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(54) Title: IMPROVED DELAY COMBINER SYSTEM FOR CDMA REPEATERS AND LOW NOISE AMPLIFIERS

(57) Abstract: Signal delay and combining techniques are used with multipath signals to provide signal diversity gain within CDMA over-the-air repeater and low noise amplifier systems. An incoming signal from a remote user is typically processed through two processing paths, wherein a differential delay is provided between the two processing paths, such as by one or more delay elements and/or filters, and is applied to the processed signal. The two signal paths are then combined and filtered through a sharp band pass filter, preferably a SAW filter. The gain of the two processing paths is typically balanced, to preserve the signal quality of the combined diversity signal. In an over the air repeater, the filtered signal is retransmitted towards a CDMA rake receiver at a base station, which can process the multipath signal to produce a clean signal representation. In a low noise amplifier, the filtered signal is transferred directly into a base station or repeater. The use of SAW filters protect the latter stages of the low noise amplifier, and also protect the base station from out-of-band signal interference. A quadruple diversity low noise amplification system for base stations embodiment is also disclosed, which provides quadruple diversity and improved sensitivity for CDMA base stations. Preferred embodiments of the delay combiner system provide adaptive gain balancing.

IMPROVED DELAY COMBINER SYSTEM FOR CDMA REPEATERS AND LOW NOISE AMPLIFIERS

FIELD OF THE INVENTION

The invention relates to the field of communications repeater systems. More particularly, the invention relates to a CDMA repeater system having receive signal diversity, as well as multiple diversity delay combining low noise amplification systems which provide receive diversity dimensionality to conventional repeaters and base station receiver systems.

BACKGROUND OF THE INVENTION

Code division multiple access (CDMA) techniques are commonly used in communication systems, to allow communications between a large number of system users. Repeaters are used as an extension between mobile users and base stations in a variety of communication systems. Tower-top amplifiers are also used as an extension of many base station and repeater designs.

K. Gilhousen, R. Padovani, and C. Wheatley, *Method and System for Providing a Soft Handoff in Communications in a CDMA Cellular Telephone System,* U.S. Patent No. 5,101,501 (31 March 1992) disclose a system for directing communications signals between a mobile user and cell sites, as the mobile user moves between cell site service areas.

K. Gilhousen, R. Padovani, and C. Wheatley, *Diversity Receiver in a CDMA Cellular Telephone System,* U.S. Patent No. 5,109,390 (28 April 1992) disclose a spread spectrum receiver subsystem for utilization in a CMDA cellular telephone system.

D. Reudink, *Narrow Beam Antenna Systems with Angular Diversity,* U.S. Patent No. 5,563,610 (08 October 1996) discloses a receiving system which includes at least one antenna providing a plurality of antenna beams. A first antenna branch processes a first plurality of signals within a first plurality of antenna beams. The first processing branch includes a plurality of delay paths, each receiving one of the first plurality of

signals. The first processing branch also includes a combiner for combining the signals after output from the delay paths. A second antenna branch processes a second plurality of signals within a second plurality of antenna beams. The second processing branch includes a plurality of delay paths, each receiving one of the second plurality of signals. The second processing branch also includes a combiner for combining the signals after output from the delay paths. A CDMA receiver has a first port coupled to an output of the first processing branch, and a second port coupled to an output of the second processing branch.

R. Dean, F. Antonio, K. Gilhousen, and C. Wheatley, *Dual Distributed Antenna System,* U.S. Patent No. 5,533,011 (02 July 1996) disclose a distributed antenna system for "providing multipath signals which facilitate signal diversity for enhanced system performance. Each node of the antenna at a common node provides a path having a different delay to the base station". While a "direct" connection is established between a distributed antenna system and a base station, wherein the distributed antenna system provides multipath signals (increasing the dimensionality) to facilitate signal diversity, the system does not disclose the use of diversity within a repeater system.

R. Dean, P. Antonio, K. Gilhousen, and C. Wheatley, *Dual Distributed Antenna System,* U.S. Patent No. 5,513,176 (30 April 1996) disclose a distributed antenna system that is utilized in a system for "providing multipath signals which facilitate signal diversity for enhanced system performance. Each node of the antenna comprises more than one antenna. Each node at a common node provides a path having a different delay to the base station".

J. Treatch, *Shared Channel Communication System*, U.S. Patent No. 5,898,382 (27 April 1999) discloses a communication system, which "includes a scanning receiver coupled to a first antenna, a plurality of repeaters coupled to a second antenna, wherein each repeater operable on any channel in a band, and a computer coupled to each repeater for controlling the operation of each repeater and coupled to the scanning receiver for obtaining traffic information from the receiver and storing the information in memory. The memory also contains a table of channels and station ID's, wherein station ID is associated with a particular channel. Each repeater operates on an available channel, as indicated by the traffic information, using the station ID associated with the channel. The repeaters themselves can be used for obtaining traffic information, eliminating the scanning receiver. The repeaters do not have final amplifiers. Instead, a

low level combining circuit couples the signals from each repeater to a single linear amplifier." While Treatch discloses a system for dynamic channel allocation and channel sharing (*i.e.* traffic routing), for a plurality of different input signals, the disclosed system fails to provide improved diversity reception for a code diversity multiple access system.

K. Gilhousen and F. Antonio, CDMA Microcellular Telephone System and Distributed Antenna System Therefor, U.S. Patent No. 5,280,472 (18 January 1994) disclose a CDMA communications system, in which "techniques are utilized in a wireless Private Branch Exchange (PBX) environment. A microcellular arrangement is defined in which a base station communicates user information signals using CDMA communications signals with subscriber terminals. A distributed antenna system is utilized in the system to provide multipath signals which facilitate signal diversity for enhanced system performance."

F. Adachi, M. Sawahashi, A. Higashi, K. Ohno, and T. Dohi, *Receiver and Repeater for Spread Spectrum Communications*, U.S. Patent No. 5,652,765 (29 July 1997) disclose a repeater for "improving the effect of a RAKE reception. A received signal from a base station parallely passes a first path including a first delay circuit and a second path including no delay circuit, and is transmitted to a mobile station. A received signal from the mobile station parallelly passes a third path including a second delay circuit and a fourth path including no delay circuit, and is transmitted to the base station. The delay time of the delay circuits are set at one chip interval or more of a spreading code. This forcedly produces multipath waves which are resolvable by a RAKE receiver. The RAKE receiver estimates amplitudes of desired wave components for individual delayed waves, performs weighting of the respective delayed wave components from detectors by using the estimated amplitudes, and makes symbol decision in terms of the combined weighted signal".

K. Anvari, *Synchronization Apparatus for a Diversity Receiver*, U.S. Patent No. 5,461,646 (24 October 1995) discloses a discloses a diversity combiner for a digital receiver, which receives a plurality of complex baseband signals, wherein the combiner differentially detects each of the complex baseband signals to produce a plurality of differential signals".

R. Kornfeld, *Method and Apparatus for Providing Antenna Diversity in a Portable Radio Telephone*, International Patent Application No. PCT/US96/20656 (Published

10 July 1997) discloses "A diversity antenna system in a mobile unit which provides time, space and antenna pattern diversity to mitigate the effects of fading in a CDMA unit. The system is comprised of a diversity antenna (105) and a main antenna (100). The main antenna (100) and diversity antenna (105) are physically separated and oriented such that they have different antenna gain patterns. In a first embodiment, the diversity antenna (105) functions as a receive antenna only, while the main antenna (100) performs both transmit and receive functions. In a second embodiment, both the main antenna (100) and the diversity antenna (105) transmit and receive signals. A delay circuit (130) couples the diversity antenna (105) to a summer (135) which sums the signals received by the main antenna (100) and the diversity antenna (105), respectively."

C.N. Zhang, W. Lam, and C. Ling, *A Low-Complexity Antenna Diversity Receiver Suitable for TDMA Handset Implementation*, (IEEE) (04/05/97), discloses an antenna diversity receiver for TDMA handset implementation, which may be implemented using three techniques, wherein "the receiver employs two branches of diversity, and is capable of adaptively choosing among three different diversity techniques". Zhang et al disclose the use of attenuators within the TDMA diversity receiver circuit, for amplitude scaling of the incoming TDMA signal.

In a CDMA delay combining structure, the use of a delay, such as a SAW filter, results in a significant attenuation of a signal passing therethrough. For example, the use of a 2 microsecond 1900 MHz SAW filter within a CDMA delay combining structure may typically result in a loss of approximately 28 dB. The use of a 4 microsecond SAW delay may typically result in a loss of approximately 56 dB. Therefore, for two incoming independent fading CDMA signals, wherein one of the signals passes through a signal processing path which imparts a delay, the differential attenuation between the two paths is substantial. Furthermore, when two or more signals, which are not phase coherent, are combined, they appear as noise energy to each other. Upstream noise sources (prior to the combining point) are added together at the combining point, and the total noise is associated with both signals. The effect of these two factors is to cause a signal to noise ratio (SNR) imbalance between the combined signals. For example, if two signals, initially having an equal signal to noise ratio (SNR), are processed and combined, and one signal has an amplitude that is 10 dB below the other after processing, then the SNR of the weaker signal will be approximately 10 dB lower than the other.

Therefore, in a delay combiner system having a significant gain imbalance between processing paths, such as introduced by the delay element, the subsequent signal information from the delayed path may be "lost" during subsequent signal processing (*i.e.* such a delay combiner would therefore fail to provide SNR improvements, since it fails to increase the number of signals which are available to a rake receiver).

The disclosed prior art systems and methodologies thus provide basic distributed antenna systems, but fail to provide a diversity within a CDMA receive diversity system having gain balancing between signal paths within an over the air repeater system, and also fail to provide delay combining diversity having gain balancing between signal paths for a tower top or low noise amplification system. It would therefore be advantageous to provide a means for gain balancing prior to combining within a CDMA delay combining structure, whereby signal quality is retained. The development of such a CDMA delay combining structure for a repeater system would constitute a major technological advance. The development of such a CDMA delay combining structure, for a tower top or low noise amplification system would constitute a further technological advance.

