input to any one of receivers **28-1** to **28-N** through respective outputs **806-1** to **806-X**, and combining circuits **807-1** to **807-X**. A controller **810** controls matrix switch **802** and matrix switch **808** using respective control lines **812** and **814**. Controller **810** receives a sample of digitized microcell traffic from each of the digitization units **130'** over sample lines **816**.

As described in more detail below, controller **18** continuously processes the digital samples received from units **130"** and in response thereto controls matrix switches **802** and **808** in order to switch each of transmitter units **23** through to one (or more or none) of units **130"** and to connect receivers **28** to one (or more or none) of units **130"**. For instance, in one exemplary switching configuration, matrix switch **802** might connect all three transmitters **23-1**, **23-2** and **23-N** through outputs **803-1** to combiner circuit **804-1**, so that all three transmitter frequencies F_1, F_2, and F_n are combined and applied to unit **130"-1** for digitization and transport to a microcell zone. In another configuration, transmitter **23-1** and might be connected to combiner **804-X** through one of outputs **803-X**, while transmitter **23-2** is connected to combiner **804-2** through one of outputs **803-2**, and transmitter **23-X** is connected to combiner **804-1**, through one of outputs **803-1**. Matrix switch **802** thus allows any one of transmitters **23** to be connected to any one of combiners **804**, in any combination.

Switch **802** thus permits a transmission frequency to "follow" a mobile unit from one microcell zone to another. For example, with reference to FIG. **35**C consider a mobile unit **820** which initiates a cellular telephone call at a time T_1 within zone **A1**. In the example, mobile unit **820** is located in a car. However, it can be hand-carried or otherwise transported from zone to zone. To set up calls and perform control, the control channel(s) for a cell A, B or C is simultaneously transmitted to and received from all zones in the respective cell, as accomplished by switches **802** and **808**. Upon call set up, which is accomplished in a conventional fashion, as for example described in "Mobile Cellular Telecommunications Systems, by William C. Y. Lee, MTSO **110** assigns mobile unit **820** to a currently available channel, for example the frequencies handled by transmitter **23-1** and receiver **28-1** (assuming a transmitter/receiver pair is currently available for assignment). MTSO **110** is programmed to recognize that the channels associated with transmitters **23-1** to **23-N** and receivers **28-1** to **28-N** are assigned, collectively, to cell A, which in this example consists of zones **A1–A6**. During the initial set up the assigned transmit and receive channels can be transmitted to received from all zones in the cell, at least until it can be determined which zone can handle the call exclusively.

Thus, as initially set up, mobile unit **820** transmits and receives on frequencies F_1 and F'_1, respectively. Controller **810** constantly monitors the signal strength of transmissions from mobile units **820** in all zones in Cell A as received at the antenna units of the remote units **102** positioned in the zones. Signal strength in each zone is detected by sampling the digitized RF microcell traffic returning from remote units

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102 to units 130". While mobile unit 820 is within microcell zone A1, the strength of the received signal F'_1 is likely the greatest because of the proximity of mobile unit 820 to the antenna unit of remote unit 102-1 in zone A1. Frequency F'_1 might, however, also be received at the antenna of remote unit 102 in zone A2, or in the more distant zone A3. Control unit 810 monitors the strength of received signal. F'_1 in all of the digitized microcell traffic streams received from all of remote units 102 in the Cell A, and, according to at least one exemplary approach, identifies the remote unit 102 which receives the strongest signal at frequency F'_1. Assuming for this example, that the signal F'_1 received at the remote unit 102 in zone A1 is the strongest among the zones, controller 810 signals matrix switch 802 to connect transmitter 23-1 to combiner 804-1, which in turn applies its output to digitizing 130"-1. Unit 130"-1 in turn transmits the digitized microcell traffic stream containing the frequency F_1 to the remote unit in zone A1, which in turn broadcasts frequency F_1 in zone A1 (along with any other frequencies switched into the combiner 804-1). On the return path, controller 810 causes matrix switch 808 to connect the output of digitizing unit 130"-1, as received on line 806-1, to receiver 28-1. Preferably, transmitter 23-1 is connected to no other digitizing units 130", such that no other remote unit 102 is broadcasting at the frequency F_1, except for unit 102-1. Similarly, it is preferable that no other digitizing units 130" are connected through matrix switch 808 to receiver 28-1. As a result, interference between adjacent microcell zones caused by broadcasting the same frequency is avoided and interference resulting from a receiver 28 receiving the same frequency (at different phases and varying distortions) from more than one zone is avoided.

