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(54) **POINT-TO-MULTIPOINT DIGITAL RADIO  
FREQUENCY TRANSPORT**

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**398/173**

See application file for complete search history.

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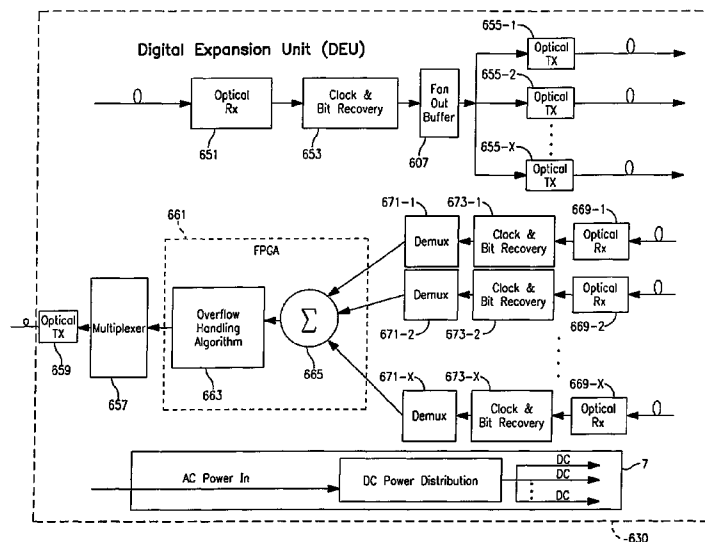
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(57) **ABSTRACT**

A digital radio frequency transport system that performs bi-  
directional simultaneous digital radio frequency distribution  
is provided. The transport system includes a digital host unit  
and at least two digital remote units coupled to the digital host  
unit. The bi-directional simultaneous digital radio frequency  
distribution is performed between the digital host unit and the  
at least two digital remote units.

**28 Claims, 8 Drawing Sheets**



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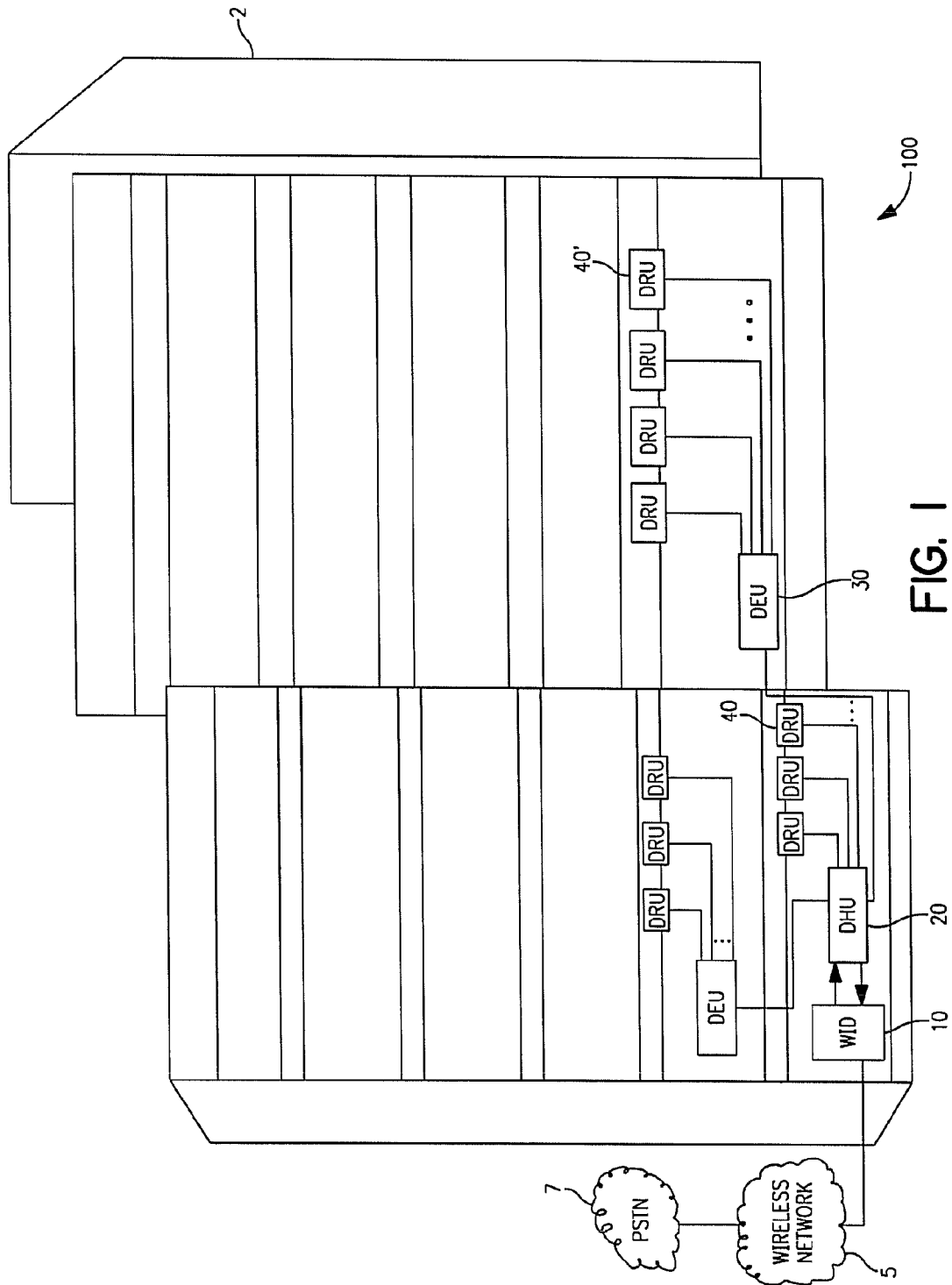
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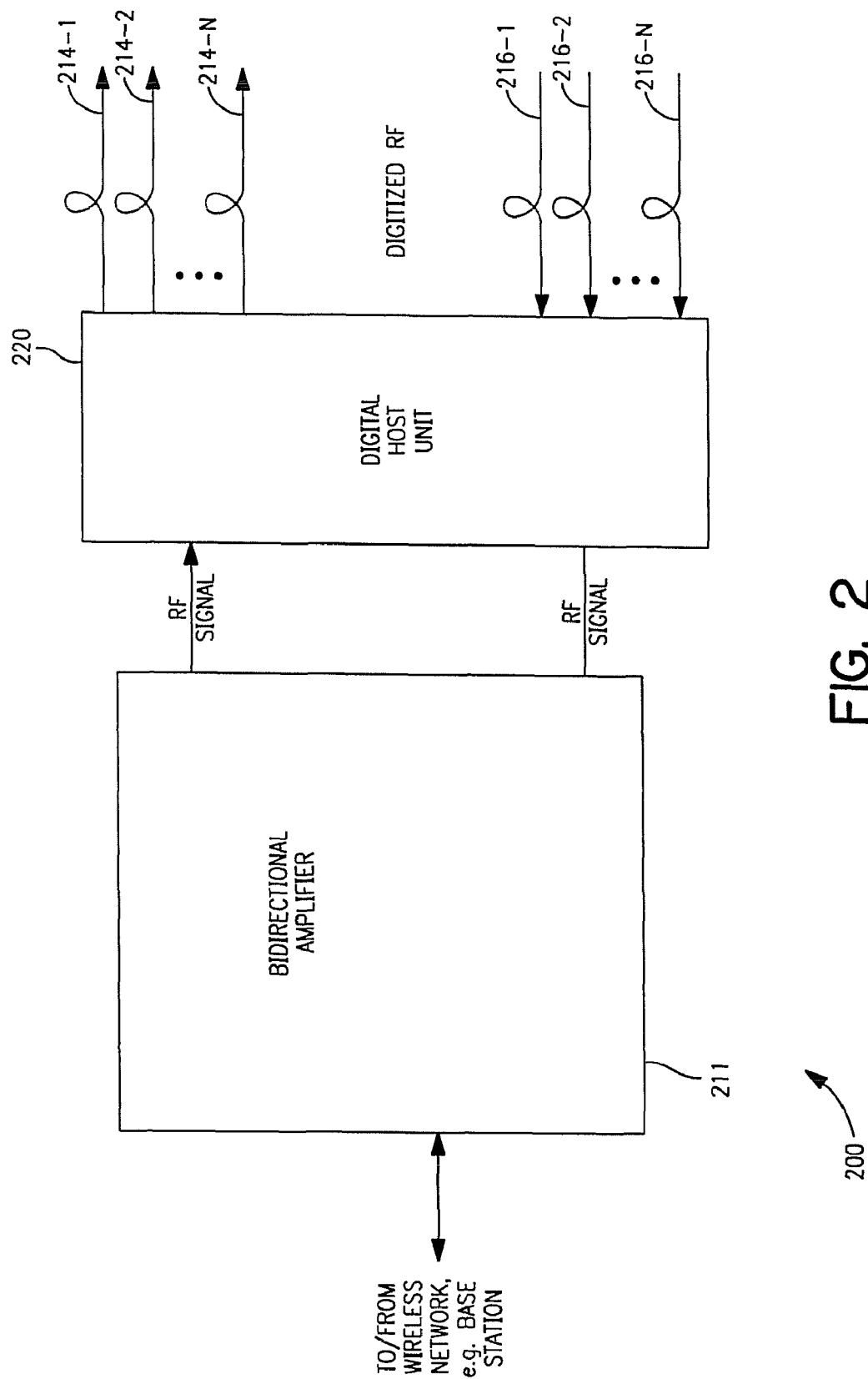


