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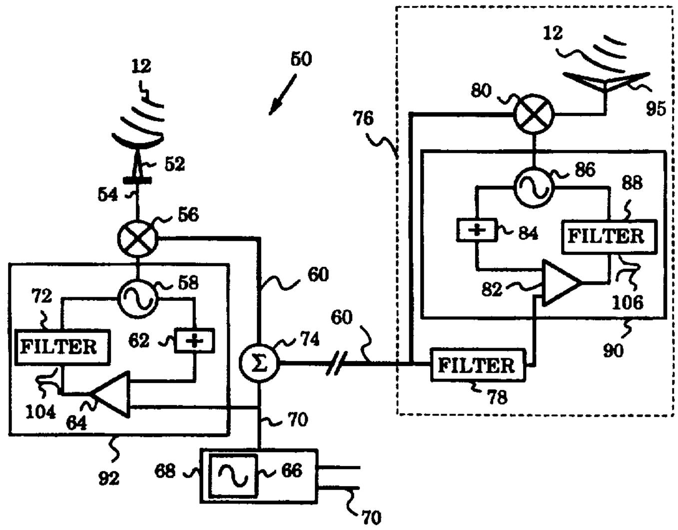

(57) Abstract

A system and method for transmitting a radio frequency (RF) signal in a RF bandwidth over a low bandwidth medium (60), e.g., in-building cabling, which has a transmission bandwidth below the RF bandwidth. The system (50) has a unit (52) for receiving the RF signal and global reference oscillator (66) for distributing a global reference tone of high stability to the entire system (50). Local oscillators (58 and 86) are controlled by adjustement signals derived from this global reference tone to deliver RF reference tones of high stability required for mixing the RF signal to obtain an intermediate frequency (IF) signal which is fed through the low bandwidth medium (60). The global reference tone is preferably delivered through the same low bandwidth medium (60) to desired locations, such as remote coverage sites in a network for cellular communications, cordless telephony, local RF communications, interactive multi-media video, and high bit-rate communications.

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DISTRIBUTION OF RADIO-FREQUENCY SIGNALS THROUGH LOW BANDWIDTH INFRASTRUCTURES

BACKGROUND -- FIELD OF THE INVENTION

The present invention relates to the field of radio-frequency (RF) signal distribution, and in particular to an apparatus and method for distributing RF signals through low bandwidth infrastructures.

BACKGROUND -- DESCRIPTION OF PRIOR ART

The demand for wireless communications continues to grow rapidly. The need for efficient and low-cost systems for distributing radio frequency (RF) signals is a direct consequence of this growth. Distribution of RF signals is particularly difficult in areas with many natural and man-made obstacles which scatter or absorb RF radiation. For example, the problem of RF distribution is especially acute inside and around building structures.

Current in-building distribution systems consist of two major parts. The first is a set of antennas and associated accessories required for re-transmitting the RF signals inside buildings. The second is a cabling system, e.g., an optical fiber network, used for interconnecting the in-building antennas with a main antenna. The latter is usually installed on top of the building or at some location where the external RF signals can be easily received. In cases where the RF signals are supplied via a high transmission bandwidth cable the main antenna can be replaced by a direct interface with the RF network, e.g., in the basement.

The cost of installing and maintaining such in-building distribution networks is very high. One of the major cost factors is the cabling network. In addition, running new cables between various rooms, floors, or wings of a building is usually time-consuming and disruptive. For this reason, desirable solutions to in-building RF distribution systems should incur minimal installation cost, require no special tooling (as necessitated, e.g., in fiber optic networks), and produce no undue disturbance in the building during installation and operation. It would also be advantageous for such networks to be consistent with common in-building cable infrastructure.

The most effective manner of satisfying these criteria would be to use an existing or standard in-building cable infrastructure. Unfortunately, several obstacles prevent this approach. The major problem is related to the frequency bands used for transmitting RF information signals. Cellular communications presently utilize a carrier frequency around 1 GHz. For, example, the Advanced Mobile Phone System (AMPS) protocol uses the bandwidth from 824-894 MHz and GSM is transmitted between 890-960 MHz. Recent legislation has allowed PCS services to move to even higher frequencies (e.g., 1.85-1.99 GHz). In comparison, the standard in-building cabling such as unshielded or shielded twisted pair (UTP and STP) used for local area networks (LAN), telephone cables, multi-mode optical fiber links, and power lines are limited to much lower transmission bandwidths. For example, category 5 (10 base T) UTP cable has signal loss and cross talk properties that limit the bandwidth to approximately 0-100 MHz for distances <100 m. Although these parameters suffice for LAN applications, they are clearly inadequate for the delivery of cellular and PCS signals to and from remote antenna sites.

For this reason, prior art solutions employ wide bandwidth media such as coaxial cables and optical fibers. These media have to be installed separately, and require specially trained personnel, as discussed above.

Thus, the challenge is to transmit high frequency RF signals over the standard low bandwidth infrastructures discussed above. The common method of accomplishing this goal is to initially down-convert the band of the RF signal to an intermediate frequency (IF) which is within the bandwidth of the cable. Then, the IF signal is fed through the standard low bandwidth cable found in the building. At the remote antenna site the IF signal is up-converted to recover the original RF signal and the recovered RF signal is re-transmitted by the remote antenna. This solution is illustrated in FIG. 1 and will be discussed in the detailed description.

A major problem encountered in implementing this solution involves the stability of local oscillators. These provide the reference signals required by the mixers to down-convert and up-convert the signals. To ensure proper operation the local oscillators must generate a stable tone at the selected high RF frequency (e.g., 800 MHz). It is critical that the frequency of the two oscillators be matched to within at least the channel spacing of the RF signals. In fact, it is desirable that the oscillators be "locked" to each other to preserve the frequency of the RF signal band. This issue becomes even more crucial at higher frequencies, e.g., the PCS bandwidth centered around 2 GHz where the relative width of the communication channels is small in comparison to the carrier frequency.

The two solutions to this problem are to either use very stable oscillators (e.g., <1 part per million stability), which are prohibitively expensive, or to distribute the oscillator tone from a central location. The second option is not viable either, since the media under consideration do not have the bandwidth required for the implementation of such a system.

The existing solutions to distributing a stable oscillator tone are limited. In U.S. patent 5,046,135 Hatcher shows how to eliminate frequency instabilities in a receiver frequency converter due to inherent local oscillator instability by adding a marker signal at the down-conversion stage. The marker signal is distorted in the same manner as the IF signal and a second stage down-converter computes this distortion by comparison with the marker signal before undertaking any further down-conversion.

This solution is complicated, since it breaks down the conversion process into two steps and requires the addition of a marker tone in addition to the oscillator frequencies and the signal. Moreover, it can not be employed in conjunction with the low bandwidth media found in buildings. Indeed, the main purpose of the invention is to gradually and reliably down-convert very high-frequency signal received, e.g., from satellites in orbit.

U.S. patent 4,959,862 issued to Davidov et al. addresses a novel scheme for the delivery of FM modulated subcarriers over a fiber-optic link for cable television transmission

(CATV). Conventional CATV systems use vestigal sideband amplitude modulation (VSB-AM) for transmission of analog video channels to home users. In comparison, frequency division multiplexed frequency modulated (FDM-FM) signals can provide a higher signal to noise ratio and a longer transmission distance. Davidov et al. describe a method for the conversion of VSB-AM channels to FDM-FM channels before transmission over the fiber-optic link. After transmission, the FM signals are re-converted back to AM signals before transmission to the home. A 4 MHz "global reference" is distributed along with the FM signals to AM signals.

Although Davidov et al. address the idea of a global signal which can be used for reference ("locking") of conversion stages, this idea is not applicable to the problem at hand. First, the reference signal is high frequency and is distributed to the remote antenna sites for the purpose of FM to AM signal conversion. It is not a signal which is compatible with a system based on a limited and low bandwidth medium for transmitting RF signals. In fact, Davidov et al. emphasize the fact that this system uses a fiber-optic medium which is broadband. Moreover, in Davidov's system architecture it is not necessary to use the global reference, rather it is provided for convenience. The only advantage Davidov et al. derive from using a centralized oscillator is the reduction of oscillator phase noise.

In U.S. patent no. 5,109,532 Petrovic et al. discuss the transmitter and receiver of a radio communication link. This link requires up- and down-conversion of the signals to be transmitted to and from the radio band of interest. The frequency and phase of the oscillators used for up- and down-conversion are a large cost and performance consideration. The problem is solved by adding a radio frequency pilot tone to the up-converted signals before transmission. At the receiver, a local oscillator is used to down-convert both the RF signal and the pilot tone. Any phase or frequency deviations of the local oscillator affect the RF signal and the pilot tone equally. Therefore, both signals can be used to cancel the phase and frequency variations, resulting in a clean recovered signal as shown in FIG. 2C in Petrovic's patent. This cancellation method solves the problem of local oscillator stability at the receiver.

Although the disclosure is intended to solve a similar problem as the present invention, namely the stability of a remote oscillator, the method by which the problem is solved is quite different. Furthermore, the method does not describe, nor is it obvious, how one would implement this technique over a low-bandwidth medium, since the pilot tone is at a RF frequency.

In addition to devising a system for proper "locking" of oscillators to be able to transmit RF signals through low bandwidth infrastructure there are additional unsolved problems. In a typical RF distribution system multiple remote antennas re-transmit the up-converted RF signal. To ensure complete coverage the coverage areas of the individual antennas overlap. Thus, a user will frequently receive signals from multiple antennas simultaneously. When the individual oscillators used for the up-conversion at those antennas are not exactly frequency matched the user will hear a baseband tone or beat at the difference between the frequencies of the two local oscillators.

Thus, efficient and reliable distribution of RF signals over low bandwidth infrastructures remains an unsolved problem.

OBJECTS AND ADVANTAGES OF THE INVENTION

In view of the shortcomings of prior art, it is an object of the invention to provide a system and method for distributing RF signals through low bandwidth infrastructure. In particular, it is an object of the invention to enable one to distribute RF signals through standard in-building cabling.

Another object of the invention is to ensure that the system is highly efficient in its use of resources, simple to install and operate, and low-cost.

Yet another object of the invention to provide a method and a system for distributing RF signals in buildings which avoid oscillator instabilities which generate beat frequencies and related effects and lead to decreased link quality.