SUMMARY OF THE INVENTION

Signal delay and combining techniques are used with multipath signals to provide signal diversity gain within CDMA over-the-air repeater and low noise amplifier systems. An incoming signal from a remote user is typically processed through two processing paths, wherein a differential delay is provided between the two processing paths, such as by one or more delay elements and/or filters, and is applied to the processed signal. The two signal paths are then combined and filtered through a sharp band pass filter, preferably a SAW filter. The gain of the two processing paths is typically balanced, to preserve the signal quality of the combined diversity signal. In an over the air repeater, the filtered signal is retransmitted towards a CDMA rake receiver at a base station, which can process the multipath signal to produce a clean signal representation. In a low noise amplifier, the filtered signal is transferred directly into a base station or repeater. The use of SAW filters protect the latter stages of the low noise amplifier, and also protect the base station from out-of-band signal interference. A quadruple diversity low noise amplification system for base stations embodiment is also disclosed, which provides quadruple diversity and improved sensitivity for CDMA

base stations. Preferred embodiments of the delay combiner system provide adaptive gain balancing.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a multipath input signal having a plurality of decorrelated signal paths received by a CDMA antenna system;

Figure 2 shows the interaction between a CDMA repeater and a base station;

Figure 3 is a block diagram of a dual diversity delay combining low noise amplifier system for use in association with a conventional (non-diversity) repeater to provide receive diversity;

Figure 4 is a detailed view of a two stage band pass filter cascade:

Figure 5 is a detailed block diagram of a CDMA repeater system;

Figure 6 is a block diagram of a secondary growth enclosure for a second CDMA carrier;

Figure 7 is a block diagram of a quadruple diversity delay combining low noise amplifier system for base stations;

Figure 8 is a first alternate embodiment of a diversity repeater, which has two separate complete repeater paths up to the output of the reverse power amplifier;

Figure 9 is a second alternate embodiment of a diversity repeater, which has two separate complete repeater paths utilizing two donor antennas;

Figure 10 is a third alternate embodiment of a diversity repeater, which has two separate complete repeater paths through the channel selective filter;

Figure 11 provides a schematic of a basic delay combiner, which shows signal strength at various points on the receiver branch paths;

Figure 12 is a schematic diagram of a delay combiner having a fixed attenuator, which shows signal strength at various points on the receiver branch paths;

Figure 13 is a schematic diagram of a delay combiner having a variable attenuator, which shows signal strength at various points on the receiver branch paths;

Figure 14 is a schematic diagram of a delay combiner having a low noise amplifier on the delayed receiver branch, which shows signal strength at various points on the receiver branch paths;

Figure 15 is a schematic diagram of a delay combiner having amplifiers on both receiver branches and a variable attenuator on one branch, which shows signal strength at various points on the receiver branch paths;

Figure 16 is a schematic diagram of a delay combiner having amplifiers and variable attenuators on both receiver branches, which shows signal strength at various points on the receiver branch paths;

Figure 17 is a schematic diagram of a delay combiner having amplifiers and delay elements on both receiver branches and means for gain balancing on one branch;

Figure 18 is a schematic diagram of a delay combiner having amplifiers, and one or more filters having inherent delays, on both receiver branches, as well as means for gain balancing on one branch; and

Figure 19 is a schematic diagram of a delay combiner which provides adaptive gain balancing.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Figure 1 shows an antenna assembly 15, and its interaction with an incoming signal 12. The antenna assembly 15 consists of a plurality of antennas 16a -16n, each of which are connected to antenna inputs 17. The incoming signal 12 is a fading signal, meaning that the amplitude of the signal is rapidly changing due to propagation effects. This signal 12 is can be received simultaneously by a plurality of antennas 16a-16n. The instantaneous amplitude of the signal 12 at any given point in space (in this case the

space that is occupied by the antenna assembly 15) will be different from the instantaneous amplitude at any other point in space. The instantaneous amplitude at any given point is space is also dependent on the polarization of each antenna 16, and the direction that each antenna 16 is pointed. This is shown in Figure 1 as a fading signal 12, consisting of a plurality of signals 12a-12n. The instantaneous amplitude of the fading signals 12a-12n are generally different. This relationship between the signals 12a-12n is called decorrelation.

The antennas 16a-16n are configured such that the fading processes affecting the signals received by each antenna 16 are not correlated. That is, the signals 12 received on each individual antenna 16a-16n fade independently of the signals on the other n-1 antennas 16. When this relationship exists between a set of signals 12, they are said to be mutually decorrelated. The antennas 16a-16n must be configured so that this mutual decorrelation exists between the signals 12. There are many different ways to configure the plurality of antennas 16a-16n such that the mutually decorrelated relationship exists between the signals 12a-12n. Any configuration which achieves this relationship is acceptable.

As described above, the instantaneous amplitude of the signals 12a-12n is a function of position, polarization, and arrival direction. Thus spatial separation, polarization separation, angular separation, or any combination of these, can be used to provide signals 12a-12n which possess a mutually decorrelated relationship.

Two common techniques for achieving mutual decorrelation in a mobile radio environment are spatial separation and polarization separation, which take advantage of the fact that position and polarization separation provide decorrelated signals. When spatial separation is used to provide decorrelated signals, the antennas 16 must typically be separated by 10-20 wavelengths to achieve satisfactory decorrelation. When polarization separation is used, the antennas 16 are polarized such that the polarization between the antennas 16 is orthogonal.

In a CDMA system, a demodulator is used to optimally combine these signals 12a-12n into a composite signal, which is much more robust than any one of the individual signals 12a-12n. This process of receiving multiple decorrelated signals and combining the signals 12a-12n is called receive diversity. Since the composite signal is more robust than any one of the individual received signal 12a-12n alone, the signal to noise ratio requirement for proper system performance is smaller than that required by a

system that does not use receive diversity techniques. This reduction in signal to noise ratio increases the capacity of CDMA systems, and increases the range of CDMA repeaters and base stations.

The signal delay and combining techniques can be used within either a CDMA over-the-air repeater, or a dual diversity delay combining low noise amplification system 46 (FIG. 3) to provide receive diversity to a conventional CDMA over-the-air repeater. The disclosed techniques can also be used within a quadruple diversity delay combining low noise amplification system 150 (FIG. 7) to further increase the receive diversity dimensionality.

Base Station Multipath Demodulator. Figure 2 shows the reverse path interaction 20 between a basic delay combine repeater 22a and a base station 39. The multipath signal 12, having decorrelated paths 12a and 12b, is transmitted toward the base station, where it is processed and eventually demodulated by a multipath demodulator, usually a rake receiver 34.

The antennas 16 used in the present invention can either be orthogonal in polarization, or they can be spatially separated, typically by 10 to 20 wavelengths, to provide the required decorrelation for diversity gain.

The reverse path (from a mobile station to a base station) uses a noncoherent modulation scheme known as 64-ary orthogonal modulation. The base station 39 uses a rake receiver 34 to demodulate the incoming signal 12. The rake receiver 34 demodulator is preferred for the multipath environment.

The rake receiver 34 simply adds the modulation symbol energy from each rake finger 36, and processes a decision based on the total energy associated with each modulation symbol. This type of multipath demodulator 36, although not optimal, is only slightly less effective than an optimal multipath demodulator (several tenths of a dB). For more details regarding rake receiver design, refer to A.J. Viterbi, *CDMA Principles of Spread Spectrum Communications*, Addison-Wesley 1995.

The rake receiver demodulator 34 is accurately modeled as a maximal ratio combiner, when the average signal power on the individual demodulator rake fingers 36 are the same. This equivalence of inter-branch signal powers is typical for most embodiments of the present invention.

The maximal ratio combiner 38 combines the energy associated with each of the incoming signal paths 12a,12b, effectively yielding the sum of the per finger per bit energy to noise density ratios, E_b/I_0. The characteristic performance of the maximal ratio combiner 38 is given by:

$$\left[\frac{E_b}{I_o}\right]_{Total} = \sum_{i=1}^{N}\left[\frac{E_b}{I_o}\right]_i \quad (1)$$

E_b represents the amount of energy associated with each information bit (Joules), and I_0 represents the noise plus interference power density (Watts/Hz). The ratio $(E_b/I_0)_i$ represents the ratio of energy per information bit to noise plus interference density, for a single path 12.

The composite signal energy output 40 of the combiner 38 is the total per bit energy to noise density ratio $(E_b/I_0)_{Total}$. The error rate of the system demodulator, for a fixed set of channel fading conditions and diversity configuration, is inversely proportional to the total per bit energy to noise density ratio $(E_b/I_0)_{Total}$. The lower this ratio, the larger the error rate.

The composite signal energy output 40 of the combiner 38 is fed to a decision device 42, which estimates which modulation symbol is sent. Once the modulation symbol is determined, the actual information bits are derived.

The multipath rake receiver demodulator 34 in one embodiment has four fingers 36, each of which can track and demodulate a single signal path 12. One finger 36 is assigned to each available signal path 12. The rake receiver 34 can only differentiate signal paths 12 which are either on different RF branches, or those which are on the same RF branch but are time dispersed from each other. Paths 12 are typically associated with antennas 16. Thus, one rake finger 36 is typically locked onto each antenna 16.

The antennas 16 (*e.g.* such as 16a and 16n) are configured to achieve a relationship of mutual decorrelation between the signals 12. There are numerous ways to configure the antennas 16, such that the mutually decorrelated relationship exists

among the signals 12. Any configuration which achieves a relationship of mutual decorrelation among the signals 12 is acceptable.

As described above, the instantaneous amplitude of the signals 12a-12n is a function of position, polarization, and arrival direction. Thus spatial separation, polarization separation, or angular separation, or any combination of these, can be used to provide signals 12a-12n which possess a mutually decorrelated relationship.

Two of the most common techniques for achieving mutual decorrelation in the mobile radio environment are spatial separation and polarization separation, since position and polarization separation provide decorrelated signals. When spatial separation is used to provide decorrelated signals, the antennas are typically be separated by 10 to 20 wavelengths, to achieve satisfactory decorrelation. When polarization separation is used, the antennas are polarized, such that the polarization between the antennas is orthogonal.