FIG. 2

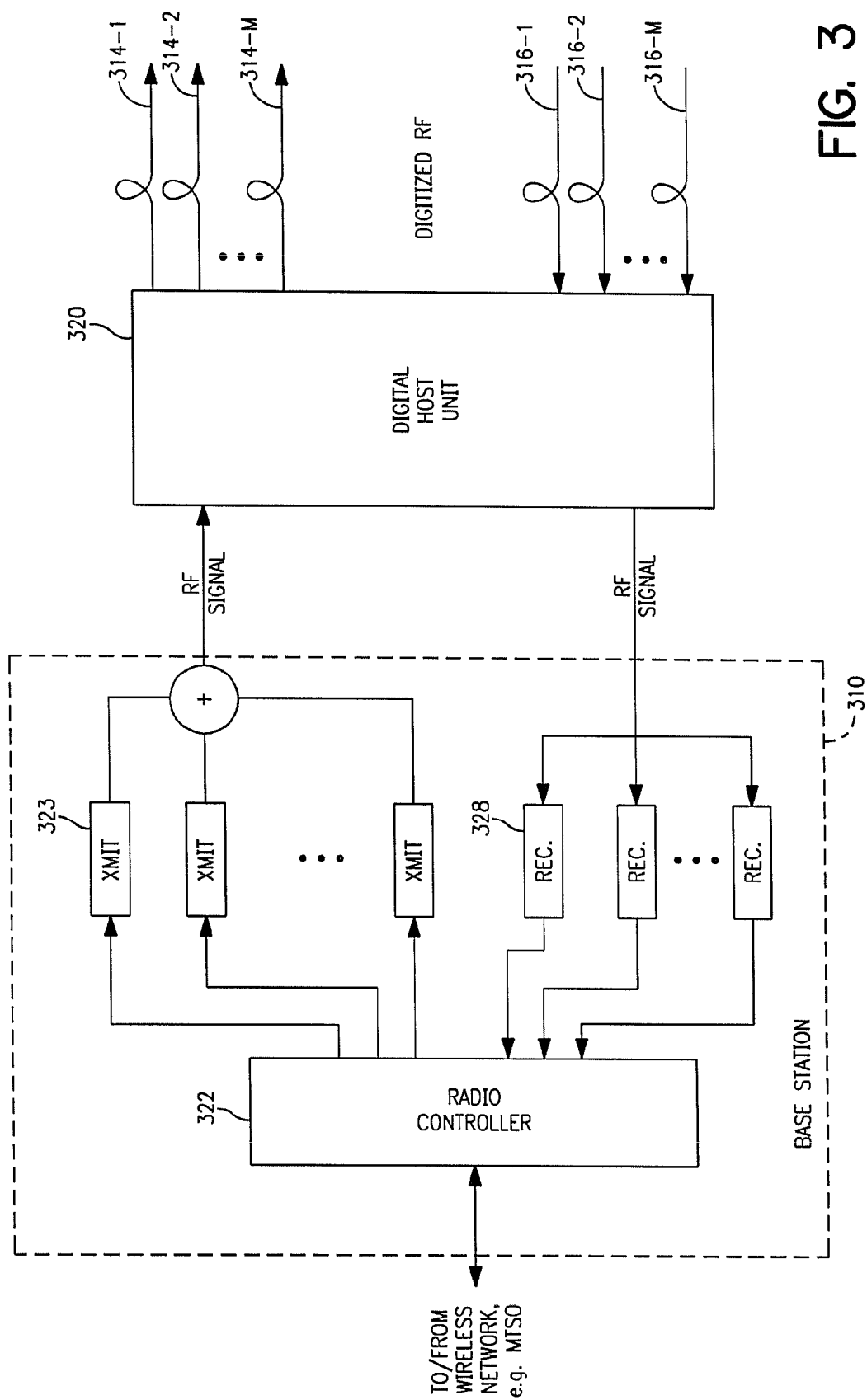


FIG. 3

FIG. 4

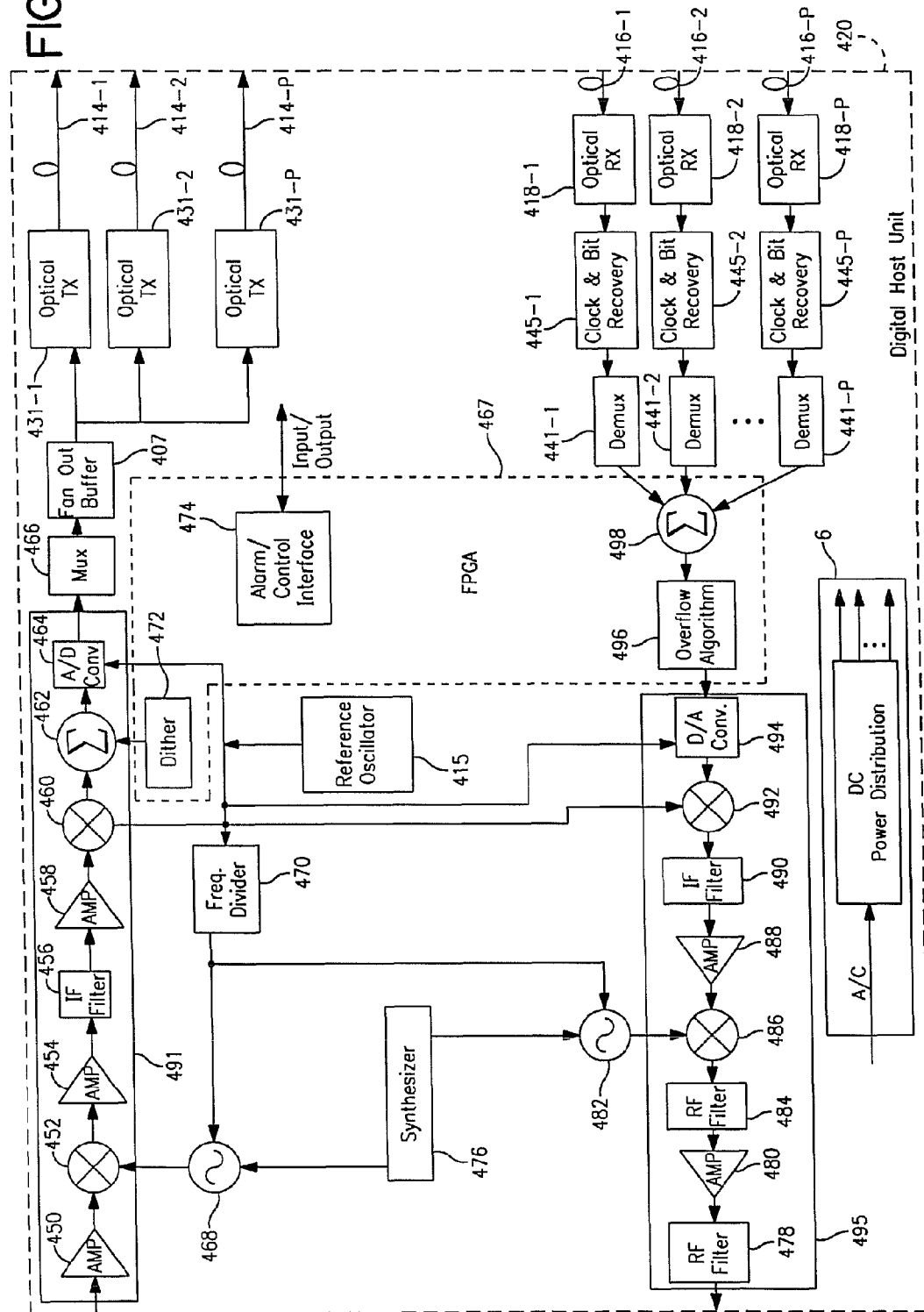
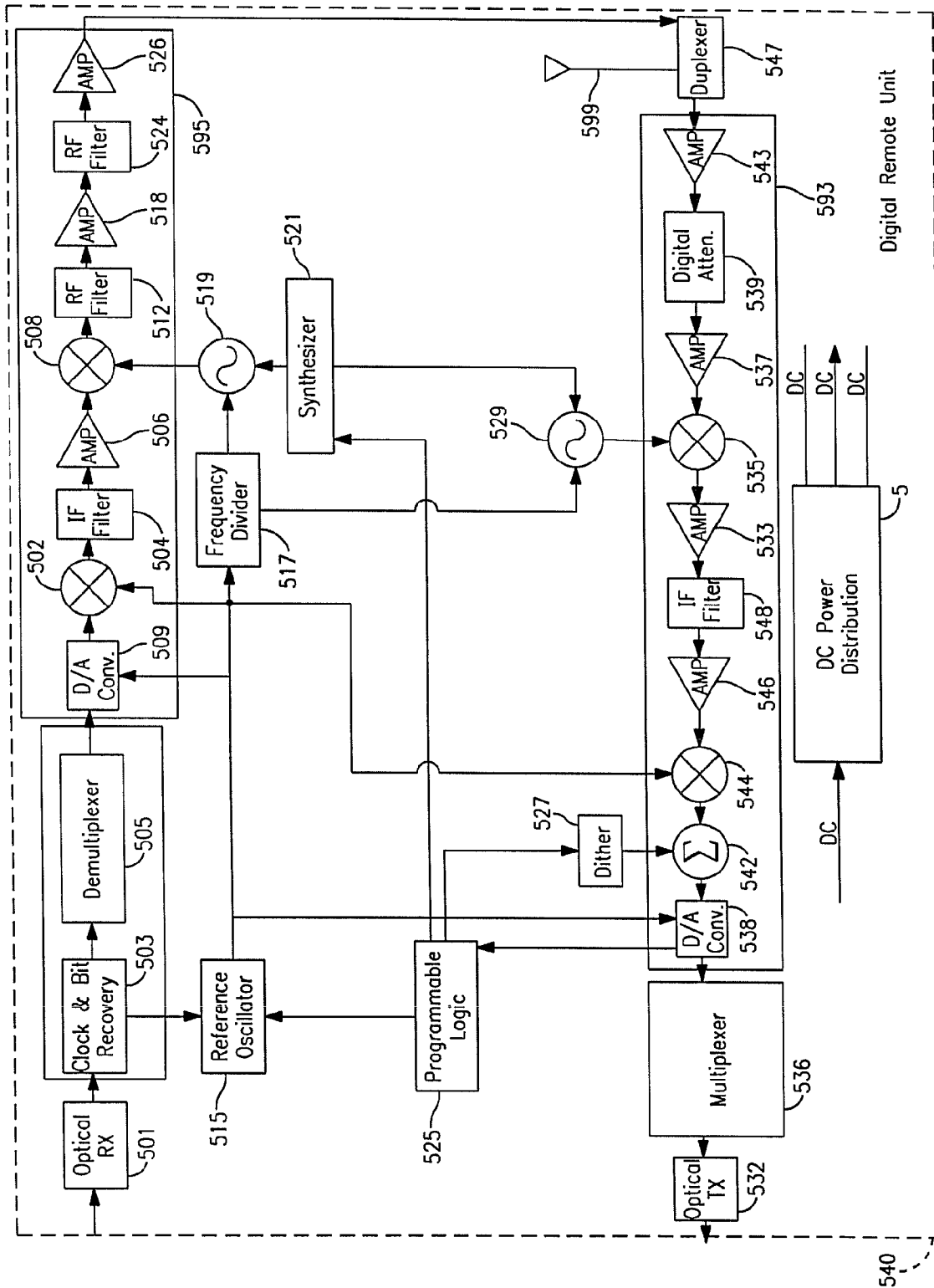