These and other objects and advantages will become more apparent after consideration of the ensuing description and the accompanying drawings.

SUMMARY OF THE INVENTION

The objects of the invention are achieved by a unique system for transmitting a radio frequency (RF) signal in a RF bandwidth over a low bandwidth medium which has a transmission bandwidth below the RF bandwidth. Typically, the low bandwidth medium is a standard cable belonging to common in-building infrastructure. The RF bandwidth is usually selected from the group of RF bandwidths used for cellular communications, cordless telephony, local RF communications, satellite television, interactive multi-media video, high bit-rate local area networks and the like. In these situations the RF bandwidth is narrower than the transmission bandwidth of the low bandwidth medium. The latter can be a 10 base T cable, a telephone wire, a fiber-optic cable, an unshielded cable, a power cable or any other low bandwidth, standard in-building infrastructure.

The system has a unit, usually a main antenna or base station, for receiving the RF signal. A global reference oscillator, preferably a very high stability oscillator such as a temperature-stabilized crystal oscillator, provides a global reference tone of high stability, e.g., <1 part per million stability, at a frequency within the transmission bandwidth of the low bandwidth medium. In the preferred embodiment the global reference oscillator is located in a safe location inside a distribution hub and the global reference tone is delivered from there to the entire system.

A first local oscillator, preferably a voltage-controlled oscillator (VCO), is controlled by a first adjustment signal derived from the global reference tone. With the aid of the first adjustment signal the first local oscillator generates a first RF reference tone of high stability. The main antenna and the first local oscillator are connected to a first mixer, such that the first RF reference tone and the RF signal are delivered to this first mixer. From these two signals the mixer generates an intermediate frequency (IF) signal, which is fed through the low bandwidth medium. The IF signal has a frequency contained within the transmission bandwidth of the low bandwidth medium.

A second local oscillator is provided at a remote location, e.g., in a remote coverage area. The second local oscillator is controlled by a second adjustment signal also derived from the global reference tone. In this manner the second local oscillator generates a second RF reference tone of high stability at the same frequency as the first RF reference tone. A second mixer is also provided at the remote location and connected to the second local oscillator and to the low bandwidth medium. Thus, the second mixer receives the second RF reference and the IF signal. By mixing these two signals the mixer recovers the original RF signal. Of course, this system can be extended to any number of remote locations, as will be necessary in a practical system which provides radio coverage to an entire building structure such as an office building or a shopping center.

The method for deriving the first and second adjustment signals relies on a phase-locking circuit or a phase-locked loop (PLL). The global reference tone can be delivered to the PLL in several ways. In particular, it can be delivered directly through a separate link, e.g., a short communication link if the global reference oscillator is positioned close to the oscillator in question. This is the case when both the local oscillator and the global reference oscillator are located in the same housing, such as a main hub. Otherwise, the global reference tone can be transmitted together with the IF signal through the low bandwidth medium.

When distributing the global reference tone through the low bandwidth medium together with the IF signal it is important that these signals do not overlap. The method of the invention stipulates that this be the case, and, in the preferred embodiment, the global reference tone has a lower frequency than the IF signal. Furthermore, a summing element is provided specifically for the purpose of adding the global reference tone to the IF signal such that both are fed through the low bandwidth medium.

A filter is used for retrieving the global reference tone from the low bandwidth medium at the remote location. This function can be performed by a simple band-pass filter with its window set for the global reference tone. The PLL in this event is located between the filter and the local oscillator at the remote location.

The phase-locking circuit itself consists of a frequency divider, also called a prescaler, connected to the local oscillator for dividing an unstable RF reference tone generated by this oscillator to derive an unstable IF reference tone near the frequency of the global reference tone. Of course, because the local oscillator is unstable, the frequencies will not be matched. A phase comparator is used to lock the unstable IF reference tone to the global reference tone by generating an output adjustment signal proportional to the mismatch between the reference and the IF signals. Preferably, another filter, also called a loop filter, is provided between the output of the phase comparator and the local oscillator. The adjustment signal stabilizes the local oscillator and induces it to generate the second RF reference tone of high stability.

The recovered RF signal can be re-transmitted at one or many remote locations, depending on the actual circumstances. Usually, local antennas with overlapping coverage areas will be used for that purpose. The low bandwidth infrastructure can be a network, e.g., a star network, a tree network, a branch network or any other type of network commonly installed inside buildings.

In the preferred manner of practicing the invention the frequency of the global reference tone is selected below the bandwidth of the IF signal. Also, the method of the invention teaches bi-directional communications as required in practical applications.

Further details and the preferred embodiment are described in the specification in reference to the attached drawing figures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of a typical prior art RF distribution system.

FIG. 2 is a diagram showing the typical RF bandwidth and a typical transmission bandwidth.

FIG. 3 is a diagram showing the transmission bandwidth and the bandwidth of the IF signal.

FIG. 4 is a schematic view of a simple RF distribution system according to the invention.

FIG. 5A is a diagram showing the stabilization of reference tones.

FIG. 5B is a diagram showing the relationship between the IF signal and the global reference tone.

FIG. 6 is a schematic view of an RF distribution system according to the invention with multiple remote coverage sites.

FIG. 7 is a schematic view of another RF distribution system according to the invention.

FIG. 8 is a schematic view illustrating the overlap in coverage areas.

FIG. 9 is a three-dimensional view of the RF distribution system according to the invention adapted to a building structure.

FIG. 10 is a diagram showing typical 10 Base T in-building cables.

FIG. 11 is a schematic diagram of another RF distribution system according to the invention.

FIG. 12 is a schematic diagram of still another RF distribution system according to the invention.

FIG. 13 is a diagram illustrating a portion of a system of the invention using multi-mode optical fiber.

FIG. 14 is a graph of the Two Tone Test for the system of FIG. 13.

FIG. 15 is a diagram of an advantageous IF signal amplification method according to the invention.

DESCRIPTION

The salient features of the invention will be best appreciated after reviewing the typical prior art distribution system **10** for radio frequency (RF) signal **12** illustrated in FIG. 1. In this typical system RF signal **12** is in a bandwidth typically used for cellular communications or the like. FIG. 2 indicates a RF bandwidth **30**, spanning the range from 824 MHz to 894 MHz. This range is typical for RF signal **12** used in cellular communications.

RF signal **12** is received by main or base antenna **14**. Connection **16**, e.g., a coaxial cable, delivers RF signal **12** from antenna **14** to one of the inputs of a first mixer **18**. The second input of mixer **18** is connected to a first local oscillator **20**. Oscillator **20** provides an RF frequency tone which is utilized by mixer **18** to down-convert RF signal **12** to an intermediate frequency (IF) and to feed it through a low bandwidth medium **33**, such as a standard, pre-installed cable.

FIG. 2 better illustrates the relationships of the various signals and their bandwidths. In particular, the down-conversion of RF signal **12** from RF bandwidth **30** yields an IF signal **32** contained in a transmission bandwidth **34**. Transmission bandwidth **34** ranges from 0 to 100 MHz, which is typical for low bandwidth media commonly installed in building structures.

Referring back to FIG. 1, IF signal **32** is transmitted through medium **33** to a remote location or site **36** delineated by a broken line. Site **36** is usually a room inside a building structure or some other area in which RF coverage is desired. At this location IF signal **32** is received by a second mixer **38**, which, with the aid of oscillator **40**, up-converts IF signal **32** to recover original RF signal **12**. Then, a remote antenna **42** is used to re-transmit RF signal **12** in remote site **36**.

As outlined in the background section, distribution system **10** and other related prior art systems suffer from instability of local oscillators **20** and **40** (unless very expensive oscillators are used). An RF distribution system **50** according to the invention and shown in FIG. 4 avoids this disadvantage in a simple and effective manner.

As in the prior art example, system **50** has a main or base antenna **52** which receives RF signal **12**. Antenna **52** is connected by a communication link **54**, e.g., a coaxial cable or any other link capable of transmitting RF signal **12** without undue distortions, to one of the inputs of a first mixer **56**. The type of device selected as mixer **56** can include any suitable single ended, balanced, double-balanced, double-double balanced or other mixer. A first local oscillator **58**, preferably a voltage-controlled oscillator (VCO), is connected to another input of mixer **56**. A low bandwidth medium **60**, such as 10 base T cable, telephone wire, fiber-optic cable, unshielded or shielded cable, power cable, or any other low bandwidth in-building medium is connected to the output of mixer **56**.

Oscillator **58** is typically a low-cost device which by itself produces an unstable RF reference tone. One output of oscillator **58** is connected to mixer **56** and another output leads to a frequency divider **62**. The function of divider **62** is fulfilled by any frequency dividing device or circuit capable of dividing the received tone by an integer. The output of divider **62** is further connected to one input of a phase comparator **64**. Suitable comparators are well-known in the art.

The second input of comparator **64** is connected to a global reference oscillator **66**. As shown, oscillator **66** is housed in a separate housing unit or distribution hub **68**. In order to ensure stability and high performance of oscillator **66** hub **68** is installed in an area not exposed to excessive temperature fluctuations, vibrations, or other external influences. These conditions are frequently met inside buildings away from windows, doors, or other openings, e.g., in basements. In addition, the preferred embodiment employs as oscillator **66** a temperature-stabilized crystal oscillator. Devices of this kind can achieve stability figures of about 1 part per million and are commercially available. The frequency of oscillator **66** will be discussed below.

It should be noted, that only one reference oscillator **66** is used in system **50**. Thus, any element of system **50** in need of the tone from oscillator **66** can be supplied with it through lines **70**. In this case, one of lines **70** connects oscillator **66** to the other input of comparator **64**.

The output of comparator **64** is connected to a filter **72**. A suitable low-pass loop filter is well-known in the art and can be constructed from commercially available components. The output of filter **72** is connected to the control input of oscillator **58**.

In the preferred embodiment system **50** has a summing element or adding device **74** connecting one of lines **70** to low bandwidth medium **60**. Device **74** can combine signals already traveling through medium **60** with any additional signal, in this case the signal produced by oscillator **66**. Devices capable of performing this operation are well-known in the art.