The required total per bit energy to noise density ratio $(E_b/I_0)_{Total}$ is usually specified for a given level of system performance under a set of predefined conditions, which include the correlation between paths 12a-12n, the number of paths 12a-12n, the speed of a mobile user, and the channel conditions encountered. Almost always, the channel conditions are assumed to be a time dispersive channel, with an amplitude that is Rayleigh distributed. The speed of a mobile user is usually assumed to be that associated with the type of morphology the mobile user is operating in. The correlation between paths 12a,12n is almost always considered to be zero (independent fading paths), which leaves only the number of paths 12a-12n and the mobile speed as the factors which determine the total per bit energy to noise density ratio $(E_b/I_0)_{Total}$.

For a fixed speed of a mobile user, the $(E_b/I_0)_{Total}$ requirement is simply a function of the number of paths. For example, in suburban morphology with one path, the $(E_b/I_0)_{Total}$ requirement for a 1% error rate, is 14 dB. For two paths the $(E_b/I_0)_{Total}$ requirement is 10 dB, and for four paths it is 9 dB. The reduction in the $(E_b/I_0)_{Total}$ is attributed to the diversity gain associated with the introduction of additional paths for demodulation. Since a typical base station 39 has at least two antennas 16, there is always a minimum of two paths (independent fading paths) to demodulate. Thus, for the worst case, the $(E_b/I_0)_{Total}$ requirement is 10 dB.

For a conventional repeater configuration, there is only a single path 12 returned to the base station 39 for demodulation. As shown in the example above, the $(E_b/I_0)_{Total}$ required is 14 dB, which is 4 dB larger than the $(E_b/I_0)_{Total}$ required for operation on the base station 39. This, however, is not an optimal configuration for a repeater, since the required $(E_b/I_0)_{Total}$ can be reduced by providing a second independent fading path for demodulation. The use of a second independent fading path reduces the required $(E_b/I_0)_{Total}$ to 10 dB, which is the same as that required for operation on a base station 39.

The present invention effectively provides a second path 12b for the base station rake receiver 34 to demodulate. This allows the performance of the repeater 22 (*e.g.* such as repeater 22a) to be optimal. In the case where the repeater 22 provides the second path 12b to the base station 39, the required $(E_b/I_0)_{Total}$ is exactly the same as the base station 39, which is 10 dB.

In a basic embodiment of the present invention, two decorrelated signal paths 12a,12b are captured (with two antennas 16), which are both fed back to the base station rake receiver 34, over a single RF channel. The process used to accomplish this is a delay combining process, which time multiplexes the two decorrelated signals over a delay combining circuit 23 (*e.g.* such as 23a in Figure 2), by introducing a greater delay to one of the signal paths 12a or 12b as compared to the other. The time delay introduced to one of the paths 12a or 12b is large enough, such that the signals are no longer coherent. The excess delay is more than two chips, and the resulting code offset ensures that the cross correlation between the two signal paths 12a,12b is zero. Thus the two signal paths 12a,12b will appear as noise to each other. Since the two signal paths 12a,12b are dispersed in time, the rake receiver 34 is able to lock onto and demodulate both signal paths 12a,12b, to provide the desired diversity gain.

In preferred embodiments of the delay combining process, means for balancing the differential gain are provided, between receiver paths 47a,47b in a delay combiner 23 (*e.g.* such as delay combiner 23b FIG. 3) having different delay values, such that signal information from each of the signal paths 12a,12b is retained.

The process used by the rake receiver 34 to find a plurality of signal paths 12a-12n comprises the following steps:

i) finding the time of arrival (TOA, relative time delay) and locking onto one of the signal paths 12a (usually the earliest one);

ii) searching around the first signal path 12a (in time) for additional multipaths 12b-12n;

iii) finding and locking onto a second signal path 12 (*e.g.* such as 12b); and

iv) demodulating the first signal path 12a and second signal path 12b.

Thus the rake receiver 34 now has at least two decorrelated signal paths 12a,12b to demodulate, and the required $(E_b/I_0)_{Total}$ is the same as that of the base station 39.

Dual Diversity Delay Combining Low Noise Amplification System. Figure 3 is a block diagram of a dual diversity delay combining low noise amplification system 46 (tower mounted or otherwise), for use in association with a conventional (non-diversity) repeater, to provide receive diversity. The dual diversity delay combining low noise amplification system 46 is used to upgrade a conventional (non-diversity repeater) to a dual diversity repeater, by providing dual branch diversity. The dual diversity delay combining low noise amplification system 46 can either be mast mounted, or can be ground mounted near a conventional repeater.

A key attribute of the dual diversity delay combining low noise amplification system 46 is the delay combiner 23b, which time multiplexes two receive paths 47a and 47b onto one RF path 49. This capability allows a conventional repeater to function as a diversity repeater, when used in conjunction with the dual diversity delay combining low noise amplification system 46. Two antennas 16a and 16b are connected to antenna connectors 17, and are implemented in a spatial and/or a polarization diversity configuration, to capture two decorrelated fading paths 12a,12b. The two signals associated with these paths are preferably fed directly from the antennas 16a, 16b into band pass filters 48, which provide protection from adjacent band radio signals. This

process is called preselection, and the band pass filters 48 are considered to be preselector filters 48.

In a preferred embodiment of the dual diversity delay combining low noise amplification system 46, after the preselector filters 48, there are low noise amplifiers (LNAs) 56, which amplify the signal, in an effort to minimize signal to noise reduction in the later stages, especially the time delay element in the path associated with the first antenna 16a. In alternate preferred embodiments of the dual diversity delay combining low noise amplification system 46, various delay combiner structures 23b-23k (FIG. 3, FIG. 10, FIGS. 12-19) may preferably be used, to provide enhanced signal processing and gain balancing between the plurality of signals paths 12a-12n.

As shown in the delay combiner structure 23b in Figure 3, after the low noise amplifiers 56, a signal 12 from the first antenna 16a is fed to a time delay element 58, and the signal from the second antenna 16b is preferably fed to a variable attenuator 60. The delay element 58, which is typically a SAW device, provides a differential delay to the signal from the first antenna 16a, as compared to the second antenna 16b. The time delay allows the base station rake receiver 34 to demodulate both paths 12a,12b, by displacing the paths 12a,12b in time. The magnitude of the differential delay between the delay combiner receiver branch paths 47a,47b must be greater than 2 chip periods (*e.g.* approximately 1.8 microseconds for IS-95 and J-STD-008). The desired delay magnitude varies with the technology employed (*e.g.* wide band CDMA). On the second branch path 47b, a variable attenuator 60 is preferably used to balance the gain between the branches 47, which is important for optimal system performance.

After the delay element 58 on the first receiver branch 47a, and after the preferred variable attenuator 60 on the second receiver branch 47b, the signals 61a and 61b are summed in a combiner 62. The combiner 62 yields the power sum of the two processed signals 61. Since the processed signals 61a and 61b are time offset from each other by more than 1 chip, the signals 61 are no longer coherent. This is due to the nature of the pseudonoise (PN) code used to modulate the reverse path (up-link) signal.

This code is specifically designed to provide minimum correlation for a one chip or greater, offset. Since the processed signals 61a and 61b are no longer

coherent, they interfere with each other on a random broad-band basis, thus creating a power sum, exactly the same way noise powers sum. Both processed signals (displaced in time) appear at the output of the combiner 62, and either signal looks like noise to the other signal. In this example, this process reduces the signal to noise ratio by 3 dB. However, this loss is gained back by the action of the rake receiver 34 at the base station 39.

Following the combiner 62, a low noise amplifier 64 is preferably used to increase the signal level, in preparation for losses which can result in latter stages. The low noise amplifier 64 is also preferably used to maintain the signal to noise ratio of the signals.

The next stage in a preferred embodiment is a receive power splitter 66, which provides an option of system expansion. The receive power splitter 66 is used to split the signal between two paths, one to the RX0/TX0 port 67b, and one to the RX1/TX1 port 67a. This configuration allows for the operation of two repeaters from one dual diversity delay combining low noise amplification system 46, which is a preferred method of system expansion. The duplex configuration, which is a conventional antenna system configuration for repeater and base station systems, is defined as the use of a common antenna and cable for both receiving and transmitting, since it minimizes the number of antenna system components required.

In a preferred embodiment in which a receive power splitter 66 is used, the signal is fed from the two outputs of the receive power splitter 66 to two separate two-stage cascade filters 70a,70b. In an embodiment in which a receive power splitter 66 is not used, the signal is fed directly from the output of the low noise amplifier 64 to a single, two-stage cascade filter 70.

The two stage cascade filters 70a,70b are each preferably comprised of a sharp receive band-pass filter 72 and a RF switching filter 74, as shown in Figure 4. The two stage cascade filters 70a,70b provide protection for the repeater from strong out of band interference signals, which are prone to cause intermodulation distortion (IMD). The two stage cascade filters 70a,70b protect the repeater, by increasing the out-of-band input intercept point.

As shown in Figure 4, within each of the two stage cascade filters 70a,70b, the first filter is a sharp pass-band filter 72, which provides protection from out-of-band interference, as described above. The second filter 74 is a preferably a high power receive (Rx) band-pass filter 74, which provides protection to the sharp pass-band filter 72 from high power transmitter signals.

Placement of dual diversity delay combining low noise amplification system 46, which in a preferred embodiment includes two-stage cascade filters 70a,70b, in front of the conventional repeater reduces the IMD contribution of the conventional repeater to insignificant levels, leaving only the IMD products generated within the dual diversity delay combining low noise amplification system 46. This increases the out-of-band input third order intercept point by 15 dB.

At this point in the dual diversity delay combining low noise amplification system circuit 46, all the signal processing required for the receive system to operate is complete. An optional receive power splitter 66 is used in a preferred embodiment, as described above, to provide two outputs for system expansion. If the receive power splitter 66 is used, there are two filter cascades 70, one for each receive power splitter output. These filters, besides serving as a protection from interference, also serve as receive side duplex filters (*i.e.* carrier rejection filters). Cascade filters 70 (*e.g.* such as 70a,70b), in conjunction with preferred preselector filters 48 and TX band-pass filters 65, provide the RF switching and filtering required to operate in the duplex configuration.