FIG. 5



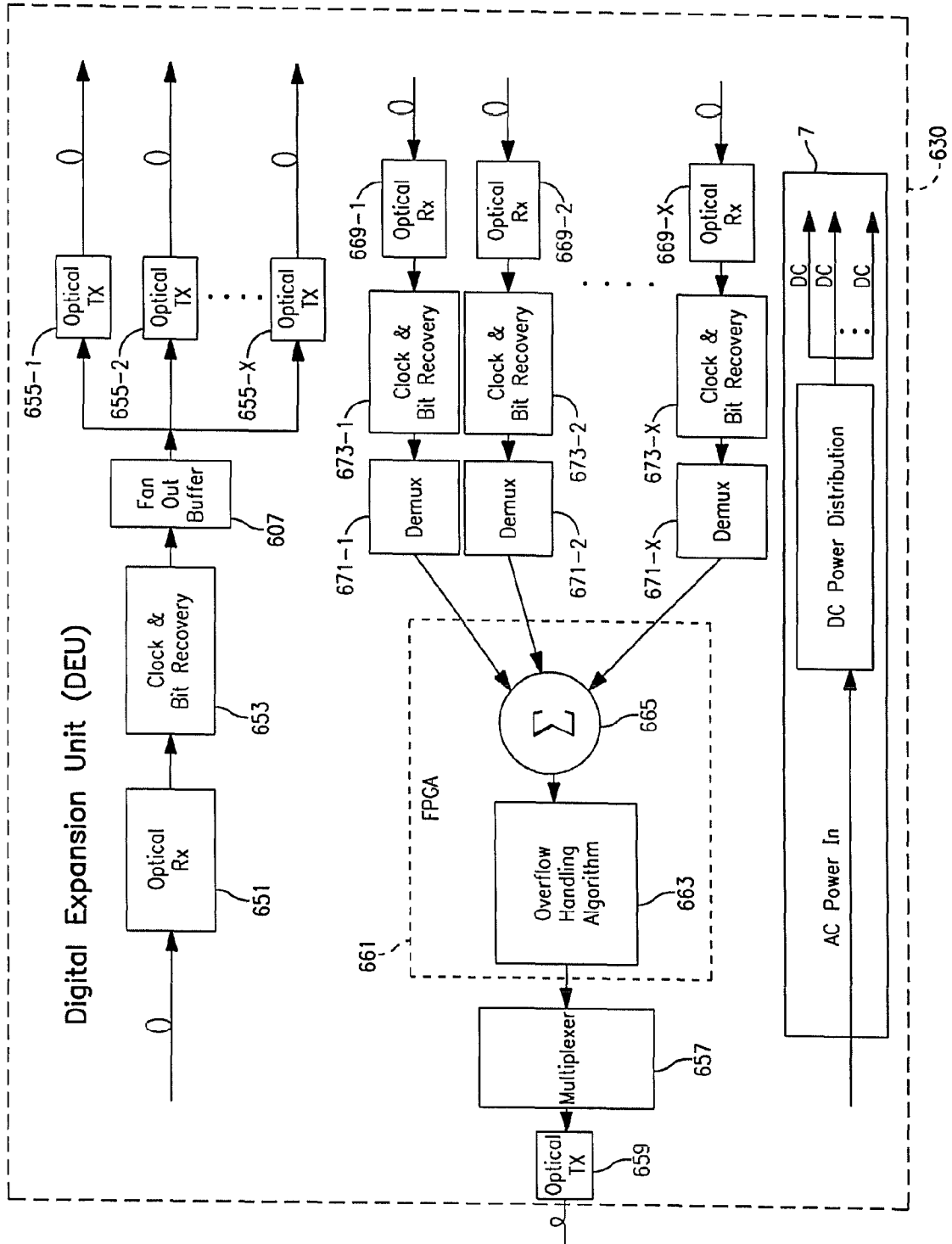


FIG. 6



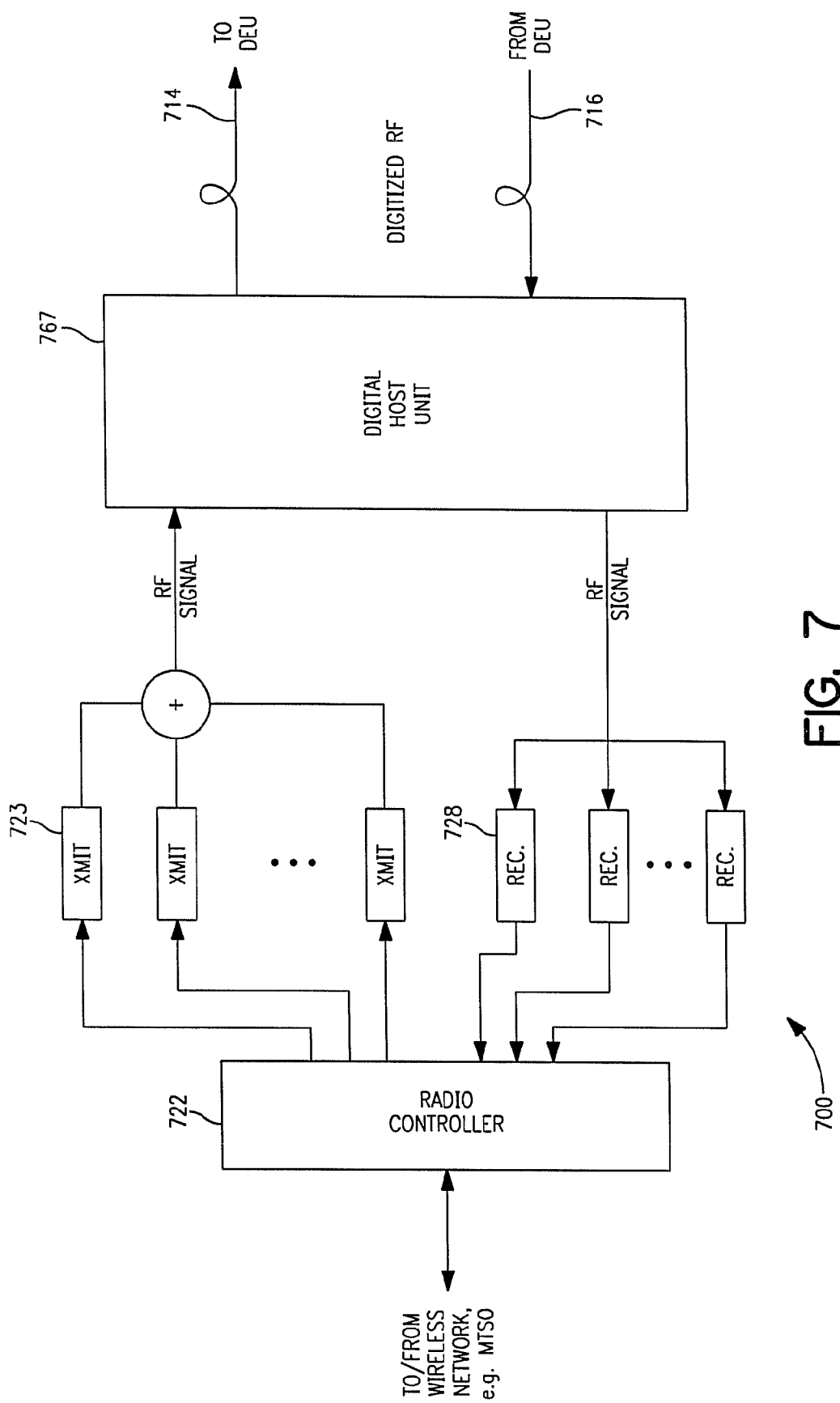


FIG. 7

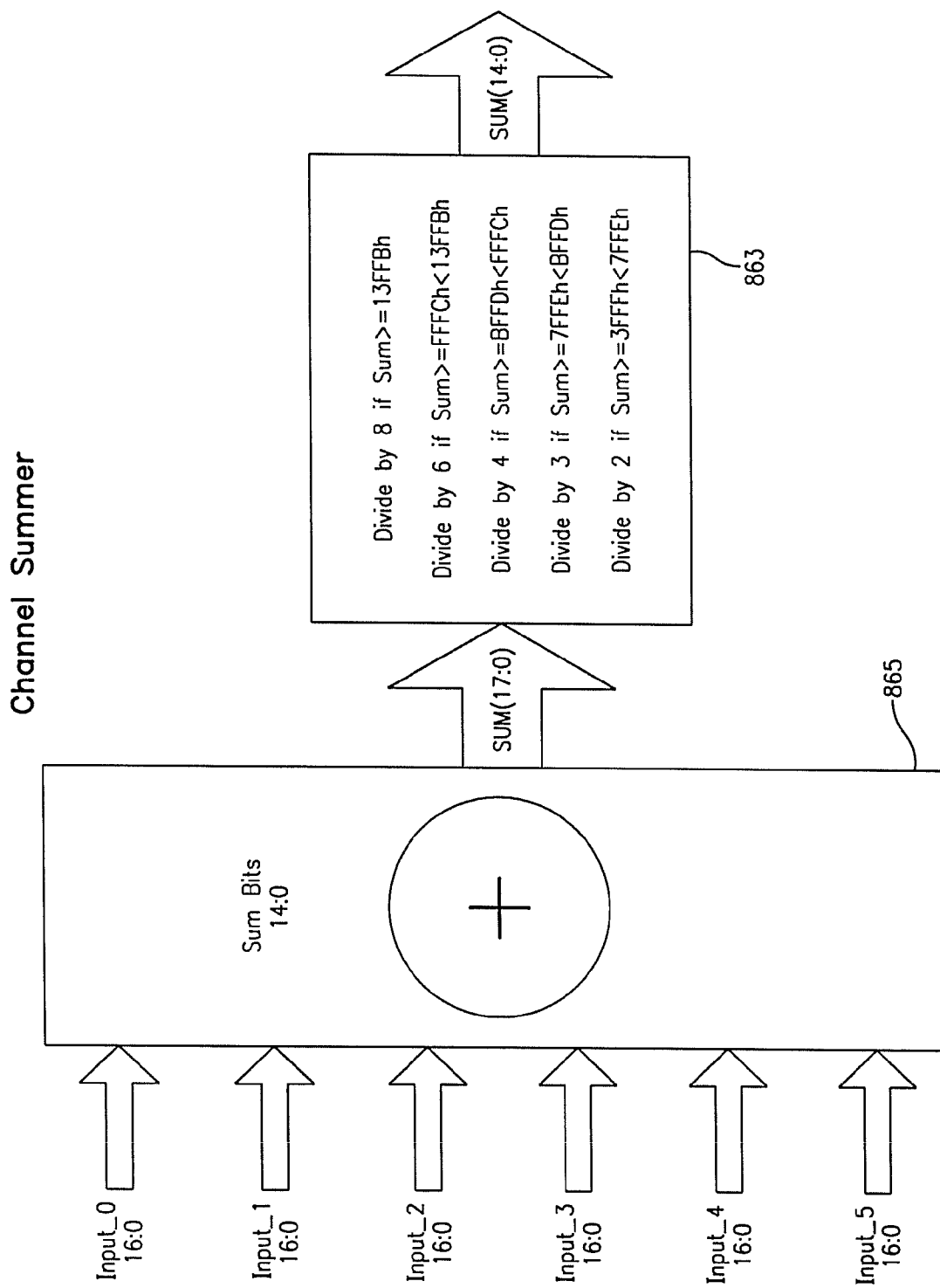


FIG. 8

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# POINT-TO-MULTIPOINT DIGITAL RADIO FREQUENCY TRANSPORT

## CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 10/740,944, filed on Dec. 19, 2003 entitled "POINT-TO-MULTIPOINT DIGITAL RADIO FREQUENCY TRANSPORT", which, in turn, is a continuation of U.S. application Ser. No. 09/619,431, filed on Jul. 19, 2000, entitled "POINT-TO-MULTIPOINT DIGITAL RADIO FREQUENCY TRANSPORT". Both U.S. application Ser. No. 10/740,944 and U.S. application Ser. No. 09/619,431 are incorporated herein by reference.

## TECHNICAL FIELD

The present invention is related to high capacity mobile communications systems, and more particularly to a point-to-multipoint digital micro-cellular communication system.

## BACKGROUND INFORMATION

With the widespread use of wireless technologies additional signal coverage is needed in urban as well as suburban areas. One obstacle to providing full coverage in these areas is steel frame buildings. Inside these tall shiny buildings (TSBs), signals transmitted from wireless base stations attenuate dramatically and thus significantly impact the ability to communicate with wireless telephones located in the buildings. In some buildings, very low power ceiling mounted transmitters are mounted in hallways and conference rooms within the building to distribute signals throughout the building. Signals are typically fed from a single point and then split in order to feed the signals to different points in the building.

In order to provide coverage a single radio frequency (RF) source needs to simultaneously feeds multiple antenna units, each providing coverage to a different part of a building for example. Simultaneous bi-directional RF distribution often involves splitting signals in the forward path (toward the antennas) and combining signals in the reverse path (from the antennas). Currently this can be performed directly at RF frequencies using passive splitters and combiners to feed a coaxial cable distribution network. In passive RF distribution systems, signal splitting in the forward path is significantly limited due to inherent insertion loss associated with the passive devices. Each split reduces the level of the signal distributed in the building thereby making reception, e.g. by cell phones, more difficult. In addition, the high insertion loss of coaxial cable at RF frequencies severely limits the maximum distance over which RF signals can be distributed. Further, the system lacks any means to compensate for variations of insertion loss in each path.

Another solution to distributing RF signals in TSBs is taking the RF signal from a booster or base station, down converting it to a lower frequency, and distributing it via Cat 5 (LAN) or coaxial cable wiring to remote antenna units. At the remote antenna units, the signal is up converted and transmitted. While down-conversion reduces insertion loss, the signals are still susceptible to noise and limited dynamic range. Also, each path in the distribution network requires individual gain adjustment to compensate for the insertion loss in that path.

In another approach, fiber optic cables are used to distribute signals to antennas inside of a building. In this approach, RF signals are received from a bi-directional amplifier or base