Extending the example further, consider now that mobile unit 820 moves from zone A1 to microcell zone A2 at a time t_2. As mobile unit 820 moves from microcell zone A1 to zone A2, controller 810 continues to sample and detect the received signal strength of transmission frequency F'_1 from all the remote units 102 in cell A. Upon movement from microcell zone A1 to A2, controller 810 should detect an increasingly stronger signal at frequency F'_1 in microcell area A2, and correspondingly a reduction in signal strength at that frequency in microcell area zone A1. When certain switching criteria are met, controller 810 performs a "passive handoff," by switching transmitter 23-1 from connection to combiner 804-1 to connection with combiner 804-2, and correspondingly switching receiver 28-1 to receive its input from digitizing 130"-2. As a result, transmission at frequency F_1 ceases at remote unit 102 in zone A1, and the signal received at that remote unit 102 is no longer applied through switch 808 to receiver 28. Thus, system 800 can passively switch a channel from one zone to another within a cell to follow a mobile unit.

The following example illustrates the operation of system 800 when the mobile unit moves from one cell to another. For example, if mobile unit 820 moves from microcell zone A3 to zone B1 at a time t_3, controller 810 again detects a corresponding reduction in signal strength received at the remote unit 102 in zone A3. However, no corresponding increase in signal strength in another zone in cell A is detected to trigger a passive handoff. Rather, the handoff from cell A to cell B is handed by MTSO 110 as MTSO 110 senses the movement of the mobile unit 820 between cell A and B. Prior to leaving the cell, as the signal strength decreases, transmission and reception may be achieved using all zones in the cell. As the unit 820 moves into the B cell, MTSO 110 operates to assign a new channel to the mobile unit, from frequencies assigned to cell B. The base station unit 114' serving cell B then operates in the same manner as described above to identify the initial zone to transmit and receive from, and to perform passive handoffs within cell B. Accordingly, switching between cells A, B or C is carried out independently of the passive handoff of assigned frequencies between zones in a cell. Cell B could, of course, be of conventional design with a single antenna serving the entire cell.

Thus, as described above, the present invention provides a passive handoff system, wherein a transmission frequency is assigned to a mobile unit, and that frequency tracks or follows the mobile unit from one microcell zone to another under the control of controller 810, and without intervention from or switching of transmission frequencies by the MTSO 110. This mode of operation is particularly advantageous in certain microcell applications, wherein multiple remote units 102 are required to cover an area, but there is not enough traffic density in a given zone within the area to support a conventional cell site installation. For example, a narrowed depression in the terrain, such as a ravine or along a road adjacent to a river bed may require multiple antenna installations to obtain adequate signal coverage, due to blockage from nearby terrain. Another example might be in an underground parking garage, or even in large office buildings where larger than normal signal attenuation results in unacceptable signal levels. Furthermore, cell sites in some cellular systems are not located close enough together, thus resulting in poor coverage areas between the cells. Still another example is along a traffic corridor between population centers. For these situations and others, it is advantageous to use a passive handoff system permitting an expansion of the area covered without assigning separate frequency sets and corresponding transmitters and receivers for each zone within the area.

Preferably, each switch 802 and 808 provides support for at least twenty (20) transmitters and twenty (20) receivers, respectively. In addition, each of switches 802 and 808 preferably permits connection of the transmitters and receivers to up to six digitizing units 130". Accordingly, matrix switch 802 may be used, for example, to connect up to twenty (20) transmitters (where N=20), through to any one of digitizing units 130". Similarly, the output from digitizers 130" may be selectively connected to any one of receivers 28, such that a single one of digitizers 130" may be connected to all of receivers 28, or all of the digitizing units 130" may be connected to a single one of receivers 28. However, it shall be understood that switches 802 and 808 may be adapted to handle more or less than twenty (20) receivers or transmitters, or more or less than six (6) units 114'.

Switches 802 and 808 are preferably matrix switches, wherein the combining function is integrated into the switch at the matrix nodes, in the form of Wilkinson combiners using nonreflective pin diode attenuators. Such components are available from Salisbury Engineering, Inc., of Salisbury, Md. The switches are preferably of the attenuator type, allowing linear control of rise and fall time. Switching is preferably make before break.