The preferred duplex configuration allows for a single cable, which carries both transmitter and receiver signals, and is connected to either the RX0/TX0 port 67b or the RX1/TX1 port 67a. The duplex configuration provides a bypass for the transmitter signals around the receiver's circuitry. The specific configuration shown in Figure 3 is a double duplexed configuration, since the signals are unduplexed at the donor input/output ports 67a, 67b (bottom RX0/TX0 and RX1/TX1) and are then re-duplexed before the subscriber antenna ports 17.

Band-pass Filters. Band pass filters 48, 72, 103 are designed to attenuate LO leakage, as well as any other spurious signals that result from the mixing processes that precede the band pass filter 48, 72, 103.

The SAW filter 72 preferably used in the dual diversity delay combining low noise amplification system 46, as shown in Figure 4, is used to improve intermodulation performance (increased out of band input intercept point).

The analogous preferred device in the repeater 22, 80 is the channel select filter. This filter provides the same effect, although its primary function is to provide individual channel selection (isolation), so that the repeater 22, 80 can isolate and repeat only the channel that the system operator desires.

Delay Combining CDMA Diversity Repeater. Figure 5 is a detailed block diagram of the primary enclosure housing a CDMA repeater system 80. By using a repeater 80 to provide diversity, a single time multiplexed signal 12, consisting of at least two independent fading paths 12a,12b, is transmitted to a base station 39, which typically includes a rake receiver 34. The rake receiver 34 at the base station 39 demodulates the time multiplexed signal 12 consisting of at least two paths 12a,12b.

A repeater in a conventional CDMA system has only one input path or signal branch, and has no signal diversity. As the single input path fades, there's not a second path there to pick up if the first one is down. The signal to noise requirement, which includes a fade margin, is large. This results in both a large link budget loss and a diminished sector capacity from a conventional repeater. The link budget for a conventional repeater is reduced by 3 to 4 dB, and the sector capacity is also reduced by 3 to 4 dB, when compared to a delay-combined diversity repeater 22,80. These are significant disadvantages to conventional repeaters, particularly if the conventional repeater is used to extend the range of a sector, but fails to maintain capacity.

The wireless repeater 80 shown in Figure 5 receives mobile signals 12 from mobile users MS, and does not act as a repeater between one stationary base station 39 and another stationary base station 39. The wireless repeater 80 is field based, and picks up mobile signals 12, acting like a base station or as an extension of a base station, using an over-the-air interface, in its own frequency. The wireless repeater 80 doesn't require extra spectrum, and extends the effective service area of a cell site.

The diversity techniques employed in the present invention only work with CDMA systems, since CDMA systems are able to recognize and demultiplex the delay imposed between the paths 12a,12b within the multipath signal 12.

The reverse path (up-link) operation of the repeater 80 is shown in figure 5, wherein mobile subscribers MS send out signals 12 to the antenna assembly 15 on the subscriber side (re-radiating side) of the repeater 81. A donor antenna assembly 117 is located on the donor side 119, to transmit processed signals to a base station 39. This processed signal is received by antennas 16a and 16b at the base station 39 (*e.g.* such as shown in Figure 1 and Figure 2). On the subscriber side 81, there is either a dual polarization antenna assembly 15, or a spatially separated vertically polarized antenna assembly, or any combination of these two schemes. The signals go through the diplexor 82, which acts as a filter to separate the transmit and receive signals 12, into two low noise amplifiers 86. The first low noise amplifier 86, in conjunction with the delay element 96, comprise the reverse path diversity front end 92. The reverse path diversity front end 92 is used for low noise amplification and signal delay. The reverse path main front end 84 is comprised of a low noise amplifier 86, a combiner 88, and a voltage controlled attenuator 120. The delay is added to the signal path associated with the reverse path diversity front end 92, as discussed above in relation to the dual diversity delay combining low noise amplifier system 46 for repeater applications.

The gain differential is preferably balanced between the reverse path main front end 84 and the reverse path diversity front end 92, such as by the voltage controlled attenuator 120, measured between the input ports and the output of the combiner 88. In preferred embodiments of the repeater 80, the gain differential is balanced between the entire lengths of the reverse path main front end 84 and the reverse path diversity front end 92, such as to include external components (*e.g.* such as but not limited to diplexors 82 and antennas 17). As described below, the gain differential may preferably be performed periodically, or may even be performed dynamically, in which a pseudonoise signal is fed into both signal receiver branch paths 47a,47b, and is subsequently analyzed, to provide a control signal for the voltage controlled attenuator 120.

As seen in Figure 5, the signal paths 12a,12b are summed 88, and are preferably fed to a channel select filter 100, which preferably comprises a sharp SAW filter, to eliminate out-of-band signals. The unwanted spurious signals and LO leakage at the output of the channel select filter 100, which result from signal conversion processes, are preferably filtered out by a band pass filter 103. The combined and filtered signal is then preferably sent through a power amplifier 102, through a diplexor 82, and is then transmitted to the base station 39, through donor antenna assembly 117. At this point, the combined signal comprises two (or more) paths 12a and 12b separated in time, as shown in Figure 1 and Figure 2. While the combined signal 12a,12b is drawn showing two path elements 12a, 12b, the elements are not necessarily discrete.

On the forward direction (down-link) side of the repeater circuit 80, a transmitted forward signal 122 is received from the base station 39 on the donor side 119. The received signal 122 is directed to the diplexor 82, and is separated out, wherein part of the signal 122 is directed through the forward path front end 85, which includes a low noise amplifier 86 and a voltage controlled attenuator 90. The forward signal 122 is then directed through a channel select filter 100, a band pass filter 103, a forward power amplifier 106, a diplexor 82, and is then transmitted on the subscriber side of the repeater 80, on either of the antennas 16 of antenna assembly 15.

The combiner 110 shown on the donor side 119 allows a second carrier reverse path (up-link) transmit path to be added, while J_1 and J_2 allow a second CDMA RF carrier path for the forward path (down-link). While the basic embodiment only requires one carrier, a typical CDMA spectrum currently has a plurality of RF carriers. Therefore, alternate embodiments of the invention can use a plurality of carrier transmit paths.

System Advantages. The wireless repeater 80, such as a personal communications services (PCS) repeater 80, provides many advantages over prior art repeater systems. The main advantage over the prior art is the reverse path receive (up-link) diversity feature. This feature improves system sensitivity and call quality, and maintains normal system capacity, which are significant improvements over the prior art. The wireless repeater 80, which in a preferred embodiment is channel selective is optimized for CDMA applications, provides a low up-link noise figure, as well as high down-link transmit power that is close to

base station power, with diversity paths in the up-link. The basic embodiment of the wireless repeater 80 is equipped with one CDMA frequency carrier. In an alternate embodiment of the repeater 80, a growth enclosure is preferably included for a second CDMA carrier 130, such as shown in Figure 6, having J-connections 118 between the first carrier 80 and the second carrier 130.

Repeater System Architecture. A block diagram for the primary enclosure housing a first CDMA frequency carrier for the channelized air-to air wireless repeater 80 is shown in Figure 5. The repeater 80 is typically connected, through subscriber antenna ports 17, to a single antenna assembly 15 on the subscriber side 81, and to a single donor antenna assembly 117, through donor antenna ports 19, on the donor side 119. This minimizes the number of antennas required, and minimizes the visual impact of a given site, which is a major concern during site development processes. The repeater 80 is also considered to be non-translating, since it does not shift the received frequency to a different transmitter frequency for the re-radiated signal or donor links. Non-translating repeaters 80 are also known as on-frequency repeaters 80.

The diplexor 82 provides common access to a single antenna 15 for both uplink and downlink signals. The isolation between the transmission (TX) and reception (RX) paths is sufficient to avoid both receiver overload and receiver desensitization caused by noise from the transmitter. The diplexor 82, as well as propagation losses, provides this isolation.

The main front end module (MFE) 84 can be used as the front end of the receive path, for both uplink signals 12 and downlink signals 12. A combiner 88 is included after the preferred low noise amplifier (LNA) 86, to combine the delayed diversity path 12. A combiner 86 is not required in the downlink circuitry. A voltage controlled attenuator (VCA) 90,120 is used for automatic level control (ALC), for protection of the repeater 80 against input overload conditions, and for calibration of the overall gain. As described above the voltage controlled attenuator 120 is also preferably used for differential gain balancing between the first receiver branch path 47a and the second receiver branch path 47b (*e.g.* such as seen in Figure 3).

The reverse path diversity front end (DFE) 92 is the front end of the reverse path diversity circuitry 94. A delay element 96 is inserted after a

preferred low noise amplifier 86, to provide at least two chip periods of time delay, for discrimination of the signal by the rake receiver 34. The output is preferably further amplified 56 to compensate the loss, and is combined with the other receive signal via the combiner 88 in the reverse path main front end 84.

In a preferred embodiment of the repeater 80, a channel select filter (CSF) 100 tunes the local oscillator to a specific channel, downconverts the RF signal to IF, provides channel filtering, and then upconverts the signal back to RF. The channel select filter 100 also provides gain adjustment for the wireless repeater 80.

A preferred reverse power amplifier (RPA) 102 provides signal amplification for the reverse path (up-link). Similarly, a preferred forward power amplifier (FPA) 106 provides high power amplification for the forward path (down-link) 108.

An alarm control unit (ACU) 112 controls and monitors all the modules within a preferred embodiment of the repeater 80. The alarm control unit 112 also communicates with the network or local craft via control software.

As discussed above, a band pass filter 103 is used to filter out image and local oscillator signals at the output of the channel select filter 100, to avoid radiation of unwanted signals.

The power supply PS 116 provides direct current (DC) power to all modules. A preferred network interface module 114 serves as an interface to the network, for alarm reporting, control, and monitoring. J-connections 118 are provided in the growth enclosure 130 for the second CDMA carrier.

In a preferred embodiment of the invention, a second CDMA carrier is added, by connecting a growth enclosure to the primary enclosure of the repeater 80, as shown in the block diagram of Figure 6. The second carrier has its own forward power amplifier 106b and reverse power amplifier 102b, to maintain the same downlink transmit power as the first carrier 80.