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station. The RF signals directly modulate an optical signal, which is transported throughout the building as analog modulated light signals over fiber optic cable. Unfortunately, conventional systems using analog optical modulation transmission over optical fibers require highly sophisticated linear lasers to achieve adequate performance. Also, analog optical systems are limited in the distance signals can be transmitted in the building. Typically, this limitation is made worse due to the use of multimode fiber that is conventionally available in buildings. Multimode fiber is wider than single mode fiber and supports a number of different reflection modes so that signals tend to exhibit dispersion at the terminating end of the fiber. In addition, analog installation typically includes significant balancing when setting up the system. Further, RF levels in the system need to be balanced with the optical levels. If there is optical attenuation, the RF levels need to be readjusted. In addition, if the connectors are not well cleaned or properly secured, the RF levels can change.

Digitization of the RF spectrum prior to transport solves many of these problems. The level and dynamic range of digitally transported RF remains unaffected over a wide range of path loss. This allows for much greater distances to be covered, and eliminates the path loss compensation problem. However, this has been strictly a point-to-point architecture. One drawback with digitally transported RF in a point-to-point architecture is the equipment and cost requirement. A host RF to digital interface device is needed for each remote antenna unit. In particular, for use within a building or building complex the number of RF to digital interface devices and the fiber to connect these devices is burdensome. For example, in a building having 20 floors, the requirement may include 20 host RF to digital interface devices for 20 remote antenna units, 1 per floor. In some applications more than one remote antenna unit per floor may be required. As a result, there is a need in the art for improved techniques for distributing RF signals in TSBs, which would incorporate the benefits of digital RF transport into a point-to-multipoint architecture.

## SUMMARY

The above-mentioned problems with distributing RF signals within a building and other problems are addressed by the present invention and will be understood by reading and studying the following specification.

In one embodiment, a digital radio frequency transport system is provided. The transport system includes a digital host unit and at least two digital remote units coupled to the digital host unit. The digital host unit includes shared circuitry that performs bi-directional simultaneous digital radio frequency distribution between the digital host unit and the at least two digital remote units.

In another embodiment, a digital radio frequency transport system is provided. The transport system includes a digital host unit and at least one digital expansion unit coupled to the digital host unit. The transport system further includes at least two digital remote units, each coupled to one of the digital host unit and the digital expansion unit. The digital host unit includes shared circuitry that performs bi-directional simultaneous digital radio frequency distribution between the digital host unit and the at least two digital remote units.

In an alternate embodiment, a method of performing point-to-multipoint radio frequency transport is provided. The method includes receiving radio frequency signals at a digital host unit and converting the radio frequency signals to a digitized radio frequency spectrum. The method also includes optically transmitting the digitized radio frequency spectrum

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to a plurality of digital remote units. The method further includes receiving the digitized radio frequency spectrum at the plurality of digital remote units, converting the digitized radio frequency spectrum to analog radio frequency signals and transmitting the analog radio frequency signals via a main radio frequency antenna at each of the plurality of digital remote units.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an illustration of one embodiment of a point-to-multipoint communication system according to the teachings of the present invention.