Referring now to FIG. 36, there is shown a first exemplary embodiment of unit 130". Unit 130" is of the same design and operation as unit 130, except it additionally includes a data bus 830 connected to the bus carrying demultiplexed digitized microcell traffic from demultiplexer 142 to digital-to-analog converter 144. Bus 830 is applied to parallel-in parallel-out FIFO buffer 832, which has an output enable controlled by an enable line 834 received from a controller 810. When enabled, buffer 832 outputs a replica of the digitized microcell traffic on data bus 836.

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Referring now to FIG. **37**, there is shown an exemplary embodiment of controller **810** according to the present invention. Controller **810** of FIG. **38**A is adapted for use with unit **130"** shown in FIG. **36**. Controller **810** includes a multiplexer **884** which is connected to the buffers **832** in each of units **130"-1** to **130"-X**, through a twelve (12) bit data bus **836** with one (1) clock line. Multiplexer **884** (preferably tri-state) selects input from one of the busses **836**, and supplies it to fast-fourier-transform (FFT) processor **856**. Selection is made under control of microprocessor system **860**, using control line **862**. FFT processor 856 clocks in digitized microcell traffic samples consisting of 12 bit words. Digital FFT processor **856** preferably uses a Raytheon Part No. 3310, available from Raytheon, Inc.

The output of FFT processor **856** is a plurality of 16 bit words in bins, with each bin representing the strength or amplitude of a 30 KHz channel (or channel of a PCS or other service) within the digitized cellular data stream. The output of FFT processor **856** is applied to system **860** over data bus **859**, using control line **861**. A select circuit **886** receives a control signal **863** from system **860**, and selectively generates signals on enable lines **834**. Enable lines **834** are used to selectively enable the outputs of buffers **832**, so that FFT processor **856** can be selectively filled with digitized microcell traffic samples from a selected source. Microprocessor system **860** is connected to a matrix switch driver **875**, which drives matrix switches **802** and **808**. The operation of controller **810** as shown in FIG. **37** will be described in more detail below.

Referring now to FIG. **38**, there is shown a simplified flow diagram of the operation of programmed microprocessor system **860** and its corresponding control over the operation of system **800**. FIG. **39** is representative of both the program **900** executed by microprocessor system **860** and the method of system **800**. Program **900** include an initialization/configuration routine **910**. System configuration provides for the identification of the channels serviced by base station **114'**. Preferably, microprocessor system **860** includes magnetic storage media such as a hard drive or the equivalent for storage of the configuration information and other data, together with computer programs. Once configured, polling and switching operation may be invoked. In this mode of operation, microprocessor system **860** first selects (routine **912**) the digitized traffic stream for a "first" zone in the cell. In the embodiment of FIG. **37**, the selection is achieved using enable lines **834**. A selected one of enable lines **834** is activated to enable the acquisition and output of the microcell traffic data from a corresponding one of buffers **832**. The enabled buffer **832** applies a replica of the digitized microcell traffic stream from demultiplexer **142** in unit **130"** to multiplexer **884**, which applies the digitized traffic stream to FFT processor **856**.

Routine **914** provides that FFT processor **856** is activated for loading of the digitized microcell traffic stream under the control of microprocessor system **860** using control line **861**. A buffer **832** may load, for instance, 1024 samples of the digitized microcell traffic. As microcell traffic data is received from a buffer **832**, FFT processor **856** clocks in digitized 12 bit microcell traffic samples or words. The output of FFT processor **856** comprising a series of 16 bit words specifying the signal strength of the respective channels carried in the digitized microcell traffic stream.

Microprocessor system **860** preferably employs an Intel brand "486" type microprocessor or better running at least 33 MHz. At this speed, the time between selection of the digitized microcell traffic stream and the receipt of the frequency spectrum analysis from FFT processor **856** can be less than 5 milliseconds. Once microprocessor system **860** has received (**916**) the frequency spectrum data from FFT circuit **856**, which contains the signal amplitude for each frequency in the zone, the data is recorded for immediate or later analysis (routine **918**). Optionally, the date and time of the signal measurement is also recorded, together with any other parameters of interest. The polling process continues if all zones in the cell have not yet been measured within the current polling cycle. If polling continues, the digitized microcell traffic stream for the next zone in the cell is selected (routine **924**) in the above-described process of data acquisition analysis and storage is repeated.