Repeater Process. The basic repeater process comprises the following steps:

i) receiving a signal 12 through a receiving antenna assembly 15 from a mobile user, said signal having a plurality of uncorrelated signal paths;

ii) preferably processing said received signal 12 through a first signal processing path and a second signal processing path, said second signal processing path having a delay element 96;

iii) combining 88 said processed signal from said first signal amplification path and said second amplification path;

iv) preferably processing said processed and combined signal through a channel select filter (CSF) 100 and/or a band pass filter 103; and

v) transmitting said combined signal though a transmission antenna 117.

Alternate Embodiments for Diversity Repeater. There are other possible delay combining embodiments for the diversity repeater, other than the preferred embodiment. Figure 8 shows a first alternate embodiment of a diversity repeater, which has two separate complete repeater paths up to the output of the reverse power amplifier. In this embodiment, the two paths are combined and transmitted back to a base station 39 via one donor antenna. One of the two paths introduces an extra 1.8 microsecond delay. This delay is introduced easiest within the channel select filter (CSF) module 100. Figure 9 shows a second alternate embodiment of a diversity repeater, which has two separate complete repeater paths utilizing two donor antennas. One of the paths introduces an extra 1.8 microsecond delay. Again, this delay is introduced easiest within the channel select filter (CSF) module 100. Figure 10 shows a third alternate embodiment of a diversity repeater, which has two separate complete repeater paths through the channel selective filter. In this embodiment, the two paths are first combined, and then are transmitted back to the base station, as in the preferred embodiment. One of these paths introduces an extra 1.8 microsecond delay. Again, this delay is introduced easiest within the channel select filter (CSF) module 100. While the alternate embodiments of the diversity

repeater are generally functionally equivalent to that of the preferred embodiment, they are generally more expensive to implement.

Quadruple Diversity Delay Combining Low Noise Amplification System 150 for Base Stations 39. Figure 7 is a block diagram of a quadruple diversity delay combining low noise amplification system 150 for base stations 39 (tower-top installations or otherwise). The quadruple diversity delay combining low noise amplification system 150 for base stations 39 is a system for increasing the diversity dimensionality of a base station 39 or microcell, from two branch to four branch diversity.

The quadruple diversity delay combining low noise amplification system 150 for base stations 39 uses four antennas 16a-d in either a spatial separation configuration, a multiple polarization configuration, or a configuration that combines these two techniques, to capture four independent fading signals (paths) 12.

These four signals (paths) 12 are first filtered 48, and then amplified with one or more low noise amplifiers 56, to minimize signal to noise ratio reduction in the following stages.

A delay element 58 is used to delay the $\phi 1$ and $\phi 3$ paths, as shown in Figure 7, which are typically delayed by a minimum of two chip periods (for one embodiment, this is greater than 1.8 microseconds). This delay is added, as described above, to allow for rake receiver demodulation of both paths. The paths associated with $\phi 1$ and $\phi 2$ are then combined with a simple 3 dB combiner 62, as are the paths associated with $\phi 3$ and $\phi 4$. Thus, the four paths are combined into two base station antenna ports.

Preferred Low noise amplifiers 64 follow each combiner 62, which are used to overcome the loss of the following SAW filter 72 (or other sharp band pass filtering device), in an effort to maintain signal to noise ratio.

This amplified signal is then preferably passed through a dual band pass filter cascade 70, comprising a SAW band pass filter 72 (or other sharp band pass filtering device) followed by another band pass filter 74, to protect the low power SAW filter from the transmitter's power. The dual band pass filter cascade 70, as discussed above, is shown in Figure 4. The purpose of the

second band pass filter 74 is to attenuate the strong RF signal from the transmitter site of the system, to protect the SAW filter from the high power RF signal of the transmitter. The first band pass filter 72 provides protection from out of band (out of receive band) interference which can result in the generation of intermodulation (IM) products. This protection greatly increases the "out of band input intercept point" of the tower top and base station cascade system configuration. Following the band pass filter cascade 70 is a junction point 152 where the receive and transmitter paths are coupled.

There is an additional path provided for the transmitter path, which comprises a band pass filter 65 and the appropriate coupling devices (junction points). The embodiment shown has two transmitter paths 53, one associated with the $\phi 1$ and $\phi 4$ receiver paths. This allows the quadruple diversity delay combining low noise amplifier system 150 to operate in a dual duplex configuration, which uses one antenna for both transmit and receive functions (a common requirement for PCS and cellular operators).

The quadruple diversity delay combining low noise amplification system 150 provides a significant increase in system reverse link sensitivity (4-5 dB), an increase in system capacity (approximately 2 dB), and an improvement in reverse link frame error performance.

Alternate Delay Combiner Embodiments Having Differential Delays and Gain Balancing. In a CDMA delay combining structure, the use of a delay, such as a SAW filter, results in a significant attenuation of a signal passing therethrough. For example, the use of a 2 microsecond 1900 MHz SAW filter within a CDMA delay combining structure 23 may typically result in a loss of approximately 28 dB. The use of a 4 microsecond SAW delay may typically result in a loss of approximately 56 dB. Therefore, for two incoming independent fading CDMA signals 12a,12b, wherein one of the signals 12 passes through a signal processing path 47 (*e.g.* 47a) which imparts a delay, the differential attenuation between the two paths 47a,47b is substantial. Furthermore, when two or more signals 12a,12b, which are not phase coherent, are combined, they appear as noise energy to each other. Upstream noise sources (prior to the combining point) are added together at the combining point, and the total noise is associated with both signals. The effect of these two factors is to cause a signal to noise ratio (SNR) imbalance between the combined

signals. For example, if two signals 12a,12b, initially having an equal signal to noise ratio (SNR), are processed and combined, and one signal has an amplitude that is 10 dB below the other, then the SNR of the weaker signal will be approximately 10 dB lower than the other.

Therefore, in a delay combiner system 23 having a significant gain imbalance between processing paths, such as introduced by a delay element, the subsequent signal information from the delayed path 47 may be "lost" during subsequent signal processing (*i.e.* such a delay combiner would therefore fail to provide SNR improvements, since it fails to increase the number of signals which are available to a rake receiver).

Figure 11 provides a schematic view 160 of a basic delay combiner 23a, such as seen in the repeater 22a in Figure 2. As seen in Figure 11, the strength of signal 12a is attenuated through the delay element 58. In some typical embodiments, the delay element 58 has a minimum loss of approximately 28 dB, such that signal quality of the combined output signal may be diminished.

Figure 12 is a schematic diagram 162 of a delay combiner 23d having a fixed attenuator 164, which shows signal strength at various points on the receiver branch paths 47a, 47b. As in the delay combiner 23a in Figure 11, the strength of signal 12a on receiver branch 47a is attenuated through the delay element 58. However, the strength of signal 12a on receiver branch 47b is attenuated through the fixed attenuator 164, such that the signals on each of the receiver branches 47a,47b have a similar signal strength before being combined in combiner 62. While the fixed attenuator 164 may provide basic gain balancing when the value of the fixed attenuator 164 is equal to the loss of the delay 58, the fixed attenuator 164 is inherently invariable, and is not adaptable to changing conditions.

Figure 13 is a schematic diagram 166 of a delay combiner 23e having a variable attenuator 60, which shows signal strength at various points on the receiver branch paths 47a, 47b. As in the delay combiner 23e in Figure 11, the strength of signal 12a on receiver branch 47a is attenuated through the delay element 58. As well, the strength of signal 12a on receiver branch 47b is attenuated through the variable attenuator 60, such that the signals 12a,12b on each of the receiver branches 47a,47b have a similar signal strength before

being combined in combiner 62, thereby providing improved diversity. The variable attenuator 164 is adaptable to changing conditions, and may preferably be adjusted statically or dynamically, to balance the gain across the receiver branch paths 47a,47b, which may also include gain balancing across the receiver antennas 16 (*e.g.* such as 16a,16b) as well.

Figure 14 is a schematic diagram 168 of a delay combiner 23f having a low noise amplifier 48 on the delayed receiver branch 47a, which shows signal strength at various points on the receiver branch paths 47a,47b. The low noise amplifier 48 amplifies the first input signal 12a, such that when the amplified input signal 12a is directed through the delay element 58, the resultant amplitude of the amplified and delayed signal 12a, under some conditions, may be similar or equal to the amplitude of the second input signal 12b before being combined in the combiner 62, thereby providing improved diversity. While the delay combiner 23f shown in Figure 14 may provide some improvement in signal diversity under some conditions, it is not adaptable to changing conditions.

Figure 15 is a schematic diagram 170 of a delay combiner 23g having amplifiers 48 on both receiver branches 47a,47b, and a variable attenuator 60 on one branch 47b, which shows signal strength at various points on the receiver branch paths 47a,47b. The low noise amplifiers 48 amplify both the first input signal 12a and the second input signal 12b. While the amplified first input signal 12a is directed through the delay element 58, and is attenuated by the delay element 58, the amplified second input signal 12b is preferably forwarded through the variable attenuator 58, such that the gain across the receiver branches 47a,47b may be balanced, producing signals having equal signal strength. The delay combiner 23g is adaptable over a wide variety of operating conditions, and provides a low noise figure. Figure 16 is a schematic diagram 172 of a delay combiner 23h having a similar structure to the delay combiner 23g, and further comprising means for gain balancing (*e.g.* such as the variable attenuator 60) on the second receiver branch 47b.

Figure 17 is a schematic diagram 174 of a delay combiner 23i having amplifiers 48 and delay elements 58 (*e.g.* such as 58a,58b,58c) on both receiver branches 47a, 47b, as well as means for gain balancing (*e.g.* such as both not limited to the variable attenuator 58 shown on the second receiver branch 47b). Figure 18 is a schematic diagram 176 of a delay combiner 23j

having amplifiers 48, and one or more filters 178 (*e.g.* such as but not limited to channel select filters 178a,178b,178c) having inherent delays, on both receiver branches 47a,47b, as well as means for gain balancing 60 on one branch 47b. Various embodiments of the delay combiner structures 23 may include a large variety of delay elements 58 or filters on one or more branches 47a-47n.