FIG. 2 is a block diagram of one embodiment of a communication system according to the teachings of the present invention.

FIG. 3 is a block diagram of another embodiment of a communication system according to the teachings of the present invention.

FIG. 4 is a block diagram of one embodiment of a digital host unit according to the teachings of the present invention.

FIG. 5 is a block diagram of one embodiment of a digital remote unit according to the teachings of the present invention.

FIG. 6 is a block diagram of one embodiment of a digital expansion unit according to the teachings of the present invention.

FIG. 7 is a block diagram of one embodiment of a microcell base station according to the teachings of the present invention.

FIG. 8 is an illustration of one embodiment of an overflow algorithm for a channel summer according to the teachings of the present invention.

#### DETAILED DESCRIPTION

In the following detailed description of the preferred embodiments, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration 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.

FIG. 1 is an illustration of one exemplary embodiment of a point-to-multipoint digital transport system shown generally at 100 and constructed according to the teachings of the present invention. The point-to-multipoint digital transport system 100 is shown distributed within a complex of tall shiny buildings (TSBs) 2. Although system 100 is shown in a complex of TSBs 2, it is understood that system 100 is not limited to this embodiment. Rather, system 100 in other embodiments is used to distribute signals in a single building, or other appropriate structure or indoor or outdoor location that exhibits high attenuation to RF signals. Advantageously, system 100 uses digital summing of digitized RF signals from multiple antennas to improve signal coverage in structures, such as TSBs.

Point-to-multipoint digital transport of RF signals is accomplished through a network of remote antenna units or digital remote units 40 and 40' and a digital host unit 20, which interfaces with a wireless network 5 which is coupled to the public switched telephone network (PSTN), or a mobile telecommunications switching office (MTSO) or other switching office/network. System 100 operates by transporting RF signals digitally over fiber optic cables. Signals received at DHU 20 are distributed to multiple DRUs 40 and 40' to provide coverage throughout a building complex. In

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addition, signals received at each of the DRUs 40 and 40' are summed together at the DHU 20 for interface to a wireless network.

In one embodiment, digital expansion unit DEU 30 is situated between the DHU 20 and one or more DRUs. In the forward path, DEU 30 expands the coverage area by splitting signals received from DHU 20 to a plurality of DRUs 40'. In the reverse path, DEU 30 receives signals from a plurality of DRUs 40', digitally sums the signals together and transports them to a DHU 20 or another DEU such as 30. This system allows for successive branching of signals using DEUs 30 and expanded coverage to multiple DRUs 40 and 40'. This system provides an efficient way of providing signal coverage for wireless communication without added attenuation loss and distance constraint found with analog systems. By using DEUs 30, antennas can be placed further from DHU 20 without adversely affecting signal strength since shorter fiber optic cables can be used.

Digital transport system 100 includes a wireless interface device (WID) 10 that provides an interface to a wireless network. In one embodiment, the WID 10 includes either conventional transmitters and receivers or all digital transmitter and receiver equipment, and interface circuitry to a mobile telecommunications switching office (MTSO). In one embodiment, the wireless interface device 10 is coupled to an MTSO via a T1 line and receives and transmits signals between the MTSO and the DHU 20. In another embodiment, the wireless interface device 10 is coupled to the public switched telephone network (PSTN). In one embodiment, WID 10 comprises a base station and connects directly to DHU 20 via coaxial cables. In another embodiment, WID 10 comprises a base station and wirelessly connects to DHU 20 via a bi-directional amplifier that is connected to an antenna. In one embodiment, the antenna is an outdoor antenna.

WID 10 communicates signals between wireless units and the wireless network via digital remote units DRUs 40 and 40'. WID 10 is coupled to DHU 20. The DHU 20 is coupled to at least one digital expansion unit DEU 30 and a plurality of DRUs 40. In addition, DEU 30 is coupled to a plurality of DRUs 40'. The DHU 20 receives RF signals from WID 10 and converts the RF signals to digital RF signals. DHU 20 further optically transmits the digital RF signals to multiple DRUs 40 either directly or via one or more DEUs 30.

Each DRU 40 and 40' is connected through a fiber optic cable (or optionally another high bandwidth carrier) to transport digital RF signals to one of DHU 20 or DEU 30. In one embodiment, the fiber optic cable comprises multimode fiber pairs coupled between the DRUs 40 and the DHU 20, between the DRUs 40 and 40' and the DEUs 30 and between the DEUs 30 and the DHU 20. In one embodiment, the DEU 30 is coupled to the DHU 20 via single mode fiber and the DEU 30 is coupled to the DRUs 40' via multimode fiber pairs. Although, transport system 100 has been described with fiber optic cable other carriers may be used, e.g., coaxial cable.

In another embodiment, the DHU 20 is coupled to the DRUs 40 by a direct current power cable in order to provide power to each DRU 40. In one embodiment, the direct current power cable delivers 48 VDC to each DRU 40 connected to the DHU 20. In another embodiment, the DEU 30 is coupled to DRUs 40' by a direct current power cable to provide power to each DRU 40'. In one embodiment, the direct current power cable delivers 48 VDC to each DRU 40' connected to the DEU 30. In an alternate embodiment, DRUs 40 and 40' are connected directly to a power supply. In one embodiment, the power supply provides DC power to the DRUs 40 and 40'. In an alternate embodiment, the power supply provides AC

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power to the DRUs **40** and **40'**. In one embodiment, DRUs **40** and **40'** each include an AC/DC power converter.

Both DHU **20** and DEU **30** split signals in the forward path and sum signals in the reverse path. In order to accurately sum the digital signals together at DHU **20** or DEU **30** the data needs to come in to the DHU **20** or DEU **30** at exactly the same rate. As a result all of the DRUs **40** and **40'** need to be synchronized so that their digital sample rates are all locked together. Synchronizing the signals in time is accomplished by locking everything to the bit rate over the fiber. In one embodiment, the DHU **20** sends out a digital bit stream and the optical receiver at the DEU **30** or DRU **40** detects that bit stream and locks its clock to that bit stream. In one embodiment, this is being accomplished with a multiplexer chip set and local oscillators, as will be described below. Splitting and combining the signals in a digital state avoids the combining and splitting losses experienced with an analog system. In addition, transporting the digital signals over multimode fiber results in a low cost transport system that is not subject to much degradation.

The down-conversion and up-conversion of RF signals are implemented by mixing the signal with a local oscillator (LO) at both the DRUs and the DHU. In order for the original frequency of the RF 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 to an equivalent end-to-end frequency offset. In the embodiments described, the down conversion and up conversion LOs 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 DHU end, there is a 142 MHz reference oscillator which establishes the bit rate of 1.42 GHz over the fiber. This reference oscillator also generates a 17.75 MHz reference clock which serves as a reference to which LO's at the DHU are locked.

At each of the DRUs, there is another 17.75 MHz clock, which is recovered from the optical bit stream with the help of the clock and bit recovery circuits. Because this clock is recovered from the bit stream generated at the host, it is frequency coherent with the reference oscillator at the host. A reference 17.75 MHz clock is then generated to serve as a reference for the remote local oscillators. Because the remote recovered bit clock is frequency coherent with the host master clock, the host and remote reference clocks, and any LO's locked to them, are also frequency coherent, thus ensuring that DHU and DRU LO's are locked in frequency. It is understood that in other embodiments the bit rate over the fiber may vary and the frequency of the clocks will also vary.

FIG. **2** is a block diagram of one embodiment of a communication system, shown generally at **200** and constructed according to the teachings of the present invention. In this embodiment, a digital host unit (DHU) **220** is coupled to a bi-directional amplifier (BDA) **211**. The BDA **211** receives communication signals from a wireless interface device (WID) and transports the communication signals as RF signals to the DHU **220** and receives RF signals from DHU **220** and transmits the RF signals to the WID. The DHU **220** receives RF signals from the BDA **211** and digitizes the RF signals and optically transmits the digital RF signals to multiple DRUs via transmission lines **214-1** to **214-N**. DHU **220** also receives digitized RF signals over transmission lines **216-1** to **216-N** from a plurality of DRUs either directly or indirectly via DEUs, reconstructs the corresponding analog RF signals, and applies them to BDA **211**. In one embodiment, DHU **220** receives signals directly from a plurality N of DRUs. The signals are digitally summed and then converted

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to analog signals and transmitted to BDA **211**. In another embodiment, DHU **220** receives signals from one or more DEUs and one or more DRUs directly. Again, the signals are all digitally summed and then converted to analog signals and transmitted to BDA **211**. The signals received via transmission lines **216-1** to **216-N** may be received directly from a DRU or signals that are received by a DEU and summed together and then transported via **216-1** to **216-N** to DHU **220** for additional summing and conversion for transport to BDA **211**. DEUs provide a way to expand the coverage area and digitally sum signals received from DRUs or other DEUs for transmission in the reverse path to other DEUs or DHU **220**. In one embodiment, transmission lines **214-1** to **214-N** and **216-1** to **216-N** comprise multimode fiber pairs. In an alternate embodiment, each fiber pair is replaced by a single fiber, carrying bi-directional optical signals through the use of wavelength division multiplexing (WDM). In an alternate embodiment, transmission lines **214-1** to **214-N** and **216-1** to **216-N** comprise single mode fibers. In one embodiment, N is equal to six. In an alternate embodiment, the number of transmission lines in the forward path direction **214-1** to **214-N** is not equal to the number of transmission lines in the reverse path direction **216-1** to **216-N**.