At a remote coverage location or site **76** medium **60** is connected to a filter **78** and to a second mixer **80**. Filter **78** has a pre-set band-pass for selecting a specific frequency from the signals transmitted through medium **60**. The output of filter **78** is connected to one of the inputs of a phase comparator **82**. The other input of comparator **82** is connected to the output of a frequency divider **84**, analogous to frequency divider **62**, which, is connected to a second local oscillator **86**. As before, local oscillator **86** is a voltage-controlled oscillator which produces an unstable RF reference tone. The output of comparator **82** is hooked up through a filter **88** to the controlling input of oscillator **86**.

Together, oscillator **86**, divider **84**, comparator **82** and filter **88** form a phase-locking device or circuit **90**, frequently also called a phase-locked loop (PLL). In fact, oscillator **58**, filter **72**, comparator **64** and divider **62** also form a phase-locking circuit **92**. Both circuits, **90** and **92**, are analogous in construction and operation, as will be shown below.

Remote coverage site **76** has a re-transmitting unit **95**, in this case an RF antenna for re-transmitting RF signal **12** from mixer **80**. Proper positioning of antenna **95** at site **76** to ensure RF coverage will be determined by the persons installing system **50** on a case by case basis.

During operation, main antenna **52** of RF distribution system **50** receives RF signal **12**. As indicated in FIG. 2, RF signal **12** is contained in RF bandwidth **30** ranging from 824 MHz to 894 MHz. In practice, however, RF signal **12** can belong to other RF bandwidths, depending on the type of communication. Thus, RF bandwidth **30** can be selected from the group of RF bandwidths used for cellular communications, cordless telephony, local RF communications, satellite television, interactive multi-media video, high bit-rate local area networks, and the like. The characteristic feature shared by all these RF bandwidths is that they are higher than transmission bandwidth **34** of medium **60**.

Antenna **52** delivers RF signal **12** via communication link **54** to first mixer **56**. Meanwhile, phase-locked loop **92** delivers a first RF reference tone **96** (see FIG. 2) of high stability to mixer **56**. According to known mixing techniques, first mixer **56** responds to these two inputs by generating an IF signal **94**, or, in other words, down-converting RF signal **12**. The result of the down-conversion--IF signal **94**--is shown in FIG. 3. In the present embodiment, IF signal **94** has a narrower bandwidth (894 MHz - 824 MHz = 70 MHz) than transmission bandwidth **34** of medium **60**. In fact, IF signal **94** only takes up the bandwidth from 24 MHz to 94 MHz. The actual bandwidth of down-converted RF signal **12**, i.e., IF signal **94**, can vary as conditioned by available in-building infrastructure. At any rate, since the output of first mixer **56** is connected to medium **60**, IF signal **94** is transmitted or fed through medium **60**.

The down-conversion process itself depends on the stability of first RF reference tone **96** supplied to first mixer **56**, and the former usually depends on the stability of first local oscillator **58**. In this case, however, the output of oscillator **58** is a first RF reference tone **96** of high stability. This result is achieved in several steps with the aid of the remainder of phase-locking circuit **92** and global reference oscillator **66**.

First, as illustrated in FIG. 5A, the original output of oscillator **58** which is an unstable RF reference tone **98** is fed to frequency divider **62**. The inherent fluctuation of tone **98** is evident from its wide spread of possible frequencies. Divider **62** is set to divide tone **98** by an integer to derive an unstable IF reference tone **100**, as shown. It is intended that unstable IF reference tone **100** match closely the frequency of a global reference tone **102** generated by global reference oscillator **66** residing in distribution hub **68**. Also, unstable IF reference tone **100** as well as global reference tone **102** are contained within transmission bandwidth **34** of medium **60**.

For most reliable operation, global reference tone **102** is in the middle of the bandwidth occupied by unstable IF reference tone **100**. Furthermore, it is preferable that the bandwidth of IF reference tone **100**, and consequently the frequency of global reference tone **102**, lie outside the bandwidth of IF signal **94**. This configuration avoids any potential interference between IF signal **94** and reference tone **100**. In FIG. 5A the bandwidth of IF reference tone **100** is below the bandwidth of IF signal **94** and centers around the frequency of global reference tone **102** equal to 8.0 MHz. Of course, these figures have been selected for demonstration purposes only.

Phase comparator **64** receives at its two inputs unstable IF reference tone **100** and, through line **70**, the highly stable global reference tone **102**. In response to these two inputs comparator **64** generates at its output a first adjustment signal **104** representative of the phase mismatch or difference between unstable tone **100** and stable tone **102**. Filter **72** clears adjustment signal **104** of high frequency noise, and ensures stability of the feedback loop. From filter **72** adjustment signal **104** passes to the control input of first local oscillator **58**. There, adjustment signal **104** is used to fine-tune the oscillation frequency of oscillator **58**.

Thanks to the feedback nature of phase-locking circuit **92**, the fine-tuning or trimming of oscillator **58** is performed continuously using the very stable global reference tone **102** as the benchmark. Consequently, the output of oscillator **58** is forced to generate first RF reference tone **96** of high stability. First mixer **56** takes advantage of this high stability reference tone **96** to produce very accurately down-converted IF signal **94**, which is then fed through medium **60**.

In the preferred embodiment distribution hub **68** is connected to summing element **74**, which interfaces with medium **60**. Thus, global reference tone **102** from oscillator **66** is delivered to summing element **74**. There, IF signal **94** already traveling through medium **60** is combined with global reference tone **102** and sent through medium **60** to remote coverage site **76**. No undesirable interference is created between IF signal **94** and tone **102** result, since their bandwidths do not overlap. In this manner, global reference tone **102** is efficiently forwarded to remote site **76** through the same medium as the useful signal.

At remote site **76** filter **78** retrieves global reference tone **102** from medium **60**. Meanwhile, IF signal **94** passes through to second mixer **80**. Phase-locking circuit **90**, operating in the same manner as phase-locking circuit **92**, uses tone **102** to stabilize the output of second local oscillator **86**. For this purpose comparator **82** produces a second adjustment signal **106** and delivers it through filter **88** to the control input of oscillator **86**. The output of oscillator **86** generates stable RF reference tone **96**. Mixer **80** uses stable RF reference tone **96** to up-convert IF signal **94** and recover RF signal **12** with minimal signal distortion. Then, RF antenna **95** receives RF signal **12** and re-transmits it throughout site **76**.

System **50** is thus well-adapted to RF distribution in buildings and other structures using existing low bandwidth media such as conventional cables. The system resources are basic. Only one cost-intensive oscillator, namely global reference oscillator **66**, is required to ensure proper up- and down-conversion of signals in this arrangement. The other essential elements are simple, easy to install, and generally low-cost. In fact, voltage-controlled oscillators, such as oscillators **58** and **86** generating stable reference RF reference tone **96** at 800 MHz using 3.125 MHz as global reference tone **102** can achieve high stability at a very low cost.

The above embodiment is very simple and serves mainly to demonstrate a few fundamental aspects of the invention. A more practical RF distribution system **110** according to the invention is illustrated in FIG. 6. Corresponding parts of this embodiment are designated with the same reference numbers as in the first embodiment.

Communication link **54** delivers RF signal **12** to a main hub **112**. Housed inside main hub **112** is first mixer **56** and first local oscillator **58**. Divider **62**, comparator **64** and filter **72** are connected and operate in the same manner as described above and are also housed in hub **112**. In fact, global reference oscillator **66** and summing element **74** are inside hub **112** as well. In this manner, all elements necessary to convert RF signal **12** to IF signal **94** are arranged in the same compact unit.

Summing element **74** is connected to three low bandwidth cables **114**, which are routed to their respective remote coverage sites **116**, **118**, **120**. Phased-locking circuits **122**, **124**, **126** and filters **128**, **130**, and **132** are connected in the same manner and perform the same functions as filter **78** and circuit **90** in the previous embodiment. In other words, circuits **122**, **124**, **126** and filters **128**, **130**, and **132** allow each remote site **116**, **118**, **120** to filter out global reference signal **102** and use it to produce a stable second RF reference signal **96**. Furthermore, each remote site **116**, **118**, **120** has its own second mixer **134**, **136**, and **138** for recovering RF signal **12** from IF signal **94**. After recovery RF signal **12** is re-transmitted at each remote site **116**, **118**, **120** by a corresponding RF antenna **140**, **142**, **144**.

Distribution system **110** is more compact and practical in some applications by virtue of using one single hub **112**. Of course, the construction and location of hub **112** have to ensure that the internal elements are protected. Especially global reference oscillator **66** has to be isolated in a manner to ensure stability of global reference tone **102**.

FIG. 7 illustrates another RF distribution system **150** according to the invention. As in the previous embodiments, RF signal **12**, received by main antenna **52**, is delivered to first mixer **56** to be down-converted to produce IF signal **94**. Global reference oscillator is housed separately in a distribution hub **152**. From there global reference tone **102** is distributed through links **154** to network hubs **156** and **158**, and to phase-locking loop **92**.

Network hubs **156** and **158** contain multiple summing elements **74** which allow one to launch global reference tone **102** on many low bandwidth cables **160**. In fact, cables **160** constitute a network **162**. Cables **160A-D**, when viewed independently, form a tree network, while all cables **160** form two star networks with hubs **156** and **158** representing their centers.

It is clear from this embodiment that distribution system **150** of the invention can be adapted to any existing network of in-building cables. In particular, any star network, tree network, ring network or branch network is suited for distributing RF signal **12** according to the invention. In addition, links **154** do not need to be part of the network infrastructure if other media for distributing global reference signal **102** are deemed convenient by the system designer. For example, global reference tone **102** can be distributed through fiber-optic links, or AC power lines.

FIG. 8 shows a particularly advantageous aspect of the invention. Two remote coverage sites **170** and **172** have corresponding RF antennas **174** and **176** for re-transmitting RF signal **12**. As in the above embodiments, IF signal **94** is fed through a low bandwidth medium, in this case power cables **178** and **180**. Units **182** and **184** contain all the elements discussed above necessary for recovering RF signal **12** from IF signal **94** according to the invention.

The RF coverage areas of sites **170** and **172** overlap. The region where this happens is hatched and designated by reference numeral **186**. In general, overlap in coverage of adjacent sites is desirable because it guarantees complete coverage. A user equipped with an RF receiver (not shown) and positioned in region **186** will intercept RF signal **12** from both antennas **174** and **176**.