The differential delay between the receiver branches 47a,47b (which is due to the sum of the delays from the delay elements 58 and/or filters 178) is preferably more than two chips, whereby the resulting code offset ensures that the cross correlation between the two signal paths 12a,12b is zero. Thus the two signal paths 12a,12b will appear as noise to each other, and may successively be combined as a diversity signal.

Delay Combiner for Adaptive Gain Balancing. Figure 19 is a schematic diagram 180 of a delay combiner 23k which provides adaptive gain balancing. A microprocessor 182 generates a known pseudonoise sequence (PNS) pilot signal 184, which is forwarded, such as through an upconverter 186, to a first input port 188a on the first receiver branch 47a, as well as to a second input port 188b on the second receiver branch 47b. The known PNS pilot signal 184 is then processed through each of the receiver branches 47a,47b, and is combined in combiner 62. The output 189 of the combiner 62 is then sampled 190, and is forwarded to an analog to digital (A/D) converter 192. The energy of the resulting processed and combined PNS pilot signal 184 is then analog-to-digital converted 192, and then the combined (*i.e.* composite) digital signal 194 is fed into the microprocessor 182, which analyzes the composite digital signal 194.

As each of the receiver branches 47a,47b comprises one or more components, such as delay elements 58 or filters 178 (FIG. 18), the microprocessor 182 can determine which portion of the combined digital signal 194 is attributable to each of the branches 47a,47b. For example the microprocessor 182 can provide an autocorrelation analysis of the combined digital signal 194, to determine the amount of noise power for each branch path 47a,47b. The microprocessor 182 then preferably sends a gain balance control signal 196, such as to the variable attenuator 60, to balance the gain between the branches 47a,47b (*e.g.* typically such that the gain for each branch 47a,47b is approximately within a tenth of a decibel from the other).

The pseudonoise sequence (PNS) pilot signal 184 is typically a low energy signal 184, such that the delay combiner system 180 may preferably provide adaptive gain balancing while the system 180 is in operation (*i.e.* while input signals 12a and 12b are processed and combined). The microprocessor 182 preferably includes firmware to control the adaptive gain balancing process, whereby the adaptive gain balancing delay combiner system 180 may be readily adapted to changing operating conditions, such as but not limited to changing operating temperatures, amplifier conditions, and/or gain changes. The adaptive gain balancing delay combiner system 180 therefore provides an improved noise figure over a wide variety of operating conditions.

Although the improved delay combiner system and its methods of use are described herein in connection with CDMA repeaters and delay combining amplification systems, the apparatus and techniques can be implemented within other communications devices and systems, or any combination thereof, as desired.

Accordingly, although the invention has been described in detail with reference to a particular preferred embodiment, persons possessing ordinary skill in the art to which this invention pertains will appreciate that various modifications and enhancements may be made without departing from the spirit and scope of the claims that follow.

CLAIMS

What is claimed is:

1. A code division multiple access signal repeater, comprising:

at least two subscriber antenna connectors adapted to connect to a subscriber antenna assembly having at least two subscriber antennas, each of said subscriber antenna connectors connected to one of said subscriber antennas, each of said subscriber antennas adapted to receive independent fading decorrelated said code division multiple access signals from at least one mobile user;

a first signal processing path and a second signal processing path for processing said received code division multiple access signals, each of said paths connected to one of said at least two subscriber antenna connectors, said first signal and said second processing path having a differential delay, said first signal processing path having a first gain, said second signal processing path having a second gain;

means for balancing differential gain between said first gain of said first signal processing path and said second gain of said second signal processing path;

a combiner connected to said first signal processing path and said second signal processing path, said combiner adapted to combine said processed code division multiple access signals; and

a donor antenna connector connected to said combiner and adapted to connect to a donor antenna assembly, said donor antenna assembly adapted to transmit said processed, combined code division multiple access signal.

2. The code division multiple access signal repeater of Claim 1, further comprising:

at least one delay element on said first signal processing path; and

at least one delay element on said second signal processing path;

wherein said differential delay is equal to the difference in delays between said at least one delay element on said first signal processing path and said at least one delay element on said second signal processing path.

3. The code division multiple access signal repeater of Claim 1, further comprising:

at least one filter having a delay on said first signal processing path; and

at least one filter having a delay on said second signal processing path;

wherein said differential delay is equal to the difference in delays between said at least one filter having a delay on said first signal processing path and said at least one filter having a delay on said second signal processing path.

4. The code division multiple access signal repeater of Claim 3, wherein each of said at least one filter having a delay on said first signal processing path are channel select filters, and wherein each of said at least one filter having a delay on said second signal processing path are channel select filters.

5. The code division multiple access signal repeater of Claim 1, further comprising:

a power amplifier connected between said combiner and said donor antenna connector.

6. The code division multiple access signal repeater of Claim 1, further comprising:

a channel select filter connected between said combiner and said donor antenna connector.

7. The code division multiple access signal repeater of Claim 1, further comprising:

means for limiting out of band interference of said processed, combined code division multiple access signal, said band limiting means connected between said combiner and said donor antenna connector.

8. The code division multiple access signal repeater of Claim 1, further comprising:

means for preserving signal to noise ratio of said processed, combined code division multiple access signal, said band limiting means connected between said combiner and said donor antenna connector.

9. The code division multiple access signal repeater of Claim 1, further comprising:

a band pass filter connected between said combiner and said donor antenna connector.

10. The code division multiple access signal repeater of Claim 1, further comprising:

means for limiting out of band interference connected between said combiner and said donor antenna connector.

11. The code division multiple access signal repeater of Claim 1, wherein each of said subscriber antennas provide code division multiple access signals that are mutually decorrelated.

12. The code division multiple access signal repeater of Claim 1, wherein each of said subscriber antennas in subscriber antenna assembly are spatially separated from other of said antennas.

13. The code division multiple access signal repeater of Claim 1, wherein each of said subscriber antennas in subscriber antenna assembly are orthogonally polarized from other of said subscriber antennas.

14. The code division multiple access signal repeater of Claim 1, wherein each of said subscriber antennas in subscriber antenna assembly are spatially separated and orthogonally polarized from other of said subscriber antennas.

15. The code division multiple access signal repeater of Claim 1, wherein said first signal processing path and said second signal processing path each include a low noise amplifier.

16. The code division multiple access signal repeater of Claim 1, wherein said means for balancing differential gain between said first gain of said first signal processing path and said second gain of said second signal processing path comprises a variable attenuator located on said second signal processing path.

17. The code division multiple access signal repeater of Claim 1, further comprising:

a first diplexor between said first subscriber antenna connector and said first signal processing path;

a second diplexor between said combiner and said donor antenna connector; and

a forward path signal processing path between said second diplexor and said first diplexor, said forward path signal processing path adapted to receive forward pass signals received by said donor antenna assembly.

18. A delay combining low noise amplification system, comprising:

at least two subscriber antenna connectors adapted to connect to a subscriber antenna assembly having at least two subscriber antennas, each of said subscriber antenna connectors connected to one of said subscriber antennas, each of said subscriber antennas adapted to receive independent fading code division multiple access signals;

a first signal processing path and a second signal processing path, each of said paths connected to one of said subscriber antenna connectors, said first signal and said second processing path having a differential delay, said first signal processing path having a first gain, said second signal processing path having a second gain;

means for balancing differential gain between said first gain of said first signal processing path and said second gain of said second signal processing path;

a combiner connected to said first signal processing path and said second signal processing path, said combiner adapted to combine said processed code division multiple access signal from said first signal processing path and said second signal processing path; and

a donor connector connected to said combiner.

19. The delay combining low noise amplification system of Claim 18, further comprising:

at least one delay element on said first signal processing path; and

at least one delay element on said second signal processing path;

wherein said differential delay is equal to the difference in delays between said at least one delay element on said first signal processing path and said at least one delay element on said second signal processing path.

20. The delay combining low noise amplification system of Claim 18, further comprising:

at least one filter having a delay on said first signal processing path; and

at least one filter having a delay on said second signal processing path;

wherein said differential delay is equal to the difference in delays between said at least one filter having a delay on said first signal processing path and said at least one filter having a delay on said second signal processing path.

21. The delay combining low noise amplification system of Claim 20, wherein each of said at least one filter having a delay on said first signal processing path are channel select filters, and wherein each of said at least one filter having a delay on said second signal processing path are channel select filters.

22. The delay combining low noise amplification system of Claim 18, further comprising:

a low noise amplifier connected between said combiner and said donor connector.

23. The delay combining low noise amplification system of Claim 18, further comprising:

a band pass filter connected between said combiner and said donor connector.

24. The delay combining low noise amplification system of Claim 18, wherein said first signal processing path and said second signal processing path each include a low noise amplifier.

25. The delay combining low noise amplification system of Claim 18, wherein each of said subscriber antennas provide code division multiple access signals that are mutually decorrelated.

26. The delay combining low noise amplification system of Claim 18, wherein each of said subscriber antennas in said subscriber antenna assembly are spatially separated from other of said antennas.

27. The delay combining low noise amplification system of Claim 18, wherein each of said subscriber antennas in said subscriber antenna assembly are orthogonally polarized from other of said subscriber antennas.

28. The delay combining low noise amplification system of Claim 18, wherein each of said subscriber antennas in said subscriber antenna assembly are spatially separated and orthogonally polarized from other of said subscriber antennas.

29. The delay combining low noise amplification system of Claim 18, wherein said first signal processing path and said second signal processing path each include a low noise amplifier.

30. The delay combining low noise amplification system of Claim 18, wherein said means for balancing differential gain between said first gain of said first signal processing path and said second gain of said second signal processing path comprises a variable attenuator located on said second signal processing path.

31. The delay combining low noise amplification system of Claim 18, further comprising:

a first diplexor between said first subscriber antenna connector and said first signal processing path;

a second diplexor between said combiner and said donor antenna connector; and

a forward path signal processing path between said second diplexor and said first diplexor, said forward path signal processing path adapted to receive forward pass code division multiple access signals received by said donor connector.