FIG. **3** is a block diagram of an alternate embodiment of a communication system shown generally at **300** and constructed according to the teachings of the present invention. Communication system **300** includes a base station **310** coupled to a DHU **320**. Base station **310** includes conventional transmitters and receivers **323** and **328**, respectively, and conventional radio controller or interface circuitry **322** to an MTSO or telephone switched network. DHU **320** is coupled to base station **310**. DHU **320** is also coupled to transmission lines **314-1** to **314-M**, which transmit in the forward path direction and transmission lines **316-1** to **316-M**, which transmit in the reverse path direction.

DHU **320** essentially converts the RF spectrum to digital in the forward path and from digital to analog in the reverse path. In the forward path, DHU **320** receives the combined RF signal from transmitters **323**, digitizes the combined signal and transmits it in digital format over fibers **314-1** to **314-M**, which are connected directly to a plurality of DRUs or indirectly to one or more DRUs via one or more DEUs.

In one embodiment, DHU **320** receives signals directly from a plurality M of DRUs. The signals are digitally summed and then converted to analog signals and transmitted to base station **310**. In another embodiment, DHU **320** receives signals from one or more DEUs and one or more DRUs directly. Again, the signals are all digitally summed and then converted to analog signals and transmitted to base station **310**. The signals received via transmission lines **316-1** to **316-M** may be received directly from a DRU or signals that are received by a DEU and summed together and then transported via **316-1** to **316-M** to DHU **320** for additional summing and conversion for transport to base station **310**. DEUs provide a way to expand the coverage area by splitting signals in the forward path and digitally summing signals received from DRUs or other DEUs in the reverse path for transmission upstream to other DEUs or a DHU. In the reverse path, DHU **320** also receives digitized RF signals over fibers **316-1** to **316-M** from a plurality of DRUs, either directly or indirectly via DEUs, reconstructs the corresponding analog RF signal, and applies it to receivers **328**.

In one embodiment, transmission lines **314-1** to **314-M** and **316-1** to **316-M** comprise multimode fiber pairs. In an alternate embodiment, each fiber pair is replaced by a single fiber, carrying bi-directional optical signals through the use of wavelength division multiplexing (WDM). In an alternate

embodiment, transmission lines **314-1** to **314-M** and **316-1** to **316-M** comprise single mode fibers. In one embodiment, M is equal to six. In an alternate embodiment, the number of transmission lines in the forward path direction **314-1** to **314-M** is not equal to the number of transmission lines in the reverse path direction **316-1** to **316-M**.

Referring now to FIG. 4, there is shown one embodiment of a DHU **420** constructed according to the teachings of the present invention. DHU **420** includes an RF to digital converter **491** receiving the combined RF signals from a wireless interface device such as a base station, BDA or the like. RF to digital converter **491** provides a digitized traffic stream that is transmitted to multiplexer **466**. Multiplexer **466** converts the parallel output of the A/D converter into a framed serial bit stream. At the output of the multiplexer is a 1 to P fan out buffer **407**, which splits the digital signal P ways. There are P optical transmitters **431-1** to **431-P** one feeding each of the P optical transmission lines **414-1** to **414-P**. The digitized signals are applied to fibers **414-1** to **414-P** for transmission to corresponding DRUs either directly or via DEUs. In one embodiment, P is equal to 6.

In one embodiment, DHU **420** includes an amplifier **450** that receives the combined RF signal from a wireless interface device such as a base station or BDA. The combined RF signal is amplified and then mixed by mixer **452** with a signal received from local oscillator **468**. Local oscillator **468** is coupled to reference oscillator **415**. In one embodiment the local oscillator is coupled to a frequency divider circuit **470**, which is in turn coupled to reference oscillator **415**. The local oscillator is locked to the reference oscillator **415** as a master clock so that the down conversion of the RF signals is the same as the up conversion. The result is end to end, from DHU to DRU, or DHU to one or more DEUs to DRU, no frequency shift in the signals received and transmitted. The local oscillator **463** is also coupled to a synthesizer circuit **476**.

The output signal of mixer **452** is provided to amplifier **454** amplified and then filtered via intermediate frequency (IF) filter **456**. The resultant signal is the combined RF signal converted down to an IF signal. The IF signal is mixed with another signal originating from the reference oscillator **415** via mixer **460**. The output of mixer **460** is summed together at **462** with a signal produced by field programmable gate array (FPGA) **467**. The output is then converted from an analog signal to a digital signal via analog/digital (A/D) converter **464** once converted the digital RF signal is applied to multiplexer **466**. In one embodiment, the A/D converter **464** is a 14-bit converter handling a 14-bit signal. In other embodiments, the A/D converter **464** may be of any size to accommodate an appropriate signal. In one embodiment, the input signal from FPGA **467** is a dither signal from dither circuit **462** that adds limited out of band noise to improve the dynamic range of the RF signal.

In one embodiment, DHU **420** includes an alternating current to digital current power distribution circuit **6** that provides direct current power to each of the DRUs coupled to DHU **420**.

DHU **420** further includes a plurality of digital optical receivers **418-1** to **418-P** in the reverse path. Receivers **418-1** to **418-P** each output an electronic digital signal, which is applied to clock and bit recovery circuits **445-1** to **445-P**, respectively, for clock and bit recovery of the electronic signals. The signals are then applied to demultiplexers **441-1** to **441-P**, respectively, which extract the digitized signals generated at the DRUs, as will be explained in detail below. Demultiplexers **441-1** to **441-P** further extract alarm (monitoring) and voice information framed with the digitized signals. The digitized signals output at each demultiplexer **441-1**

to **441-P** are then applied to FPGA **467** where the signals are summed together and then applied to digital to RF converter **495**. Converter **495** operates on the sum of the digitized signals extracted by demultiplexers **441-1** to **441-P**, reconstructing baseband replicas of the RF signals received at all the digital remote units. The baseband replicas are then up-converted to their original radio frequency by mixing with a local oscillator **482** and filtering to remove image frequencies. Local oscillator **482** is coupled to synthesizer **476** and reference oscillator as discussed with respect to local oscillator **468** above.

In one embodiment, digital to RF converter **495** includes digital to analog (D/A) converter **484** coupled to an output of FPGA **467** the digitized RF signals are converted to analog RF signals and then mixed with a signal from reference oscillator **415** by mixer **492**. The signal is then filtered by IF filter **490** and amplified by amplifier **488**. The resultant signal is then mixed with a signal from local oscillator **482** and then applied to RF filter **484**, amplifier **480** and RF filter **478** for transmission by a wireless interface device such as a BDA or base station.

In one embodiment, FPGA **467** includes an alarm/control circuit **474**, which extracts overhead bits from DRUs to monitor error and alarm information. In one embodiment, the FPGA **467** includes a summer **498**, which mathematically sums together the digital RF signals received from fibers **416-1** to **416-P**. In another embodiment FPGA includes an overflow algorithm circuit **486** coupled to the output of summer **486**. The algorithm circuit **496** allows the summed digital RF signals to saturate and keep the summed signal within a defined number of bits. In one embodiment, the algorithm circuit includes a limiter. In one embodiment, the RF signals are 14-bit signals and when summed and limited by summer **498** and overflow algorithm **496** result in a 14-bit output signal.

For example, in one embodiment each of the digital RF signals received from fibers **416-1** to **416-P**, where P is equal to 6, comprise 14 bit inputs. All of those 6 different 14 bit inputs then go into summer **498**. In order to allow for overflow, at least 17 bits of resolution is needed in the summer **498** to handle a worst-case scenario when all 6 of the 14 bit inputs are at full scale at the same time. In this embodiment, a 17-bit wide summer **498** is employed to handle that dynamic range. Coming out of summer **498** is needed a 14-bit signal going in the reverse path. In one embodiment, an algorithm circuit **496** for managing the overflow is implemented. In one embodiment, the summer and **498** and overflow algorithm **496** are included in FPGA **467**. In one embodiment, overflow algorithm **496** acts like a limiter and allows the sum to saturate and keeps the summed signal within 14 bits. In an alternate embodiment, overflow algorithm circuit **496** controls the gain and scales the signal dynamically to handle overflow conditions.

FIG. 8 illustrates one embodiment of an algorithm **863** for a channel summer **865** in order to limit the sum of input signals **0** to **5** to 14 bits. In this embodiment, input signals **0** to **5** comprise 6 signals that are summed together by summer **865**. The sum of input signals **0** to **5** is reduced to a signal having 14 bits or less by the algorithm **863**. It is understood that the algorithm **865** is by example and is not meant to restrict the type of algorithm used to limit the sum of signals **0** to **5** to 14 bits or less.

For example, when the sum of the 6 input signals **0** to **5** is greater than or equal to 13 FFBh then the sum is divided by 6 for a signal that is 14 bits or less. When the sum of the 6 input signals **0** to **5** is greater than 13 FFBh but less than or equal to FFFCh then the sum is divided by 5 for a signal that is 14 bits

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or less. When the sum of the 6 input signals **0** to **5** is greater than FFFCh but less than BFFDh then the sum is divided by 4 for a signal that is 14 bits or less. When the sum of the 6 input signals **0** to **5** is greater BFFDh but less than 7 FFEh then the sum is divided by 3 for a signal that is 14 bits or less. Finally, when the sum of the 6 input signals **0** to **5** is greater than 7 FFEh but less than or equal to 3 FFFh then the sum is divided by 2 for a signal that is 14 bits or less.