In prior art systems the instability of local oscillators, even of high-quality devices, incurs a small frequency difference, Δf, between RF signal **12** coming from antenna **174** and the same RF signal **12** arriving from antenna **176**. This frequency difference, (typically about ± 500 Hz), creates an audible beat frequency. Besides being annoying to the user, e.g., by interfering with the conversation in the case of telephonic communications, the beat frequency can impair the functioning of the electrical components and introduce spurious signals. RF distribution systems used for data transfer can experience higher bit error rates (BER) and other degrading effects.

Fortunately, RF distribution systems according to the invention can recover RF signal **12** with no frequency shift at all. Thus, in the present case, RF signal **12** radiated from antenna **174** and from antenna **176** will have the same frequency and not induce any beats.

FIG. 9 illustrates an RF distribution system **190** according to the invention used in a building structure **192**. In this case system **190** is bi-directional, i.e., RF antennas **194** installed in various locations throughout structure **192** can re-transmit and receive RF signals **12**. For better understanding, transmitted RF signals are designated by **12A** and received RF signals are indicated by **12B**. A main antenna **196** mounted on the roof of structure **192** can also transmit and receive RF signals **12A** and **12B**.

System **190** utilizes in-building low bandwidth network including cables **198**, **200**, **202**, **204**, and wiring closets **206** and **208** to distribute RF signal **12**. In this particular arrangement, wiring closet **208** houses a distribution hub **210**. The latter supplies global reference tone **102** from a temperature-stabilized crystal oscillator serving as the global reference oscillator (not shown). Protection of hub **210** from external influences is ensured by virtue of location of closet **208** on the ground floor and away from openings such as doors or windows.

It should be noted that cables **198**, **200**, **202**, **204** may constitute a pre-existing network which can not be extensively modified by the designer without expensive re-routing work. For example, cables **198**, **200**, **202**, **204** are standard AC power cables which are truly ubiquitous even in old structures. The choice of AC power cables will allow one to distribute RF signals in virtually any environment without altering the in-building cabling, thus providing an ultra-low-cost RF distribution network. An additional advantage of using AC power lines is that the power for operating antennas **194** and any other necessary electronics (not shown) can be provided through cables **198**, **200**, **202**, and **204** simultaneously with the IF signal. Of course, since AC power lines are pre-installed, the designer of the RF distribution system will encounter some limitations. Indeed, in some rooms the locations of antennas **194** may be imposed by the infrastructure.

For example purposes, system **190** is assumed to be used for cordless telephony. Cordless telephones operate in the 900 MHz frequency band and has a narrow bandwidth which can be transmitted through cables **198**, **200**, **202**, **204**. Of course, in this application antennas **194** should be placed in locations outside building **192** as well (e.g., near a swimming pool, etc.).

FIG. 10 illustrates the most common low bandwidth medium **220** found inside buildings. In particular, medium **220** is a cable consisting of four twisted pairs **222**, **224**, **226**, **228** or wire pairs. These can all be used for distributing signals for cellular communications, cordless telephony, local RF communications, satellite television, interactive multi-media video, or high bit-rate local area networks.

FIG. 11 illustrates schematically yet another RF distribution system **230** according to the invention. Main antenna **232** is positioned on top of a building **234** to receive and transmit RF signals **12A** and **12B**. System **230** consists of three star networks **238A**, **238B**, **238C**, one per floor, individually fed from antenna **232**. Networks **238A**, **238B**, **238C** have RF antennas **240** and independent hubs **242A**, **242B**, **242C** for housing the essential components discussed above.

FIG. 12 illustrates another advantageous RF distribution system **250** inside same building **252**. System **250** takes advantage of a pre-installed private branch exchange **254** (PBX) and does away with a main antenna as the unit for receiving and re-transmitting RF signals **12A** and **12B**.

In this embodiment RF signals **12A** and **12B** are delivered to PBX **254** and received from it by any suitable high bandwidth medium (not shown). Thus, RF signals **12B** are fed by PBX **254** to hubs **258A**, **258B**, **258C** of three star networks **256A**, **256B**, **256C**. Then, RF signals **12A** are received from star networks **256A**, **256B**, **256C** and sent back to PBX **254**, which re-transmits them via the high bandwidth medium.

Since PBX systems are widespread, this embodiment is very practical. No additional cables need to be routed from any external RF antennas in this case. In fact, PBX systems are found in many locations and are frequently pre-wired for indoor within one or more building structures, and, in some cases, outdoor operation as well. Few modifications will be required to install an RF distribution system according to the invention in this manner.

FIG. 13 illustrates a portion of yet another system **260** according to the invention. A low bandwidth medium **262**, in this case a multi-mode fiber optic cable, connects a LED (Light Emitting Diode) unit **264** to a low-speed analog detector **266** at a remote site **270**. Because the transmission bandwidth of optic cable **262** required for this invention is below 100 MHz the length of cable **262** can exceed 1 km. The ability to cover such distances renders the embodiment particularly useful in shopping centers and other structures covering large areas.

Same mixer **56** as in FIG. 4 delivers IF signal **94** to LED unit **264** via low bandwidth medium **268**. Medium **268** may belong to a pre-installed network, e.g., AC power mains or telephone wires.

Low-cost LEDs exhibit an excellent response at low frequencies, in particular within the transmission bandwidth of medium **262**, (<100 MHz), and no response at higher frequencies, e.g., 1 GHz. Thus, LED unit **264** is well-suited for feeding IF signal **94** through medium **262**. Conventional optical systems use lasers and single-mode optical fibers, both of which are expensive, to send signals at various frequencies. This embodiment is very low cost in comparison with conventional systems and very efficient in the desired frequency range. In support of this fact, FIG. 14 shows the results of a standard Two Tone Test for LED unit **264** operating at 1.3 um and 1 km long cable **262**.

Finally, FIG. 15 shows an advantageous addition to a portion of a system **280** according to the invention. System **280** uses a summing element **288** for adding global reference tone **102** to IF signal **94**, as discussed above, and feeding both through a network **290** consisting of low bandwidth cables **286**. Two standard amplifiers **282** and **284** for amplifying signals within transmission bandwidth **34** are connected to cables **286**.

During operation amplifiers **282** and **284** amplify IF signal **94** while it passes through cables **286**. If desired, both or one of amplifiers **282**, **284** can also amplify global reference tone **102**. A person skilled in the art will appreciate the fact that amplifying signals at lower frequencies is simpler and less costly than amplifying RF frequency signals. Thus, the present embodiment points out a particularly advantageous method for preserving the strength of signals distributed by a system according to the invention. This "repeater function" can be incorporated in any of the above embodiments by installing suitable low frequency amplifiers (<100 MHz) at frequencies corresponding to the IF signals and/or to the global reference tone.

The versatility of RF distribution systems according to the invention and its numerous embodiments teach a method of distributing RF signals. Indeed, a person skilled in the art will be able to glean from the examples given the characteristic features of the method of the invention.

CLAIMS

We claim:

1. A system for transmitting a RF signal contained in a RF bandwidth over a low bandwidth medium having a transmission bandwidth below said RF bandwidth, said system comprising:
   a) a receiving means for receiving said RF signal;
   b) a global reference oscillator for providing said system with a global reference tone of high stability at a frequency within said transmission bandwidth of said low bandwidth medium;
   c) a first local oscillator controlled by a first adjustment signal derived from said global reference tone, such that said first local oscillator generates a first RF reference tone of high stability;
   d) a first mixing means connected to said receiving means and to said first local oscillator for mixing said first RF reference tone with said RF signal to produce an IF signal within said transmission bandwidth, said first mixing means being further connected to said low bandwidth medium for feeding said IF signal through said low bandwidth medium;
   e) a second local oscillator at a remote location from said first local oscillator, said second local oscillator being controlled by a second adjustment signal derived from said global reference tone, such that said second local oscillator generates a second RF reference tone of high stability at the same frequency as said first RF reference tone; and
   f) a second mixing means connected to said second local oscillator and to said low bandwidth medium for receiving and mixing said IF signal with said second RF reference tone to recover said RF signal.

2. The system of claim 1 further comprising a first phase-locking means switched before said first local oscillator for deriving said first adjustment signal from said global reference tone.

3. The system of claim 1 further comprising a second phase-locking means switched before said second local oscillator for deriving said second adjustment signal from said global reference tone.

4. The system of claim 3 further comprising a summing means connected to said low bandwidth medium and to said global reference oscillator for adding said global reference signal to said IF signal such that both said IF signal and said global reference signal are transmitted through said low bandwidth medium.

5. The system of claim 3 wherein said second local oscillator is a voltage-controlled oscillator and delivers an unstable RF reference tone, and said second phase-locking means comprises:
a) a frequency divider connected to said second local oscillator for dividing said unstable RF reference tone to derive an unstable IF reference tone at the frequency of said global reference tone;
b) a phase comparator for locking said unstable IF reference tone to said global reference tone, such that the output of said phase comparator delivers said second adjustment signal; and
c) a filter for filtering and delivering said second adjustment signal to said second local oscillator, said second adjustment signal stabilizing said second local

oscillator such that said second local oscillator generates said second RF reference tone of high stability.

6. The system of claim 1 comprising a distribution hub for housing said global reference oscillator, such that said global reference signal is provided to said system from said distribution hub.

7. The system of claim 1, wherein said low bandwidth medium comprises a network.

8. The system of claim 1 wherein said RF bandwidth is selected from the group of RF bandwidths used for cellular communications, cordless telephony, local RF communications, satellite television, interactive multi-media video, high bit-rate local area networks.

9. The system of claim 1 wherein said RF bandwidth is narrower that said transmission bandwidth of said low bandwidth medium.

10. The system of claim 9 wherein said low bandwidth medium is selected from the group consisting of 10 base T cable, telephone wire, fiber-optic cable, unshielded cable, and power cable.

11. A method for transmitting a RF signal contained in a RF bandwidth over a low bandwidth medium having a transmission bandwidth below said RF bandwidth, said method comprising the steps of:

a) receiving said RF signal;

b) providing said system with a global reference tone of high stability at a frequency within said transmission bandwidth of said low bandwidth medium;

c) generating a first RF reference tone of high stability by using a first adjustment signal derived from said global reference tone to control the output of a first local oscillator, such that said first local oscillator generates said first RF reference tone;

d) mixing said first RF reference tone with said RF signal to produce an IF signal within said transmission bandwidth;

e) feeding said IF signal through said low bandwidth medium;

f) generating a second RF reference tone of high stability by using a second adjustment signal derived from said global reference tone to control the output of a second local oscillator, such that said second local oscillator generates said second RF reference tone; and

g) mixing said second RF reference tone with said IF signal fed through said low bandwidth medium to recover said RF signal.