Once all zones have been measured in a current cycle, microprocessor system **860** determines the channel (i.e., transmitter/receiver) zone assignments based on the signal levels recorded during the cycle. The particular manner in which this determination is made is not essential to the invention, but preferably may take one of the forms described below.

It is contemplated that the switching algorithms for the transmit and receive paths of unit **114'** will be different. In the transmit path, it is contemplated that the method of switching will use the coverage received signal strength in a given zone over a period of ½ second to 3 seconds, with the zone with the greatest strength chosen as the active zone. Alternatively, a zone which is not currently fading, even if at a lower signal strength, may be chosen. If it doesn't matter which zone is used, for example, if signal strengths are comparable, a zone may be chosen which evens out the distribution of channel assignments in the cell. Where the optimum zone cannot be determined, several or all zones can be selected or active, for example, as might occur when a mobile unit is on the edge of a cell.

For switching receivers, instantaneous and average levels are tracked, and fades are tracked so that trends can be predicted and the switching from one zone to another on the receive side can be anticipated. If the received signal strength is below a threshold level, then a receiver may be connected for reception from all zones, for instance where a mobile unit is on the edge of a cell. Switching on the receive side is typically accomplished at a much faster rate of change, than on the transmit side owing to the greater problem of reception and fading from the relative low power transmitters in the mobile units.

Of course, other switching algorithms for both the transmit and receive channels are possible, and certainly those applicable to conventional cellular switching are good candidates.

Once the new channel (transmitter/receiver) assignment has been determined, system **860** switches the transmitters and receivers using switches **802** and **808**, through matrix switch drivers **875**.

As an alternative to the operation specified for program **900** described above, channel (transmitter/receiver) zone assignments may be determined on a continual basis after each new frequency spectrum measurement is obtained. For instance, program **900** of FIG. **38** may be modified by inserting steps **930** and **932** between step **920** and **924**, and eliminating decision step **922**. Thus, as described above, system **810** may complete an analysis of all channels in a given zone in under 2 ms. In a handoff system with 6 zones, all analysis can be done in under 12 ms. One advantage to such fast channel analysis is in the capability of base station receive diversity, which may improve signal quality in areas at the fringes of cell coverage or where signal is momentarily blocked on one zone. Since fading is a major problem

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in, for example, remote areas, the ability to quickly switch between receiver sources allows a form of diversity reception using the antennas in different zones as "diversity" antennas for each other.

A possible side advantage of fast analysis would be to accumulate statistical data on fading that might assist service providers in finding optimum antenna/microcell placement.

As mentioned above, microprocessor system **860** may optionally record the date and time of each measurement of the frequency spectrum of the digitized microcell traffic stream. Accordingly, a history of channel usage and signal strength within any given channel may be readily obtained, and later used for the purpose of reconfiguring the system, for example, by moving antenna units. Accordingly, the present invention further contemplates a method of recording the use of the channels within the zones and the corresponding signal strength, and later using this information to reconfigure the system.

As an alternate exemplary embodiment, the system of FIG. **35**A (and FIG. **39** below) can be modified so that the digitized RF signal is carried to the zones over a switched telephone network, as for example illustrated in FIG. **30**, or modified to transport the digitized RF over a cable system, as for example illustrated herein.

In the alternate embodiment of FIG. **39**A, base station **114'** is modified to provide all digital base station **114"** All digital base station **114"**, like the system of FIG. **11**A, uses a digital synthesizer **212'** and digital demodulator **224** to replace the analog RF radio equipment in the base station. A T1 Interface **202** interfaces to MTSO **110**, and applies a digital form of each telephone signal all control signal from the MTSO to each digital synthesizer **212'**. Each synthesizer receives control signals from the controller **810'** over line **812'**. Each digital synthesizer **212'** is responsive to controller **810'** to create a synthesizer digital data stream for framing and transport to an associated unit **106** in a zone, so that any combination of the channels assigned to the cell can be broadcast in the cell.

On the return path, the digitized sample **816** is taken from the demultiplexed digital data stream returning from the units **106**, and supplied to controller **810'**. The digital samples are obtained from the demultiplexer **221'** in a like manner as described above with respect to FIG. **36**. Controller **810'** in turn uses the sample data as described above with respect to control **810** to control switching. Selector **880** can be used to select the received signal for any desired channel from any one of demodulators **224**, for application to T1 interface **202**. Alternatively, selector/processor **880** is configured to process two or more of the incoming streams for each channel to create a reduced noise composite stream.