FIG. **5** is a block diagram of one embodiment of a digital remote unit (DRU) **540** constructed according to the teachings of the present invention. A digital optical receiver **501** receives the optical digital data stream transmitted from a DHU directly or via a DEU. Receiver **501** converts the optical data stream to a corresponding series of electrical pulses. The electrical pulses are applied to clock and bit recovery circuit **503**. The series of electrical pulses are then applied to demultiplexer **505**. Demultiplexer **505** extracts the digitized traffic signals and converts the signals from serial to parallel. The output parallel signal is then applied to digital to RF converter **595** for conversion to RF and transmission to duplexer **547**. RF converter **595** is connected to the main antenna **599** through a duplexer **547**. Accordingly, radio frequency signals originating from a wireless interface device are transmitted from main antenna **547**.

In one embodiment, digital to RF converter **595** includes a digital-to-analog (D/A) converter **509**, which reconstructs the analog RF signal and applies it to IF **504** and amplifier **506**. The analog signal is mixed with an output signal of reference oscillator **515** by mixer **502**. The output of amplifier **506** is mixed with a signal from local oscillator **519** that locks the RF signal with the return digital signal via reference oscillator **515** that is coupled to local oscillator **519**. In one embodiment, the reference oscillator is coupled to frequency divider **517** that in turn is coupled to local oscillators **519** and **529**. The local oscillators **519** and **529** are also coupled to synthesizer **521** that is coupled to programmable logic device **525**.

RF signals received at main antenna **599** are passed through duplexer **547** to RF to digital converter **593**. The RF signals are converted to digital signals and then applied to multiplexer **536** converted from parallel-to-serial and optically transmitted via optical transmitter **532** to a DEU or DHU.

In one embodiment, RF to digital converter **593** includes a first amplifier **543** that receives RF signals from duplexer **547**, amplifies the signals and transmits them to digital attenuator **539**. In one embodiment, amplifier **543** is a low noise amplifier. Digital attenuator **539** receives the amplified signals and digitally attenuates the signal to control the levels in case of an overload situation. RF to digital converter **593** further includes a second amplifier **537**, which receives the attenuated signals, amplifies the signals and applies the amplified signals to mixer **535**. Mixer **535** mixes the amplified signals with a signal received from local oscillator **529**. The resultant signals are applied to a third amplifier **533** an IF filter **548** and a fourth amplifier **546** in series to down convert to an IF signal. The IF signal is then mixed with a signal from reference oscillator **515** and the mixed signal is summed with a signal from dither circuit **527**. The resultant signal is applied to analog-to-digital converter **538** and converted to a digital signal. The output digital signal is then applied to a multiplexer **536**. In one embodiment, the multiplexer **536** multiplexes the signal together with a couple of extra bits to do framing and control information. In one embodiment, multiplexer **536**, clock and bit recovery circuit and demultiplexer **505** comprise a multiplexer chip set.

Programmable logic circuit **525** programs synthesizer **521** for the reference oscillator and for the up and down conver-

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sion of local oscillators **519** and **529**. The programmable logic circuit **525** looks for error conditions, for out of lock conditions on the oscillators and reports error modes and looks for overflow condition in the A/D converter **538**. If an overflow condition occurs the programmable logic circuit **525** indicates that you are saturating and adds some extra attenuation at digital attenuator **539** in order to reduce the RF signal levels coming in from RF antenna **599** and protect the system from overload.

In one embodiment, DRU **540** includes an internal direct current power distribution system **5**. In one embodiment, the distribution system receives 48 VDC and internally distributes **3** outputs of +3.8V, +5.5V and +8V.

FIG. **6** is a block diagram of one embodiment of a digital expansion unit (DEU) **630** constructed according to the teachings of the present invention. DEU **630** is designed to receive optical signals and transmit optical signals. An optical receiver **651** receives digitized RF signals and transmits them to clock and bit recovery circuit **653** that performs clock and bit recovery to lock the local clock and clean up the signal. The signals are then split into X RF digital signals by **1** to X fan out buffer **607**. The signals are then transmitted via optical transmitters **655-1** to **655-X** to X receiving units such as DEUs or DRUs. The X receiving units may be any combination of DEUs or DRUs. In one embodiment, X is equal to six.

DEU **630** also includes optical receivers **669-1** to **669-X**, which receive digitized RF signals directly from DRUs or indirectly via DEUs. In operation the signals are received, applied to clock and bit recovery circuits **673-1** to **673-X** respectively to lock the local clock and clean up the signals and then applied to demultiplexers **671-1** to **671-X**. Demultiplexers **671-1** to **671-X** each extract the digitized traffic and apply the samples to field programmable gate array **661**. The signals are summed together digitally and transmitted to multiplexer **657**, which multiplexes the signal together with a couple of extra bits to do framing and control information. In addition, the multiplexer **657** converts the signals parallel to serial. The signals are then applied to optical transmitter **659** for further transmission. In one embodiment, the signals are directly transmitted to a DHU or indirectly via one or more additional DEUs.

In one embodiment, the FPGA **661** includes summer **665**, which mathematically sums together the digital RF signals received from demultiplexers **671-1** to **671-X**. In another embodiment, FPGA **661** includes an overflow algorithm circuit **663** coupled to the output of summer **665**. The algorithm circuit **663** allows the summed digital RF signals to saturate and keep the summed signal within a defined number of bits. In one embodiment, the algorithm circuit includes a limiter. In one embodiment, the RF signals are 14-bit signals and when summed and limited by summer **665** and overflow algorithm **663** result in a 14-bit output signal.

In one embodiment, DEU **630** includes an alternating current to digital current power distribution circuit **7** that provides direct current power to each of the DRUs coupled to DEU **630**.

In an alternate embodiment, the digital host unit (DHU) and wireless interface device (WID) are located some distance from the building being served. The DHU in the building is replaced by a DEU, and the link between that DEU and the remotely located DHU is via single mode fiber. FIG. **7** is a block diagram of this embodiment. A microcell base station shown generally at **700** includes conventional transmitters and receivers **723** and **728**, respectively, and conventional radio controller or interface circuitry **722**. In the forward path, a DHU **767** receives the combined RF signal from transmitters **723**, digitizes the combined signal and transmits it in

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digital format over single mode fiber to a DEU. In the reverse path, DHU 767 receives digitized RF signal from a DEU, reconstructs the corresponding analog RF signal, and applies it to receivers 728.

In another alternate embodiment, the wireless interface device (WID) is a software defined base station, and the interface between the DHU and WID takes place digitally, eliminating the need for the RF to digital conversion circuitry in the DHU.

## CONCLUSION

A digital radio frequency transport system has been described. The transport system includes a digital host unit and at least two digital remote units coupled to the digital host unit. The digital host unit includes shared circuitry that performs bi-directional simultaneous digital radio frequency distribution between the digital host unit and the at least two digital remote units.

In addition, a digital radio frequency transport system has been described. The transport system includes a digital host unit and at least one digital expansion unit coupled to the digital host unit. The transport system further includes at least two digital remote units, each coupled to one of the digital host unit and the digital expansion unit. The digital host unit includes shared circuitry that performs bi-directional simultaneous digital radio frequency distribution between the digital host unit and that at least two digital remote units.

Further, a method of performing point-to-multipoint radio frequency transport has been described. The method includes receiving analog radio frequency signals at a digital host unit and converting the analog radio frequency signals to digitized radio frequency signals. The method also includes splitting the digitized radio frequency signals into a plurality of a digital radio frequency signals and optically transmitting the digital radio frequency signals to a plurality of digital remote units. The method further includes receiving the digital radio frequency signals at a plurality of digital remote units, converting the digital radio frequency signals to analog radio frequency signals and transmitting the signals via a main radio frequency antenna at each of the plurality of digital remote units.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement which is calculated to achieve the same purpose may be substituted for the specific embodiments shown. For example, a digital remote unit is not limited to the receipt and summing and splitting and transmitting of digitized radio frequency signals. In other embodiments, the digital host unit is capable of receiving and summing analog radio frequency signals in addition to or instead of digitized radio frequency signals. As well, the digital host unit is capable of splitting and transmitting analog radio frequency signals in addition to or instead of digitized radio frequency signals. This application is intended to cover any adaptations or variations of the present invention. Therefore, it is intended that this invention be limited only by the claims and the equivalents thereof.

What is claimed is:

1. A system for wireless radio frequency signal distribution within a coverage area in which one or more wireless units wirelessly transmit in an upstream wireless radio frequency spectrum, the system comprising:

- a host unit; and
- a plurality of remote units communicatively coupled to the host unit using at least one communication medium,

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wherein each of the plurality of remote units is associated with a portion of the coverage area;

wherein each of the plurality of remote units receives a respective original upstream analog wireless signal comprising the upstream radio frequency spectrum and any upstream transmissions from any of the wireless units that are within the portion of the coverage area associated with that remote unit;

wherein each of the plurality of remote units generates respective upstream digital RF samples indicative of the respective original upstream analog wireless signal received at that remote unit;

wherein each of the plurality of remote units communicates the respective upstream digital RF samples generated by that remote unit to the host unit using the at least one communication medium;

wherein the host unit digitally sums corresponding upstream digital RF samples received from the plurality of remote units to produce summed upstream digital RF samples; and

wherein the host unit converts the summed upstream digital RF samples to a replicated upstream analog wireless radio frequency signal.