12. The method of claim 11 wherein said global reference tone does not overlap with the bandwidth of said IF signal.

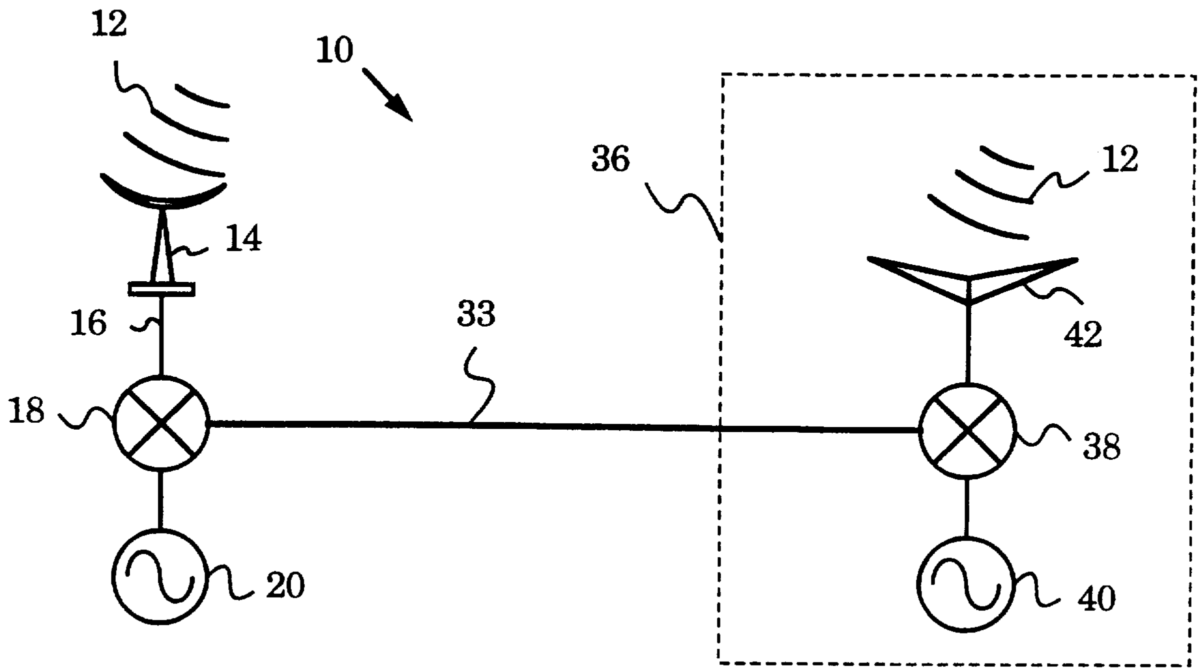
13. The method of claim 11 wherein the frequency of said global reference tone is below the bandwidth of said IF signal.

14. The method of claim 11 wherein said RF signal is received at a base station and fed through said low bandwidth medium to a remote coverage site.

15. The method of claim 11 wherein said RF signal is received at a remote coverage site and transmitted to a base station through said low bandwidth medium.