An alternate embodiment of the system of FIG. **39**A is illustrated in FIG. **39**B. The system of FIG. **39**B is similar to the system of FIG. **11**B, in that the digital synthesizer **212'"** receives an analog telephone signal input from radio controller **22**, and operates like synthesizer **212'** of FIG. **11**B. Similarly, digital demodulator **224'** operates like demodulator **224'** of FIG. **11**B, delivering an analog signal to radio controller **22**.

Yet another two alternate embodiments of the system of FIG. **35** are shown in FIGS. **39**C and **39**D, which are modified in a manner similar to the systems of FIGS. **11**C and **11**D, so that transport is over the switched network and the synthesizer produces individual digitized channels for application to the network.

Referring now to FIG. **40**, there is shown yet another exemplary embodiment of the system of FIG. **35**A, in this case modified to communicate through the switched telephone network by replacing units **130"** with a modified version **614"** (modified to obtain the samples of the digitized traffic stream) of circuit **614'** of FIG. **32**B. In this embodiment, only those channels actually used in the antenna units **106** are transported to the units, saving bandwidth in the same way as system **614'**.

Referring to FIGS. **41**A–C, there is illustrated other alternate exemplary embodiments of the passive handoff microcell system of the present invention. In the systems of FIG. **41**A–C, redundancy is achieved by arranging the microcell units **102** such that each area of the cell, or "macro cell", is covered by at least two microcell units. Accordingly, in the event of a failure of one of the units, the redundant microcells **103** are available to provide coverage in the area lost due to the failure.

In FIG. **41**A, a macrocell **103** is covered by three primary microcells **102** and by three secondary microcells **105**. In the example shown secondary microcells **105** are placed in a distribution similar to that of primary microcells **102** but rotated 45 degrees around the center of macrocell **103**. It should be apparent that other distributions could be used advantageously to provide similar redundant coverage.

In normal operation, primary microcells **102** provide full coverage over macrocell **103**. In case of a failure in one of the microcells **102**, however, the two adjacent microcells **105** can provide coverage over the region served by the failed primary microcell **102**. In another embodiment, primary microcells **102** provide primary coverage to first regions of macrocell **103** and secondary coverage to second regions of macrocell **103** while secondary microcells **105** provide primary coverage to the second regions of macrocell **103** and secondary coverage to the first regions.

A second method of providing redundant coverage is illustrated in two embodiments shown in FIGS. **41**B and C, respectively. In the embodiments shown in FIGS. **41**B and **41**C, each microcell **102** is provided with two power levels. In normal operation, each microcell **102** is operated at the power level necessary to provide microcell **102** coverage. In cases where, however, a microcell **102** fails, adjoining microcells **102** are raised to a higher power level (shown as **102'**). As can be seen in FIGS. **41**B and **41**C, such an increase in power level provides coverage over the failed microcell **102**. Although the microcells **102** of FIGS. **41**A and **41**B are shown divided into three sectors, it should be apparent that other sectorization, or no sectorization, can be used within the above-described redundancy scheme.

Sectorization

Sectorization will be discussed next.

According to yet another aspect of the invention, the microcell system of the present invention may be used to replace the conventional base station transmitter **12** in a conventional cell as for example shown in FIG. **1**A. In addition, as can be seen in FIGS. **41**A and **41**B, each microcell could be split into a number of sectors, each sector driven by a directional microcell antenna unit. According to such embodiments, shown generally in FIG. **42**, a sectorized antenna unit **900** having a plurality of transmit and receive antenna pairs **902** divides a micro or macrocell into a number of sectors. Each antenna pair **902** broadcasts and receives using a different channel set. For example, according to one preferred embodiment, a microcell **16** is divided into three 120-degree sectors with one antenna pair **902** assigned to each sector. Each antenna pair **902** utilizes ten transmit and receive channels for its sector, with a 21

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channel separation between channels within the sector. In addition, according to one exemplary embodiment, there is provided seven channel separation between channels, between sectors.

The antenna pairs **902** in each macrocell are supported by a remote unit **904** which receives digitized RF for the channels in all three sectors, and converts the digitized RF into analog RF for transmission into the sectors covered by the antenna pairs **902**. Remote units **904** further include analog-to-digital converters for digitizing RF received in each sector, and for transmitting the digitized RF to the sectorized base station units **906**. Each of the sectorized base station units **906** is connected to the MTSO **17**, which in turn is connected in turn to the switched telephone network **15**.