2. The system of claim 1, wherein the host unit receives an original downstream analog wireless signal comprising a downstream radio frequency spectrum and any downstream transmissions for the wireless units;

wherein the host unit generates downstream digital RF samples indicative of the original downstream analog wireless signal;

wherein the host unit communicates the downstream digital RF samples to at least some of the plurality of remote units using the at least one communication medium; and

wherein each of the at least some of the plurality of remote units to which the host unit communicates the downstream digital RF samples converts the downstream digital RF samples to a replicated downstream analog wireless radio frequency signal.

3. The system of claim 2, wherein the host unit comprises: an analog-to-digital converter to digitize the original downstream analog wireless radio frequency signal in order to produce the downstream digital RF samples; and

a multiplexer to frame the downstream digital RF samples for communication to at least some of the plurality of remote units as a downstream framed signal; and

wherein each of the plurality of remote units comprises: a respective demultiplexer to extract the downstream digital RF samples from the downstream framed signal received from the host unit; and

a respective digital-to-analog converter to convert the downstream digital RF samples to the respective replicated downstream analog wireless radio frequency signal.

4. The system of claim 2, wherein the respective replicated downstream analog wireless radio frequency signal generated at each of the at least some of the plurality of remote units is radiated from at least one antenna associated with that remote unit.

5. The system of claim 1, wherein each of the plurality of remote units comprises:

- a respective analog-to-digital converter to digitize the original upstream analog wireless radio frequency signal received at that remote unit in order to produce the respective upstream digital RF samples; and



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a respective multiplexer to frame the respective upstream digital RF samples for communication to the host unit as a respective upstream framed signal; and wherein the host unit comprises:

- at least one demultiplexer to extract the respective upstream digital RF samples from the respective upstream framed signals received from the plurality of remote units; and
- a digital-to-analog converter to convert the summed upstream digital RF samples to the replicated upstream analog wireless radio frequency signal.

6. The system of claim 1, wherein the replicated upstream analog wireless radio frequency signal is communicated from the host unit to at least one base station.

7. The system of claim 6, wherein the replicated upstream analog wireless radio frequency signal is communicated from the host unit to the at least one base station using at least one bi-directional amplifier.

8. The system of claim 1, wherein the host unit digitally sums the corresponding upstream digital RF samples received from the plurality of remote units in order to produce the summed upstream digital RF samples at a resolution greater than a resolution of the upstream digital RF samples being summed.

9. The system of claim 1, wherein the upstream radio frequency spectrum comprises a cellular radio frequency spectrum.

10. The system of claim 1 wherein the at least one communication medium comprises at least one of: a single mode optical fiber, a multi-mode optical fiber, and a coaxial cable.

11. The system of claim 1 further comprising:

- a digital expansion unit that is communicatively coupled to the host unit; and
- a second plurality of remote units that are communicatively coupled to the digital expansion unit;

wherein each of the second plurality of remote units receives a respective original upstream analog wireless signal comprising the upstream radio frequency spectrum and any transmissions from any of the wireless units that are within the portion of the coverage area associated with that remote unit;

wherein each of the second plurality of remote units generates respective upstream digital RF samples indicative of the respective original upstream analog wireless signal received at that remote unit;

wherein each of the second plurality of remote units communicates the respective upstream digital RF samples generated by that remote unit to the digital expansion unit;

wherein the digital expansion unit digitally sums corresponding upstream digital RF samples received from the second plurality of remote units to produce summed upstream digital RF samples;

wherein the digital expansion unit communicates the summed upstream digital RF samples to the host unit; and

wherein the host unit digitally sums the upstream digital RF samples received from the digital expansion unit with corresponding digital RF samples received from the plurality of remote units.

12. A host unit for wireless radio frequency signal distribution within a coverage area in which one or more wireless units transmit in an upstream wireless radio frequency spectrum, the host unit comprising:

- an interface to communicatively couple the host unit to a plurality of remote units using at least one communication medium, wherein each of the plurality of remote

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units is associated with a portion of the coverage area and each of the plurality of remote units receives a respective original upstream analog wireless signal comprising the upstream radio frequency spectrum and any upstream transmissions from any of the wireless units that are within the portion of the coverage area associated with that remote unit and wherein each of the plurality of remote units generates respective upstream digital RF samples indicative of the respective original upstream analog wireless signal received at that remote unit, wherein the interface is used to receive the upstream digital RF samples from the plurality of remote units;

- a digital summer to digitally sum corresponding upstream digital RF samples received from the plurality of remote units to produce summed upstream digital RF samples; and
- a digital-to-analog converter to convert the summed upstream digital RF samples to a replicated upstream analog wireless radio frequency signal.

13. The host unit of claim 12, wherein the interface is used to receive, at the host unit, an original downstream analog wireless signal comprising a downstream radio frequency spectrum and any downstream transmissions for the wireless units; and

- wherein the host unit further comprises an analog-to-digital converter to digitize the original downstream analog wireless radio frequency signal in order to generate downstream digital RF samples indicative of the original downstream analog wireless signal;
- wherein the interface is used to communicate the downstream digital RF samples to at least some of the plurality of remote units using the at least one communication medium; and
- wherein each of the at least some of the plurality of remote units to which the host unit communicates the digital RF samples converts the downstream digital RF samples to a replicated downstream analog wireless radio frequency signal.

14. The host unit of claim 13, wherein the host unit comprises a multiplexer to frame the downstream digital RF samples for communication to at least some of the plurality of remote units as a downstream framed signal.

15. The host unit of claim 12, wherein each of the plurality of remote units frames the respective upstream digital RF samples for communication to the host unit as a respective upstream framed signal; and

- wherein the host unit comprises at least one demultiplexer to extract the respective upstream digital RF samples from the respective upstream framed signals received from the plurality of remote units.

16. The host unit of claim 12, wherein the host unit communicates the replicated upstream analog wireless radio frequency signal to at least one base station.

17. The host unit of claim 16, wherein the replicated upstream analog wireless radio frequency signal is communicated from the host unit to the at least one base station using at least one bi-directional amplifier.

18. The host unit of claim 12, wherein the digital summer digitally sums the corresponding upstream digital RF samples received from the plurality of remote units at a resolution greater than a resolution of the upstream digital RF samples being summed.

19. The host unit of claim 12, wherein the upstream radio frequency spectrum comprises a cellular radio frequency spectrum.

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20. The host unit of claim 12 wherein the at least one communication medium comprises at least one of: single mode optical fiber, multi-mode optical fiber, and coaxial cable.

21. A digital expansion unit for wireless radio frequency signal distribution within a coverage area in which one or more wireless units transmit in an upstream wireless radio frequency spectrum, the digital expansion unit comprising:

a host unit interface to communicatively couple the digital expansion unit to a host unit;

a remote unit interface to communicatively couple the digital expansion unit to a plurality of remote units, wherein each of the plurality of remote units is associated with a portion of the coverage area and each of the plurality of remote units receives a respective original upstream analog wireless signal comprising the upstream radio frequency spectrum and any upstream transmissions from any of the wireless units that are within the portion of the coverage area associated with that remote unit and wherein each of the plurality of remote units generates respective upstream digital RF samples indicative of the respective original upstream analog wireless signal received at that remote unit, wherein the remote unit interface is used to receive the upstream digital RF samples from the plurality of remote units; and

a digital summer to digitally sum corresponding upstream digital RF samples received from the plurality of remote units to produce summed upstream digital RF samples; and

wherein the digital expansion unit communicates at least a portion of the summed upstream digital RF samples to the host unit.

22. The digital expansion unit of claim 21, wherein each of the plurality of remote units frames the respective upstream digital RF samples for communication to the digital expansion unit as a respective upstream framed signal;

wherein the digital expansion unit comprises at least one demultiplexer to extract the respective upstream digital RF samples from the respective upstream framed signals received from the plurality of remote units; and

wherein the digital expansion unit comprises a multiplexer to frame the summed upstream digital RF samples for communication to the host unit.

23. The digital expansion unit of claim 21, wherein the digital summer digitally sums the corresponding upstream digital RF samples at a resolution greater than a resolution of the upstream digital RF samples being summed.

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24. The digital expansion unit of claim 21, wherein the upstream radio frequency spectrum comprises a cellular radio frequency spectrum.

25. A method of distributing wireless radio frequency signals within a coverage area in which one or more wireless units transmit in an upstream wireless radio frequency spectrum, the method using a host unit and a plurality of remote units, each of the plurality of remote units being associated with a portion of the coverage area, the method comprising:

at each of the plurality of remote units:

receiving a respective original upstream analog wireless signal comprising the upstream radio frequency spectrum and any upstream transmissions from any of the wireless units that are within the portion of the coverage area associated with that remote unit;

generating respective upstream digital RF samples indicative of the respective original upstream analog wireless signal received at that remote unit; and communicating the respective upstream digital RF samples generated by that remote unit to the host unit using at least one communication medium; and

at the host unit:

digitally summing corresponding upstream digital RF samples received from the plurality of remote units to produce summed upstream digital RF samples; and converting the summed upstream digital RF samples to a replicated upstream analog wireless radio frequency signal.

26. The method of claim 25, wherein each of the plurality of remote units frames the respective upstream digital RF samples for communication to the digital expansion unit as a respective upstream framed signal;

wherein the method further comprises, at the host unit, for each of the plurality of remote units, extracting the respective upstream digital RF samples from the respective upstream framed signal received from that remote unit; and

wherein the method further comprises, at the host unit, framing the summed upstream digital RF samples for communication to the host unit.

27. The method of claim 25, wherein the corresponding upstream digital RF samples are digitally summed at a resolution greater than a resolution of the upstream digital RF samples being summed.

28. The method of claim 25, wherein the upstream radio frequency spectrum comprises a cellular radio frequency spectrum.

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