16. The method of claim 11 wherein said RF signal is transmitted over said low bandwidth medium bi-directionally.

17. The method of claim 11 wherein said IF signal is amplified while passing through said low bandwidth medium.



PRIOR ART
FIG. 1

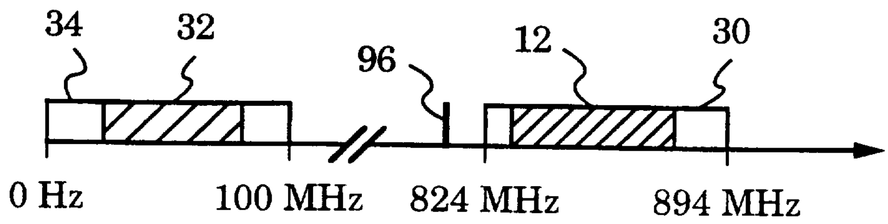


FIG. 2

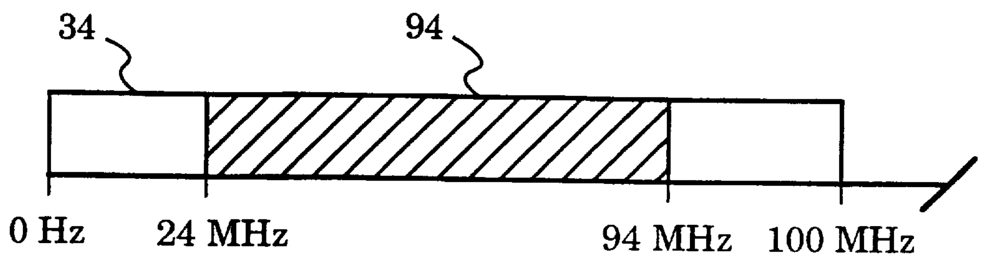


FIG. 3

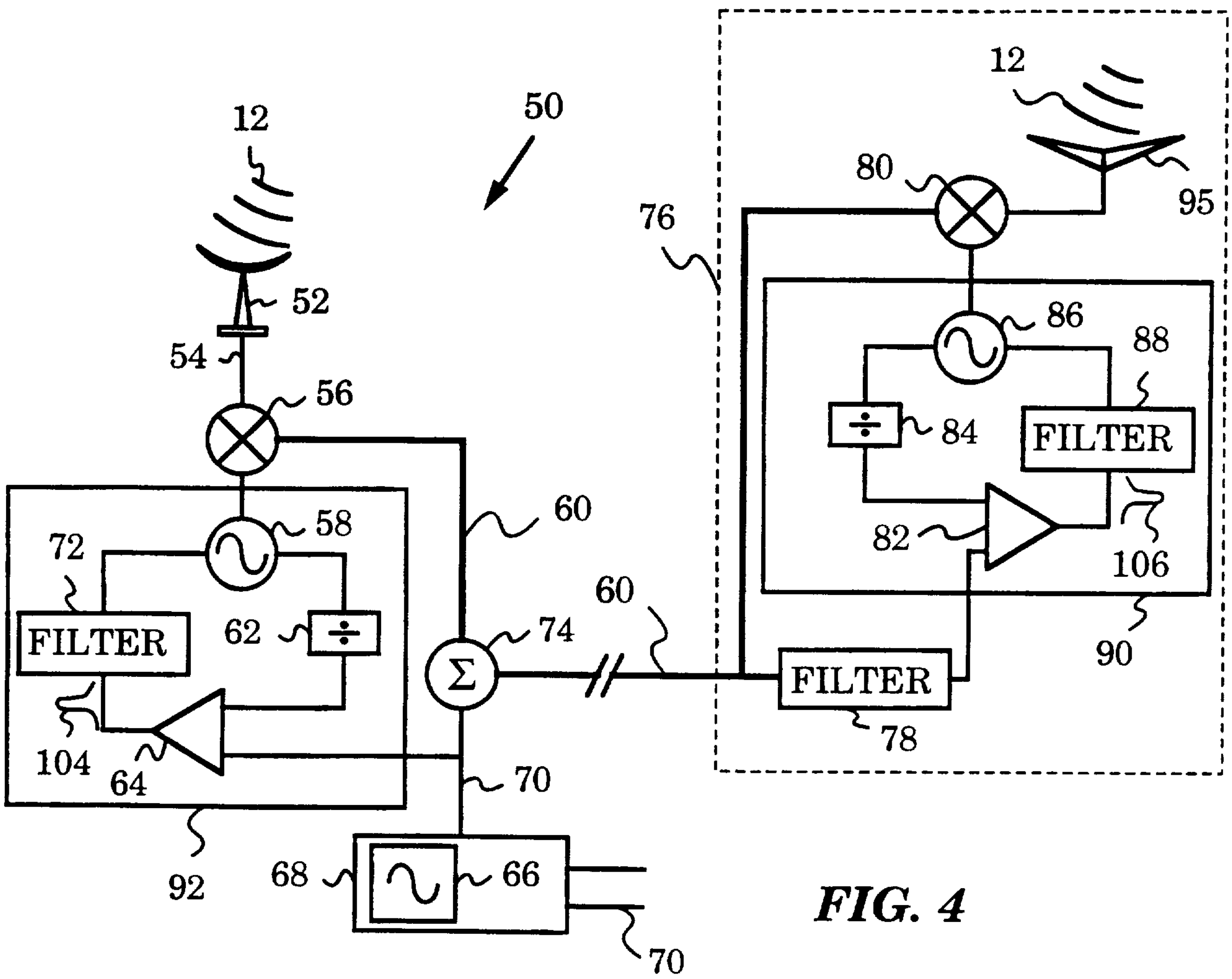


FIG. 4

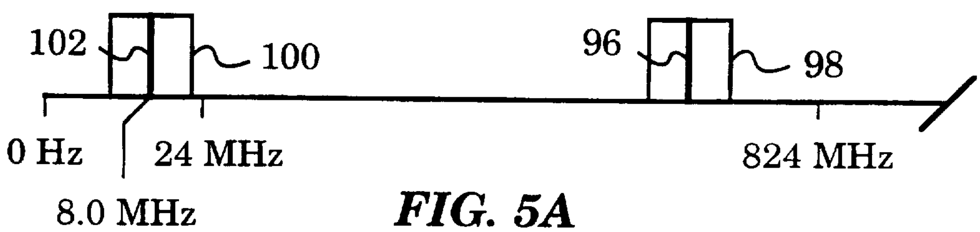


FIG. 5A

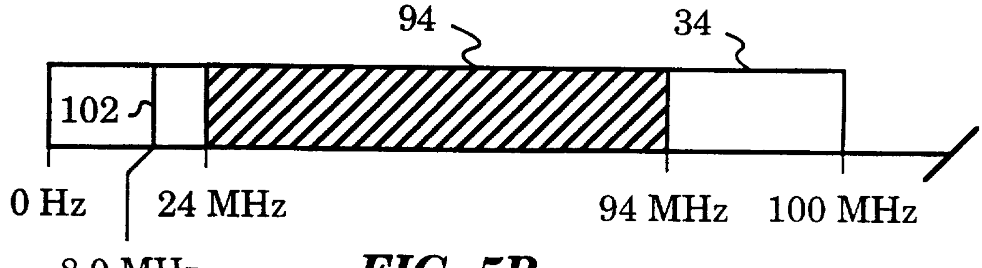


FIG. 5B

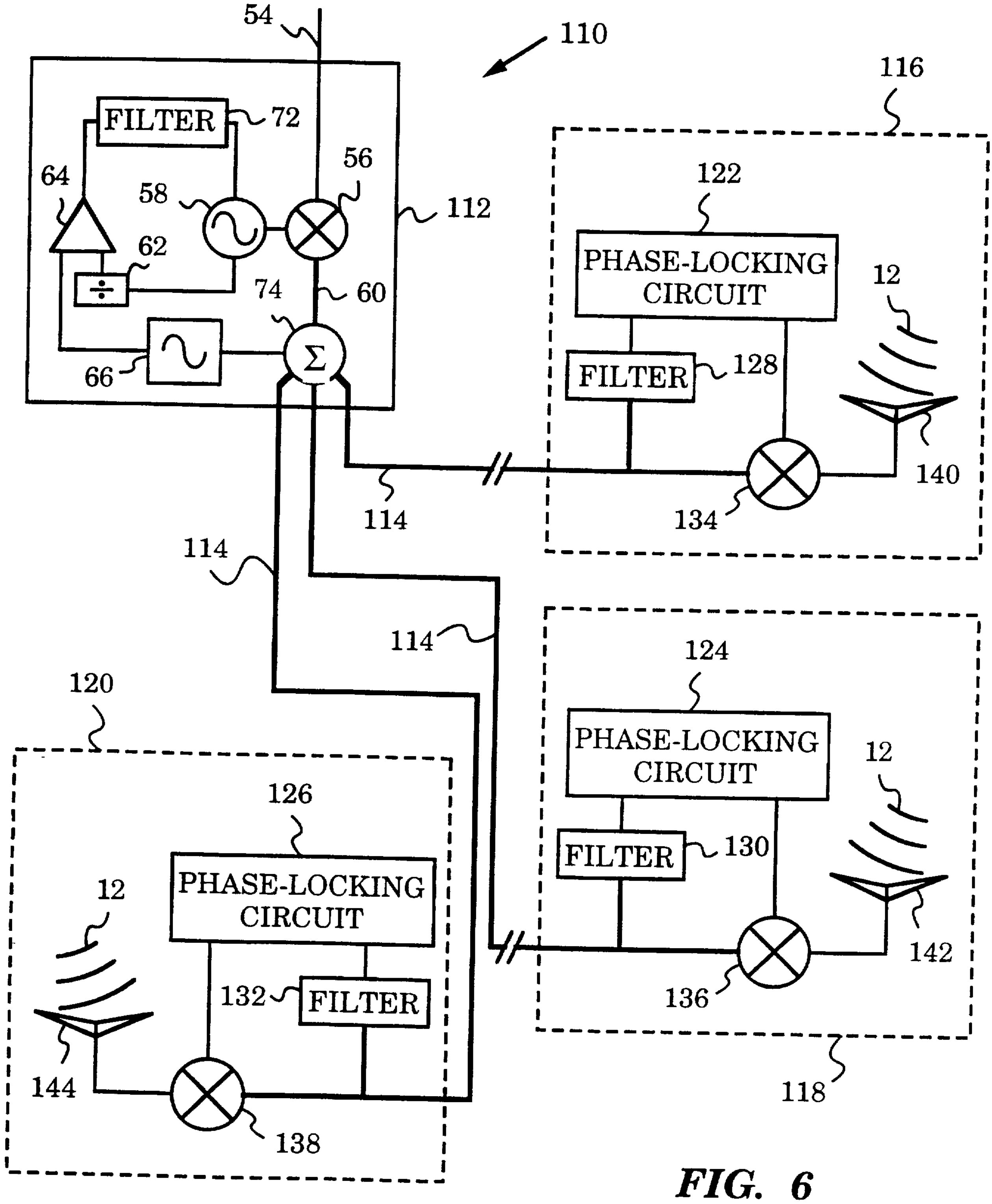

54
110
116
FILTER
72
56
64
58
112
122
62
PHASE-LOCKING CIRCUIT
12
74
60
66
FILTER
128
140
114
134
114
114
124
120
PHASE-LOCKING CIRCUIT
12
126
FILTER
130
PHASE-LOCKING CIRCUIT
12
142
132
FILTER
136
144
118
138