32. A process, comprising the steps of:

receiving an independently fading code division multiple access signal through at least two subscriber antenna connectors adapted to connect to a subscriber antenna assembly having at least two subscriber antennas, each of said subscriber antenna connectors connected to one of said subscriber antennas, each of said subscriber antennas adapted to receive said independent fading code division multiple access signals;

processing said received independent fading code division multiple access signals through a first signal processing path having a first gain and a second signal processing path having a second gain, each of said signal processing paths connected to one of said at least two subscriber antenna connectors;

providing a differential delay between said processed code division multiple access signal on said first signal processing path and said processed code division multiple access signal on said second signal processing path;

balancing differential gain between said first gain of said first signal processing path and said second gain of said second signal processing path;

combining said processed code division multiple access signals from said first signal processing path and said second signal processing path in a combiner; and

transmitting said processed and combined code division multiple access signal though a donor antenna connector adapted to connect to a donor antenna assembly.

33. The process of Claim 32, wherein providing a differential delay further comprises:

providing at least one delay element on said first signal processing path; and

providing at least one delay element on said second signal processing path;

wherein said differential delay is equal to the difference in delays between said at least one delay element on said first signal processing path and said at least one delay element on said second signal processing path.

34. The process of Claim 32, wherein providing a differential delay further comprises:

providing at least one filter having a delay on said first signal processing path; and

providing at least one filter having a delay on said second signal processing path;

wherein said differential delay is equal to the difference in delays between said at least one filter having a delay on said first signal processing path and said at least one filter having a delay on said second signal processing path.

35. The process of Claim 34, wherein each of said at least one filter having a delay on said first signal processing path are channel select filters, and wherein each of said at least one filter having a delay on said second signal processing path are channel select filters.

36. The process of Claim 35, further comprising the step of:

connecting a power amplifier between said combiner and said donor antenna connector.

37. The process of Claim 32, further comprising the step of:

connecting a channel select filter between said combiner and said donor antenna connector.

38. The process of Claim 32, further comprising the step of:

connecting a means for limiting out of band interference of said processed, combined code division multiple access signal between said combiner and said donor antenna connector.

39. The process of Claim 32, further comprising the step of:

connecting a means for preserving signal to noise ratio of said processed, combined code division multiple access signal between said combiner and said donor antenna connector.

40. The process of Claim 32, further comprising the step of:

connecting a band pass filter between said combiner and said donor antenna connector.

41. The process of Claim 32, further comprising the step of:

connecting a means for limiting out of band interference between said combiner and said donor antenna connector.

42. The process of Claim 32, wherein each of said subscriber antennas provide code division multiple access signals that are mutually decorrelated.

43. The process of Claim 32, wherein each of said subscriber antennas in subscriber antenna assembly are spatially separated from other of said antennas.

44. The process of Claim 32, wherein each of said subscriber antennas in subscriber antenna assembly are orthogonally polarized from other of said subscriber antennas.

45. The process of Claim 32, wherein each of said subscriber antennas in subscriber antenna assembly are spatially separated and orthogonally polarized from other of said subscriber antennas.

46. The process of Claim 32, wherein said first signal processing path and said second signal processing path each include a low noise amplifier.

47. The process of Claim 32, wherein said step of balancing differential gain between said first gain of said first signal processing path and said second gain of said second signal processing path is provided by a variable attenuator located on said second signal processing path.

48. The process of Claim 32, further comprising the steps of:

providing a first diplexor between said first subscriber antenna connector and said first signal processing path;

providing a second diplexor between said combiner and said donor antenna connector; and

providing a forward path signal processing path between said second diplexor and said first diplexor, said forward path signal processing path

adapted to receive forward pass code division multiple access signals received by said donor antenna assembly.

49. A code division multiple access signal repeater, comprising:

at least two subscriber antenna connectors adapted to connect to a subscriber antenna assembly having at least two subscriber antennas, each of said subscriber antenna connectors connected to one of said subscriber antennas, each of said subscriber antennas adapted to receive independent fading decorrelated said code division multiple access signals from at least one mobile user;

a first signal processing path and a second signal processing path for processing said received code division multiple access signals, each of said paths connected to one of said at least two subscriber antenna connectors, said first signal processing path having a delay element, said first signal processing path having a first gain, said second signal processing path having a second gain;

means for balancing differential gain between said first gain of said first signal processing path and said second gain of said second signal processing path;

a combiner connected to said first signal processing path and said second signal processing path, said combiner adapted to combine said processed code division multiple access signals;

a donor antenna connector connected to said combiner and adapted to connect to a donor antenna assembly, said donor antenna assembly adapted to transmit said processed, combined code division multiple access signal.

means for inputting a pilot signal on said first signal processing path and said second signal processing path;

means for measuring energy of said input pilot signal to determine noise power for said input pilot signal though said first signal processing path and said second signal processing path; and

means for sending a differential gain balance signal to said means for balancing differential gain, based upon said determined noise power for said input pilot signal though said first signal processing path and said second signal processing path.

50. The code division multiple access signal repeater of Claim 49, further comprising:

a power amplifier connected between said combiner and said donor antenna connector.

51. The code division multiple access signal repeater of Claim 49, further comprising:

a channel select filter connected between said combiner and said donor antenna connector.

52. The code division multiple access signal repeater of Claim 49, further comprising:

means for limiting out of band interference of said processed, combined code division multiple access signal, said band limiting means connected between said combiner and said donor antenna connector.

53. The code division multiple access signal repeater of Claim 49, further comprising:

means for preserving signal to noise ratio of said processed, combined code division multiple access signal, said band limiting means connected between said combiner and said donor antenna connector.

54. The code division multiple access signal repeater of Claim 49, further comprising:

a band pass filter connected between said combiner and said donor antenna connector.

55. The code division multiple access signal repeater of Claim 49, further comprising:

means for limiting out of band interference connected between said combiner and said donor antenna connector.

56. The code division multiple access signal repeater of Claim 49, wherein each of said subscriber antennas provide code division multiple access signals that are mutually decorrelated.

57. The code division multiple access signal repeater of Claim 49, wherein each of said subscriber antennas in subscriber antenna assembly are spatially separated from other of said antennas.

58. The code division multiple access signal repeater of Claim 49, wherein each of said subscriber antennas in subscriber antenna assembly are orthogonally polarized from other of said subscriber antennas.

59. The code division multiple access signal repeater of Claim 49, wherein each of said subscriber antennas in subscriber antenna assembly are spatially separated and orthogonally polarized from other of said subscriber antennas.

60. The code division multiple access signal repeater of Claim 49, wherein said first signal processing path and said second signal processing path each include a low noise amplifier.

61. The code division multiple access signal repeater of Claim 49, wherein said means for balancing differential gain between said first gain of said first signal processing path and said second gain of said second signal processing path comprises a variable attenuator located on said second signal processing path.

62. The code division multiple access signal repeater of Claim 49, further comprising:

a first diplexor between said first subscriber antenna connector and said first signal processing path;

a second diplexor between said combiner and said donor antenna connector; and

a forward path signal processing path between said second diplexor and said first diplexor, said forward path signal processing path adapted to receive forward pass signals received by said donor antenna assembly.

63. A delay combining low noise amplification system, comprising:

at least two subscriber antenna connectors adapted to connect to a subscriber antenna assembly having at least two subscriber antennas, each of said subscriber antenna connectors connected to one of said subscriber antennas, each of said subscriber antennas adapted to receive independent fading code division multiple access signals;

a first signal processing path and a second signal processing path, each of said paths connected to one of said subscriber antenna connectors, said first signal and said second processing path having a differential delay, said first signal processing path having a first gain, said second signal processing path having a second gain;

means for balancing differential gain between said first gain of said first signal processing path and said second gain of said second signal processing path;

a combiner connected to said first signal processing path and said second signal processing path, said combiner adapted to combine said processed code division multiple access signal from said first signal processing path and said second signal processing path;

a donor connector connected to said combiner;

means for inputting a pilot signal on said first signal processing path and said second signal processing path;

means for measuring energy of said input pilot signal to determine noise power for said input pilot signal though said first signal processing path and said second signal processing path; and

means for sending a differential gain balance signal to said means for balancing differential gain, based upon said determined noise power for said input pilot signal though said first signal processing path and said second signal processing path.