Each sectorized base station unit **906** includes radio frequency transmitters and receivers for each of the channel sets used in each of the sectors of the macrocell, and digital-to-analog and analog-to-digital conversion units for transmitting digitized RF to the remote units and for receiving digitized RF and applying it to the receiver units. Sectorized base station units **906** are preferably connected to remote units **904** over a single fiber optic link **905** using wave division multiplexing as described above, although separate transmit and receive links could be used if desired.

Referring now to FIG. **43**, there is shown in more detail a sectorized base station unit **906**. Each sectorized base station unit **906** includes a radio controller **22** for each of the sectors serviced by the base station unit **906**. Each of the radio controllers **22** are connected to the MTSO **17**. A corresponding number of transmitter and receiver banks **912** are provided, each with a plurality of transmitters and receivers. Preferably, according to the exemplary embodiment shown herein, each bank **912** includes ten transmitters and ten receivers. The output of the transmitters of each bank **912** is combined and applied to analog-to-digital conversion unit **914**, which may be of a design similar to those described hereinabove, for example as shown in FIG. **4**. Analog-to-digital conversion unit **914** digitizes and frames the digitized RF, and applies an optical output to wave division multiplexer **916**, which is in turn connected to fiber **905**. At the same time, optical information received from remote unit **904** is applied through wave division multiplexer **916** to an optical filter **918** which filters out the signal received from remote units **904** as distinct optical wavelengths, for example in the case of a three sector system, wavelengths of 1520, 1550, and 1580 nm can be used. Each of the filtered, separate wavelengths is applied to the input of one or more digital-to-analog conversion units **920**, which demultiplex and convert from digital-to-analog form RF signals received from the remote units **904**, for each of the sectors serviced by the remote unit **904**. The analog output of digital-to-analog conversion units **920** is applied to the respective receivers in each bank **912**.

Referring now to FIG. **44**, there is shown in more detail a remote unit **904**. Each remote unit **904** includes a wave division multiplexer **930** connected to fiber **905**. Wave division multiplexer **930** receives from sectorized base station unit **906** the digitized optical signal carrying the channels of all sectors serviced by remote unit **904**, and applies the digital optical signal to digital-to-analog converter unit **932**, the output of which is an analog RF signal representative of all channels represented in the sectors serviced by the remote unit **904**. The analog output of conversion unit **932** is applied to splitter **934**, which splits the analog RF signal into N paths (where N=the number of sectors) corresponding to channels assigned to each of the antenna pairs **902** applies the analog RF to channel filter units **936**. Each antenna pair **902** has its own channel filter unit **936** to filter out of the RF signals from splitters **934**, those channels to be transmitted in the respective sector. The output of channel filter unit **936** is applied to an amplifier **938**, which is in turn applied to a band pass filter **940**, which passes only those channels within the band assigned to the particular sector. The output of band pass filter **940** is applied to a transmitter antenna **902***a* of antenna pair **902**. Meanwhile, a receiving antenna **902***b* of that antenna pair **902**, receives RF signals predominantly from within the same sector, and applies the received signals to a band pass filter **942**. Band pass filter **942** passes only those channels within the band, and applies the filtered radio frequency signal to analog-to-digital conversion unit **944**, which converts the analog RF signal to a corresponding digitized optical output signal at a unique optical wavelength, for example, one of the optical wavelengths noted above. Each of analog-to-digital conversion units **944** may be of generally the same design shown with respect to unit **102** shown in FIG. **8**. The optical outputs of each of the units **944** is applied to optical combiner **946**, which in turn applies its output to wave division multiplexer **930**. Digital-to-analog conversion units **932** are preferably of generally the same design shown with respect to unit **130** in FIG. **4**.