FIG. 6

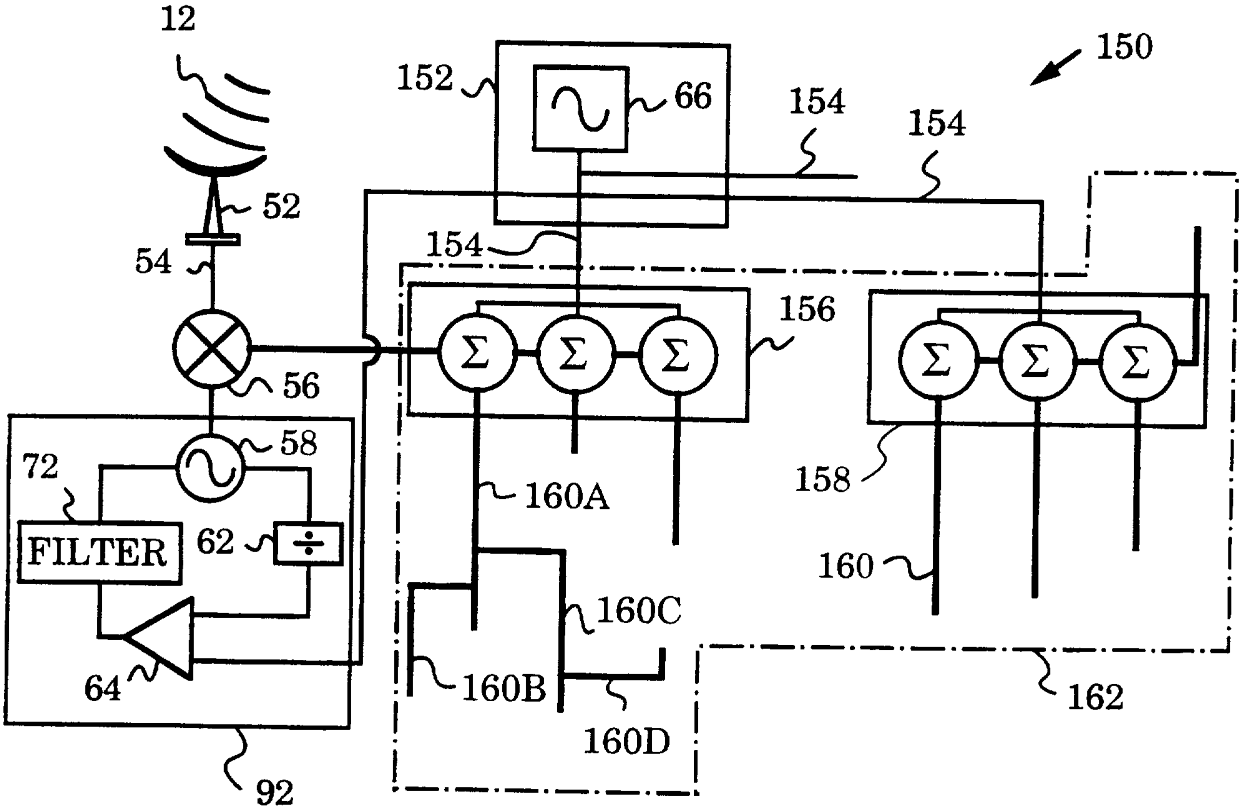

12
52
54
56
58
72
FILTER
62
÷
64
92
152
66
154
154
154
150
156
Σ
158
160A
160B
160C
160D
160
162

FIG. 7

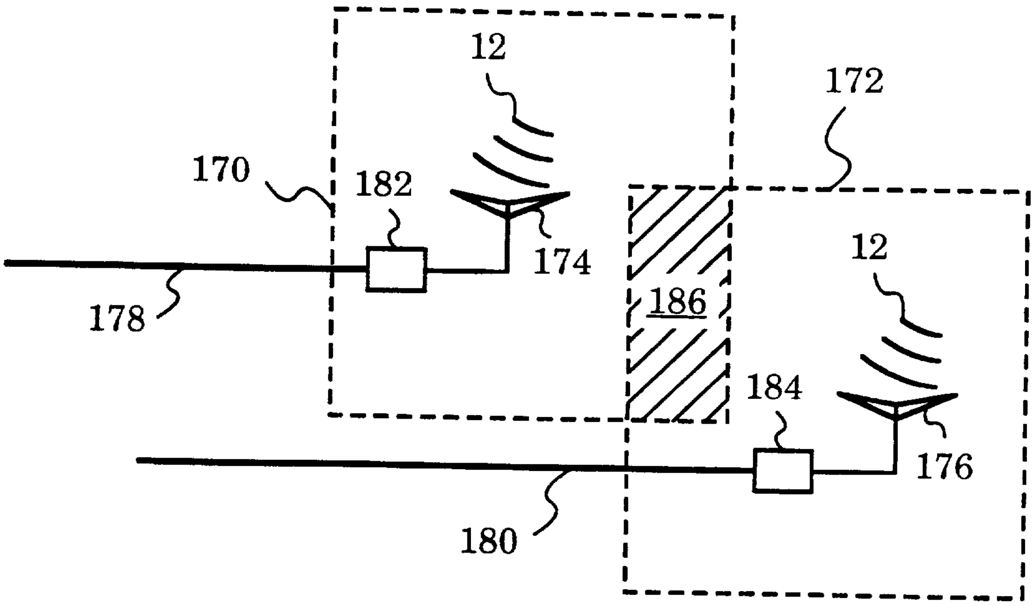

12
170
182
174
172
178
186
12
184
176
180

FIG. 8

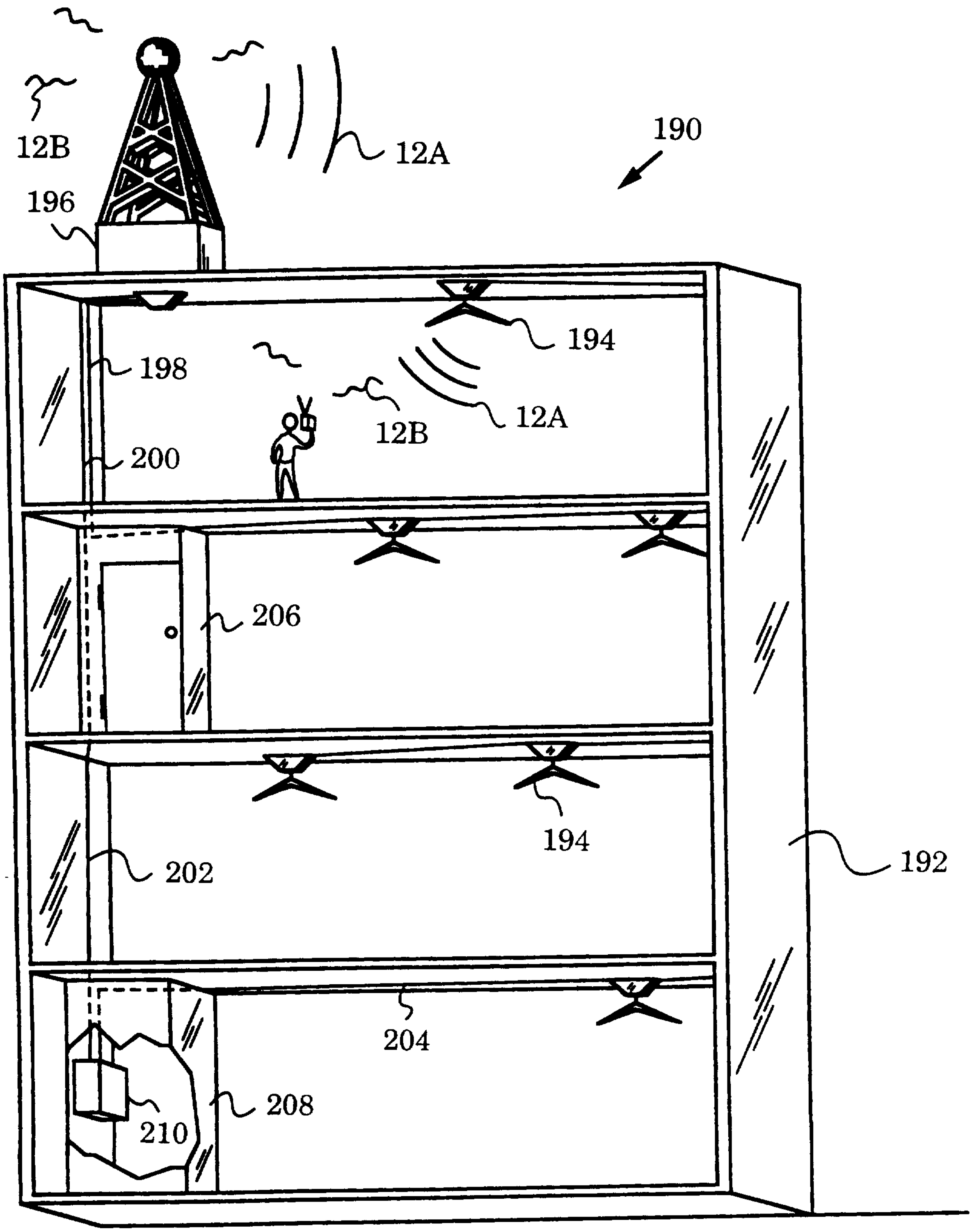


FIG. 9

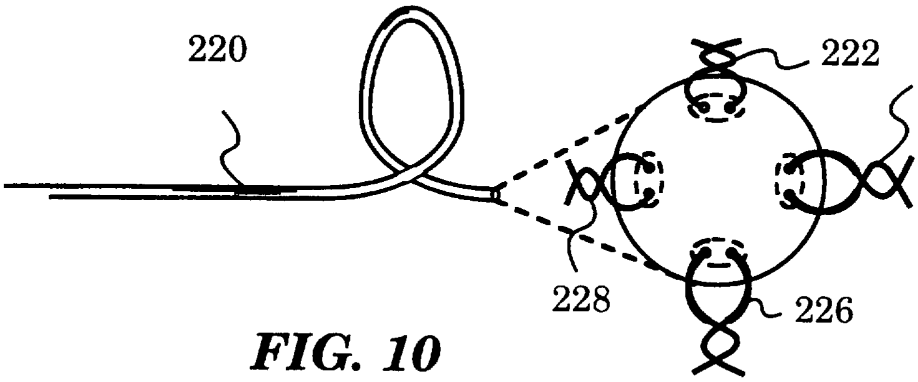

220
222
224
228
226

FIG. 10

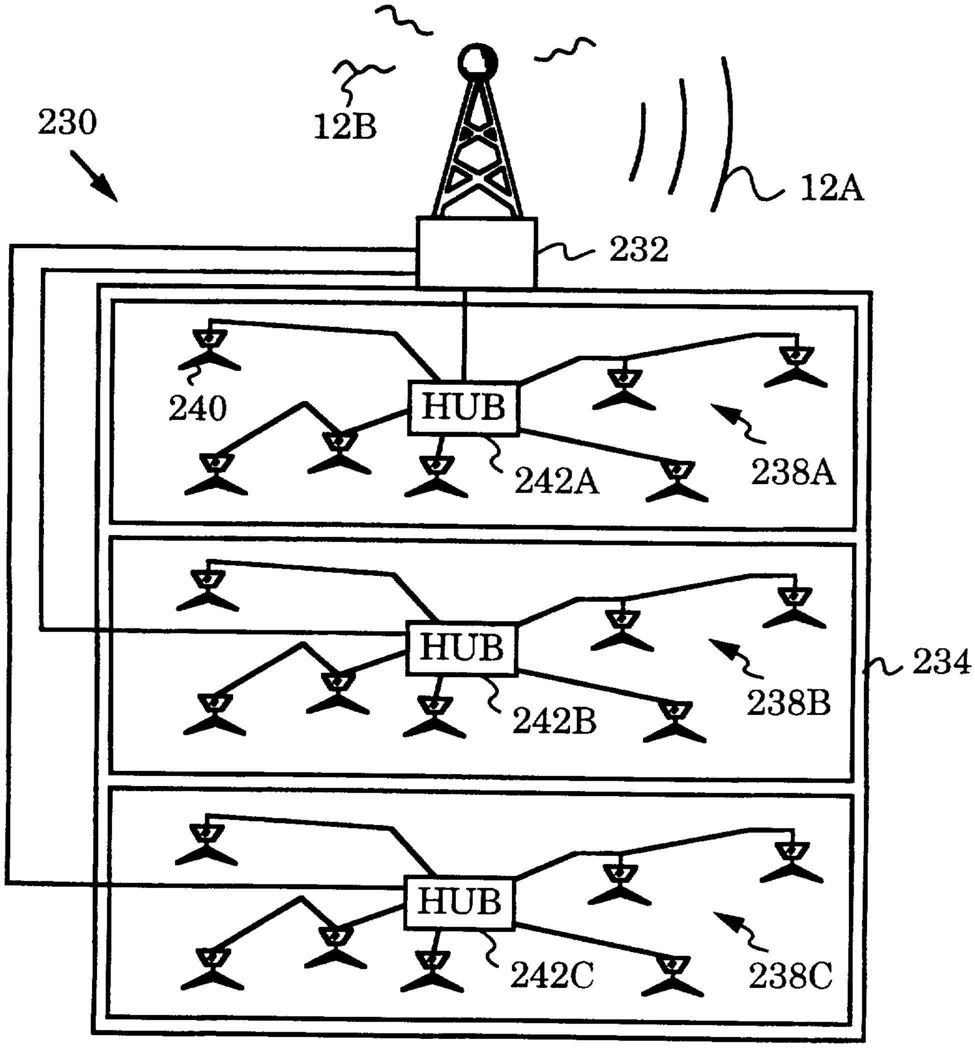

230
12B
12A
232
HUB
240
242A
238A
HUB
242B
238B
234
HUB
242C
238C

FIG. 11

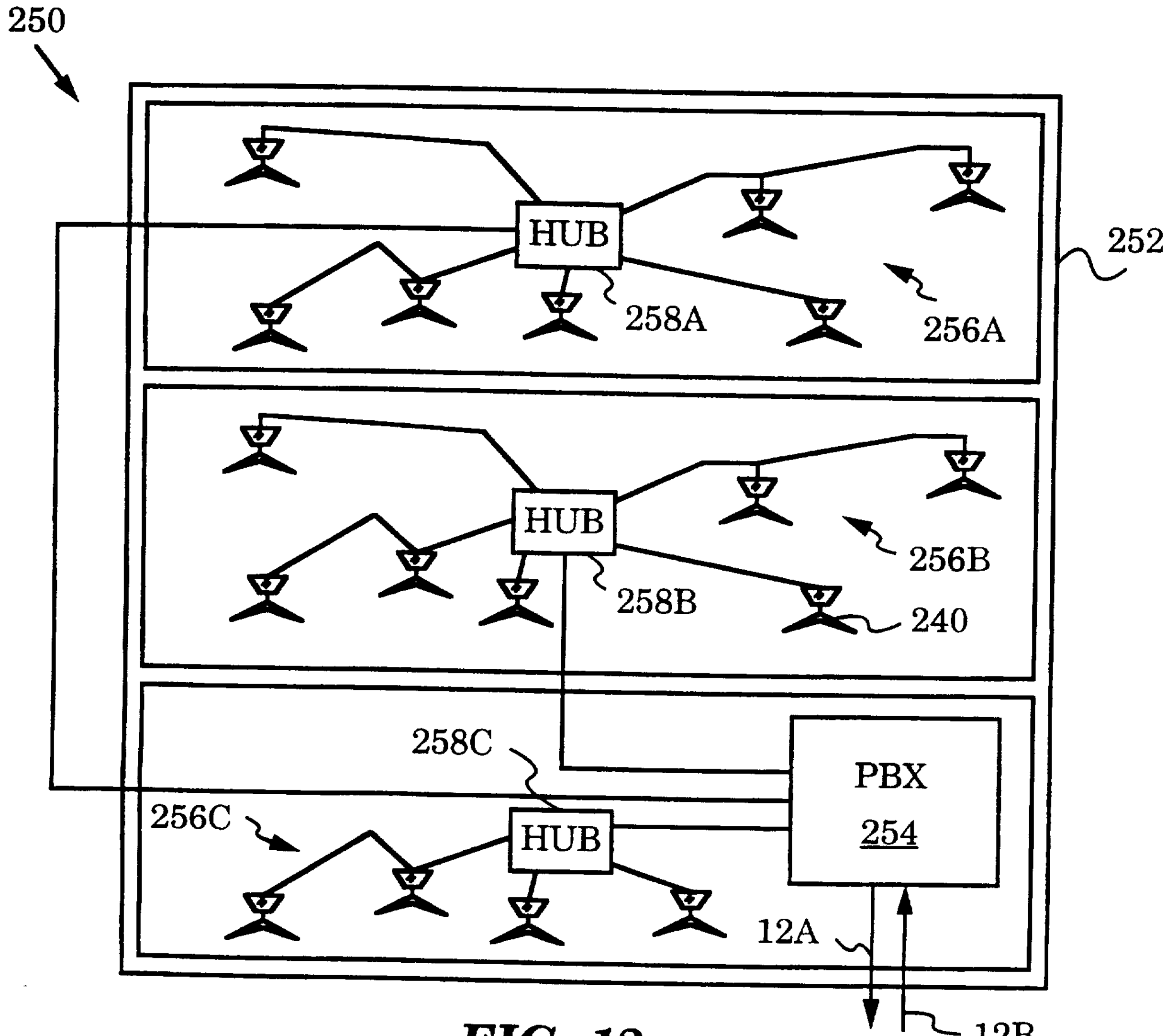

250
HUB
258A
256A
252
HUB
256B
258B
240
258C
PBX
254
256C
HUB
12A
12B

FIG. 12

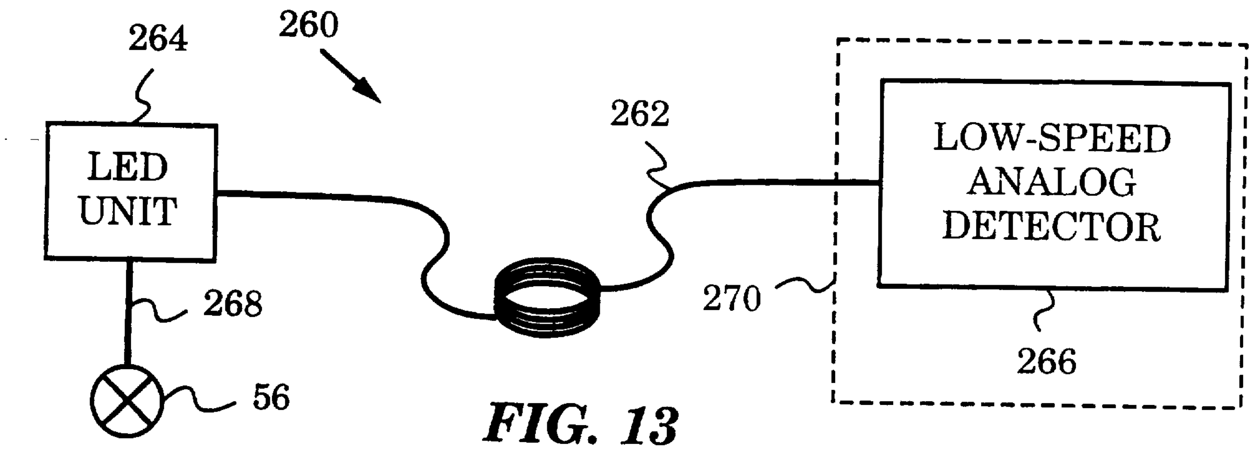
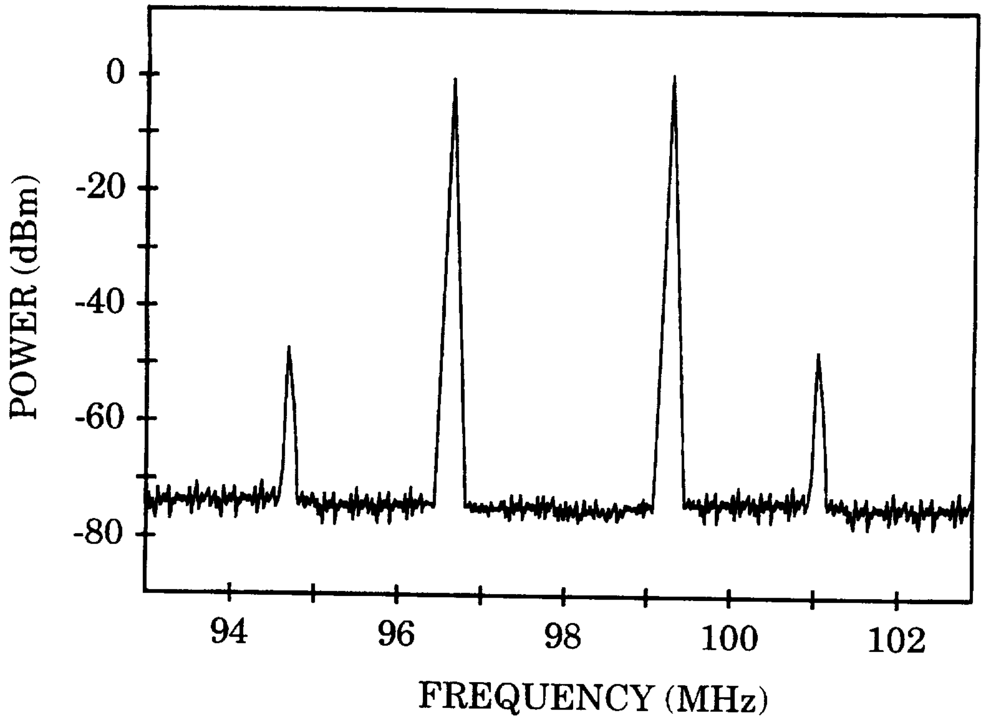
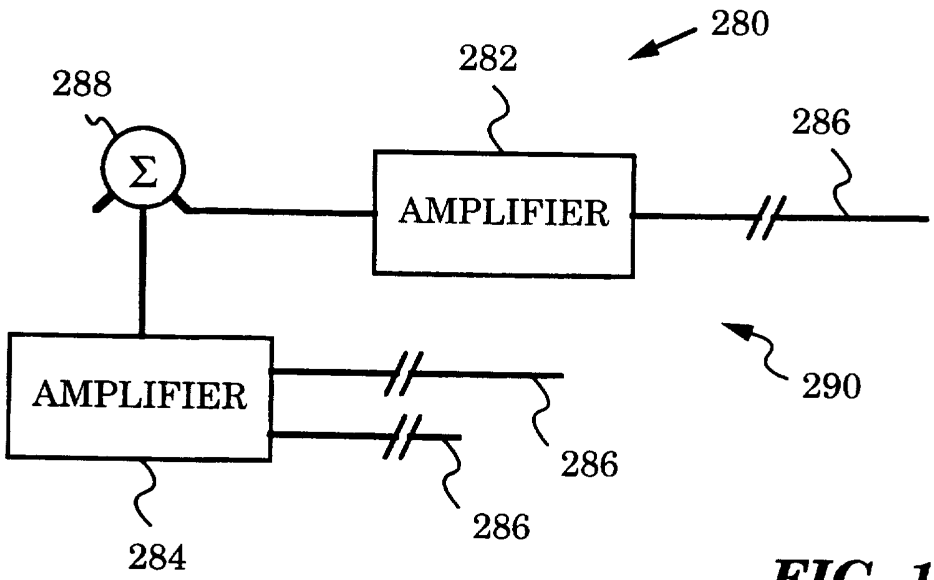

264
260
LED
UNIT
262
LOW-SPEED
ANALOG
DETECTOR
268
270
266
56

FIG. 13



POWER (dBm)
0
-20
-40
-60
-80
94
96
98
100
102
FREQUENCY (MHz)

FIG. 14



280
282
288
286
Σ
AMPLIFIER
AMPLIFIER
290
286
286
284

FIG. 15

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/06920

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 4,417,279 (SHINKAWA ET AL) 22 November 1983, Fig. 1.	1-15 and 17
A	US, A, 5,361,407 (SAWADA ET AL) 01 November 1994, Fig. 1.	1-15 and 17
A	US, A, 5,109,532 (PETROVIC ET AL) 28 April 1992, Fig. 1.	1-15 and 17
A	US, A, 4,959,862 (DAVIDOV ET AL) 25 September 1990, Fig. 1.	1-15 and 17
A	US, A, 4,856,085 (HORVAT) 08 August 1989, Fig. 1.	1-15 and 17
A	US, A, 4,449,246 (SEILER ET AL) 15 May 1984, Fig. 1.	1-15 and 17
A	US, A, 4,186,347 (BROCKMAN ET AL) 29 January 1980, Fig. 4.	1-15 and 17
A	US, A, 4,063,173 (NELSON ET AL) 13 December 1977, Fig. 1).	1-15 and 17
A	US, A, 2,747,083 (GUANELLA) 22 May 1956, Fig. 1 and column 2, lines 36-48.	1-15 and 17
A	US, A, 2,671,850 (MARCOU) 09 March 1954, Fig. 1.	1-15 and 17

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/06920

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04B 7/185, 15/00
US CL :455/6.1, 12.1, 14, 20, 22, 63, 66, 208, 209, 316, 317, 318, 319
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 455/6.1, 12.1, 14, 20, 22, 63, 66, 208, 209, 316, 317, 318, 319

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 5,428,836 (SANECKI ET AL) 27 June 1995, Fig. 1	1-15 and 17
Y	US, A, 5,046,135 (HATCHER) 03 September 1991, column 2, lines 34-49.	12, 13 and 17
Y	US, A, 4,901,368 (ARNOLD ET AL) 13 February 1990, Fig. 5.	6
Y	US, A, 4,556,988 (YOSHISATO) 03 December 1985, Fig. 2.	5
Y	US, A, 4,500,976 (DUBROFF) 19 February 1985, Fig. 10	2, 3, 5 and 7
Y	US, A, 4,476,574 (STRUVEN) 09 Octrober 1984, column 2, lines 11-14.	14 and 15

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 JUNE 1997	05 AUG 1997

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