Referring now to FIG. **45**, there is shown in more detail one of channel filter units **936**. Each unit **936** preferably includes a linear programmable pre-amplifier **950**, which is used to provide the gain needed to compensate for the losses of the splitters and combiners. The output of amplifier **950** is applied to splitter **952**, which splits the analog signal into M paths (where M=the number of transmit channels assigned to a sector) a plurality of paths. Each path in turn passes through a narrow band filter **954** tuned to the particular channel. Each narrow band filter **954** is preferably programmable, and designed to maintain a bandwidth of 30 KHz over temperature. Preferably, this is accomplished by first downconverting the required RF channel to a 70 MHz IF signal. The 70 MHz signal is then passed through a crystal filter in a manner known in the art to achieve the narrow filtering required. The IF frequency is then upconverted to the required RF frequency. Preferably, the frequency is microprocessor controlled, and the RF frequency can be set in 1 Hz increments to the required frequency using a computer, such as a laptop unit. Frequency stability is preferably achieved using a clock recovered from the encoded signal sent over fiber link **905**. Ideally, narrow band filter **954** should be narrow enough that an adjacent channel within the sector will be greater than 50 dB down a master clock generated at base station unit **906**. The output of each of the narrow band filters **954** is applied to a combiner **956**, which in turn provides its output to the amplifier **938**. In the exemplary embodiment of the present invention, amplifier **938** preferably constitutes a 25 watt PA.

In the preferred embodiment, frequency offset will be minimized by synchronizing remote unit **904** with sectorized base station unit **906**. In one such embodiment, sectorized base station unit **906** transports the RF spectrum by down-converting from RF to an IF (in, for example, the 0–30 MHz range), and then digitizing. After being transported to the other end, the IF signal is reconstructed, and then up-converted back to RF.

The down-conversion and up-conversion are implemented by mixing the signal with a local oscillator (LO). In order for the original frequency of the signal to be restored, the signal must be up-converted with an LO that has exactly the same frequency as the LO that was used for down conversion. Any difference in LO frequencies will translate

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to an equivalent end to end frequency offset. In the embodiment described above, the down conversion and up conversion LO's are at locations remote from one another. Therefore, in one preferred embodiment, frequency coherence between the local and remote LO's is established as follows: at the host end, there is a 552.96 MHz master clock which establishes the bit rate over the fiber. This clock also generates a 30.72 MHz clock (30.72=522.96÷18), which serves as a reference to which the host digitizer LO's are locked.

At the remote end, there is another 552.96 MHz clock, which is recovered from the optical bit stream with the help of a phase lock loop. Because this clock is recovered from the bit stream generated at the host, it is frequency coherent with the master clock. A 30.72 MHz clock is then generated to serve as a reference for the remote local oscillators. Because the 552.96 MHz clocks are frequency coherent, so are the 30.72 MHz references, and any LO's locked to them, thus ensuring that host and remote LO's are locked in frequency.

Referring now to FIGS. **45** and **46**, there is shown yet another alternate exemplary embodiment to the sectorized microcell system according to the present invention. In this embodiment, sectorized base station unit **906**, provides that an analog-to-digital multiplexer and digital-to-analog demultiplexer unit **960** receives a separate input from each of the channel banks **912**, and separately converts each of the RF composite signals from the channel banks to a corresponding digitized RF stream. This digitized RF stream is in turn multiplexed into a single digitized stream, which is output in optical form for application to wave division multiplexer **916**. In the reverse direction, a single digitized RF stream is received from wave division multiplexer **916**, and demultiplexed into N separate digital streams, each corresponding to one of N sectors (where N=3 in the example shown in FIG. **42**). Each of the digital streams represents a desynchronized of the analog RF received by the respective sector antenna in pair **902**. The demultiplexed digital stream is then converted from digital-to-analog form, and applied to each of the respective receivers in the channel banks **912**.

FIG. **47** illustrates an alternate embodiment of remote unit **904** of FIG. **42**. Remote units **900** of FIG. **47** include a multiplexer/demultiplexer unit **970**, which receives the digitized stream from wave division multiplexer **930**, and converts the multiplexed digitized signals from each of the respective banks in the sectorized base station unit **906** shown in FIG. **46**. The demultiplexed data streams for each of the banks is applied to respective digital-to-analog and analog-to-digital conversion units **972** which convert the digitized signal to a corresponding analog RF signal. The analog RF signal is applied to an amplifier **938**, which is in turn applied to band pass filter **940** and to transmitter antenna **902***a*, in a manner similar to that described for FIG. **44**. Similarly, RF receiving antenna **902***b* is applied to band pass filter **942**, which in turn applies its output to unit **972**, wherein the analog signal is converted to a digital form for application to multiplexer/demultiplexer **970**. The digitized data streams from each of units **972** is multiplexed in unit **970**, converted to an optical output, and applied to wave divisional multiplexer **932**, for transmission over fiber **905** to sectorized base station unit **906** of FIG. **46**. The digitized data stream is received by wave division multiplexer **916**, in sectorized base station unit **906** of FIG. **46**, applied to unit **960**. Unit **960** demultiplexes the digitized stream into a digital stream associated with each sector and converts each sector digital stream to a sector RF signal. The sector RF signal is applied to the receivers of the respective channel banks for the sectors.

Thus, the sectorized microcell system of the present invention allows for the replacement of the conventional cell site base station in a convention macrocell. In the above described embodiments, the antennas used for each sector are directional, and are all located in the same place. Each directional antenna, one transmit and receive for each sector, is then directed outwardly across the sector serviced by them. For instance, the sectors may be pie-shaped, with the directional antennas positioned at the center of the pie. Alternatively, nondirectional antennas could be used and positioned at different locations in the cell site. In such a case, the antennas are coupled to the cell site through coaxial cables. In addition, though the above sectorization examples have been described using antenna pairs, it should be obvious to one skilled in the art that sector units having one antenna, or even units having three or more antennae may be used advantageously within such a system. Furthermore, although the examples described entail only the digitization of RF signals generated from the telephone signal received from the MTSO, it should be apparent that the techniques of digital synthesis described in the context of FIG. **10** et al. also apply to a sectorized microcell system. Diversity channels may also be implemented as described above.

Finally, although each of the examples above describes the use of an analog RF signal transmitted and received by each remote unit, it should be obvious that the above system and method can be applied advantageously to a digital RF cellular system in a manner well known in the art.

Thus, as described above, the sectorized cell replacement system provides for greater reuse of channels, by dividing conventional cells or even microcells into a plurality of sectors. Furthermore, the system provides all the benefits and advantages of the microcell systems described hereinabove, wherein the transmitters and receivers for all the channels in the cell are centrally located in a convenient and inexpensive location.

Thus, as described above, the present inventions provide a variety of digital systems and methods for transporting cellular traffic to and from antenna units, and for passively switching. Although the invention(s) has been described in its preferred form, those of skill in the art will recognize that many modifications and changes may be made thereto without departing from the spirit and the scope of the claims appended hereto.

We claim:

1. A method of passive switching in a cellular phone system having a plurality of macrocells including a first macrocell, each macrocell sharing a common set of channels, comprising the steps of:

(a) dividing the first macrocell into a plurality of primary microcells;

(b) placing a plurality of primary microcell antenna units so as to provide coverage over the first macrocell;

(c) dividing the first macrocell into a plurality of secondary microcells;

(d) placing a plurality of secondary microcell antenna units to provide coverage over the first macrocell overlapping the coverage of the primary microcells;

(e) at a base station,

(1) generating a digitized representation of a telephone signal received from a mobile telephone switching office,

(2) selecting a microcell from said plurality of primary and secondary microcells, and

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(3) transmitting the digitized representation to the microcell antenna unit of the selected microcell;

(f) at the selected microcell,

(1) receiving the digitized representation,

(2) generating a corresponding RF signal by digital-to-analog conversion, and

(3) broadcasting the RF signal in the selected microcell;

(g) at each of the plurality of primary and secondary microcells,

(1) receiving RF signals from mobile units within the set of channels,

(2) converting the RF signals received to corresponding digitized RF signal representations, and

(3) transmitting the RF signals back to the base station;

(h) at the base station,

(1) receiving the digitized RF signal representations from the primary and secondary microcells, and

(2) monitoring the digitized RF signal representations from each of the primary and secondary microcells; and

(3) based on an energy level of each channel in each microcell,

(A) selectively controlling the channels broadcast into each of the primary and secondary microcells by controlling the generation of the digitized representations as performed in step (e), and

(B) selectively choosing a particular microcell from the plurality of primary and secondary microcell in which a received channel is received so that passive switching is accomplished.

2. The method according to claim **1** wherein the step of generating a digitized representation of a telephone signal received from a mobile telephone switching office comprises digitally synthesizing a digitized representation of RF signals to be transmitted for each channel from the telephone signal received from the mobile telephone switching office.

3. The method according to claim **1** wherein the step of generating a digitized representation of a telephone signal received from a mobile telephone switching office comprises generating a digitized representation of RF signals generated for each channel.

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