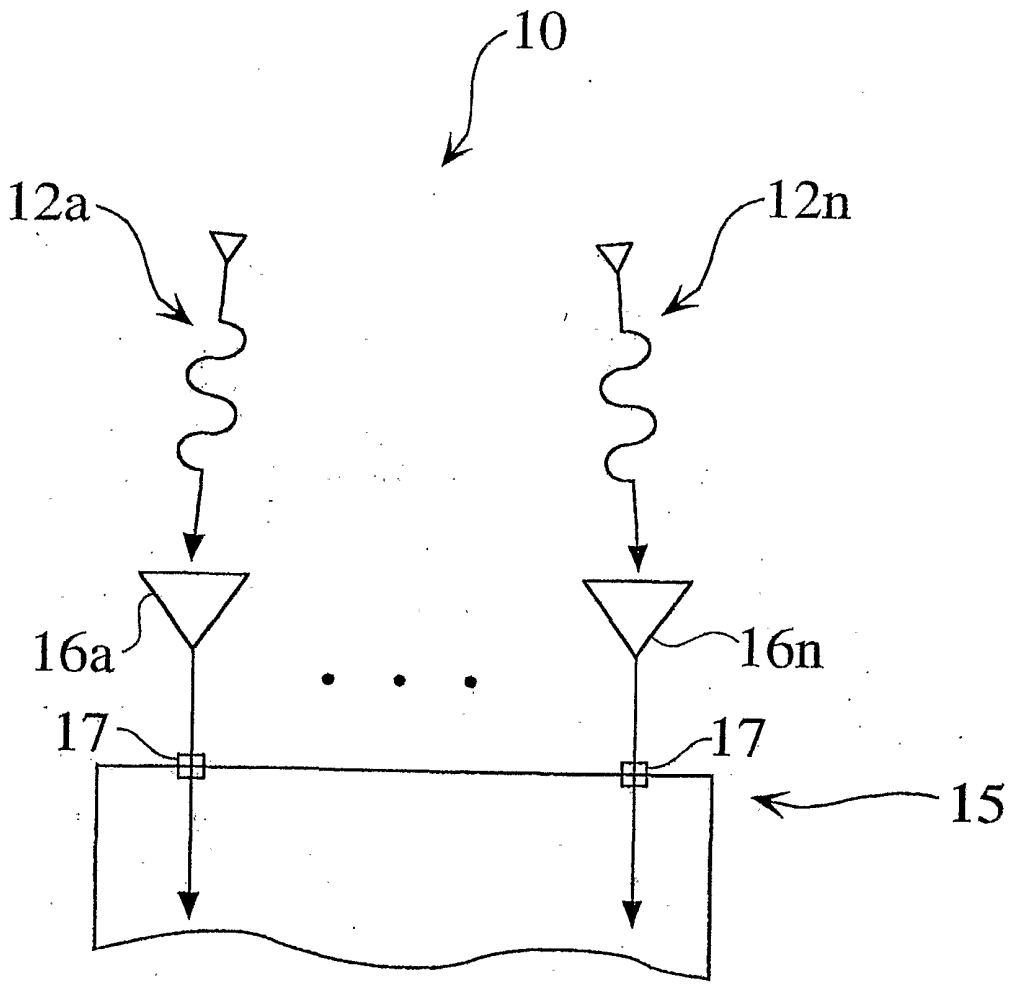


Fig. 1

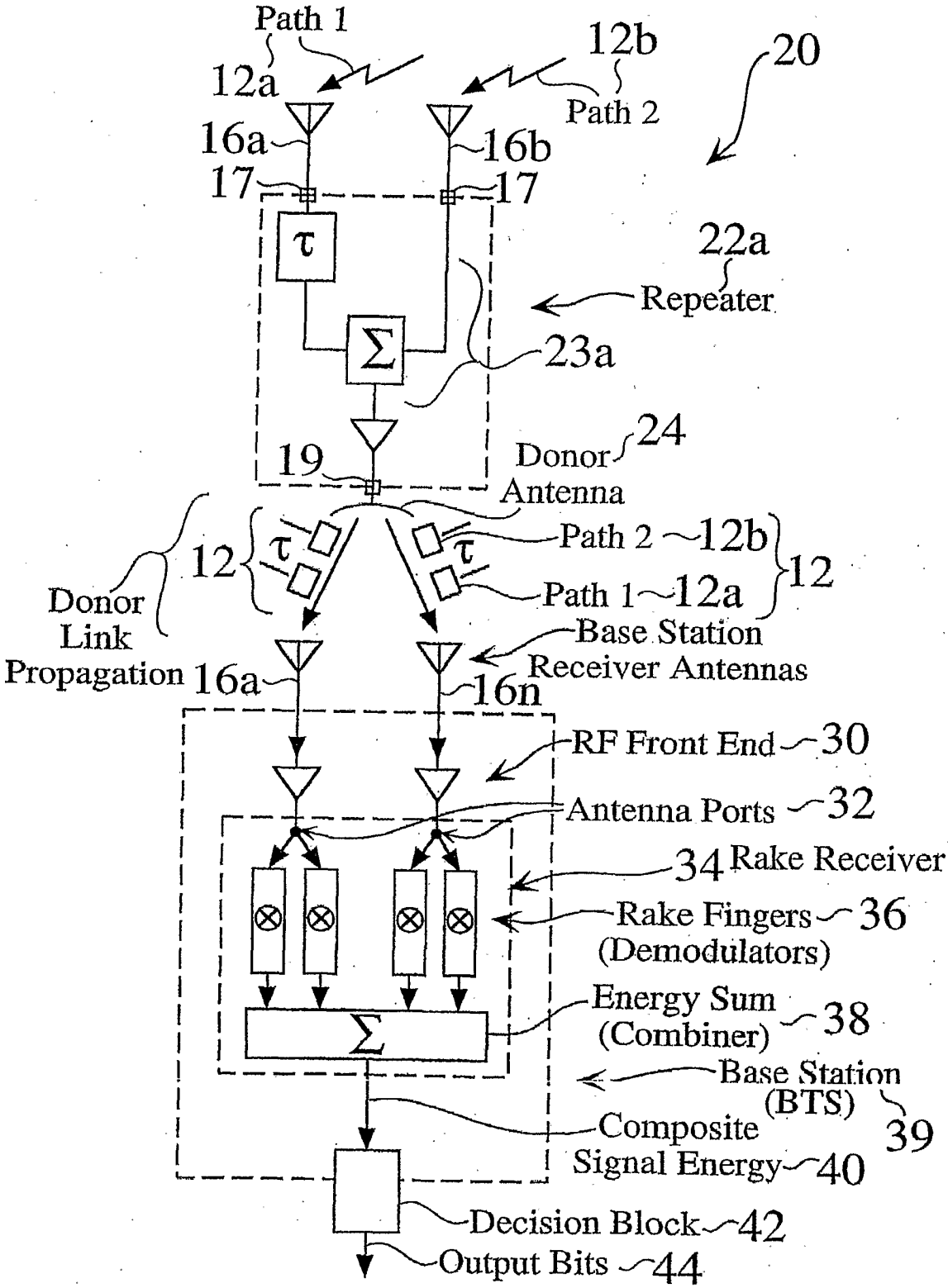

Path 1
12a
12b
Path 2
20
16a
16b
17
17
τ
22a
Repeater
Σ
23a
19
Donor
24
Antenna
Donor
Link
Propagation
12
τ
τ
Path 2
12b
12
Path 1
12a
Base Station
Receiver Antennas
16a
16n
RF Front End
30
Antenna Ports
32
34
Rake Receiver
Rake Fingers
36
(Demodulators)
Energy Sum
(Combiner)
38
Σ
Base Station
(BTS)
39
Composite
Signal Energy
40
Decision Block
42
Output Bits
44

Fig. 2

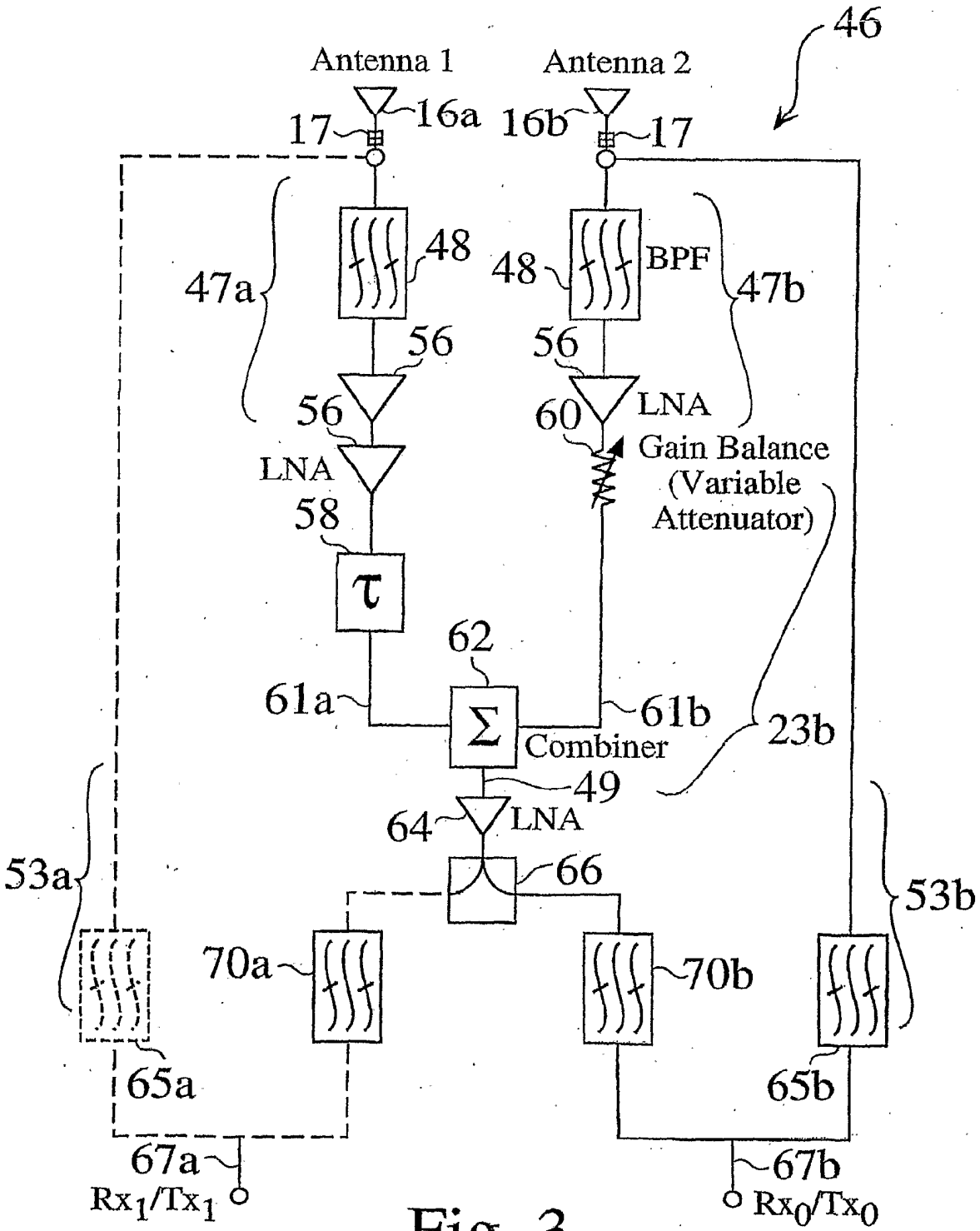

46
Antenna 1
Antenna 2
17
16a
16b
17
47a
48
48
BPF
47b
56
56
56
60
LNA
LNA
Gain Balance
(Variable
Attenuator)
58
τ
62
61a
Σ
61b
Combiner
23b
49
64
LNA
53a
66
53b
70a
70b
65a
65b
67a
67b
Rx1/Tx1
Rx0/Tx0

Fig. 3

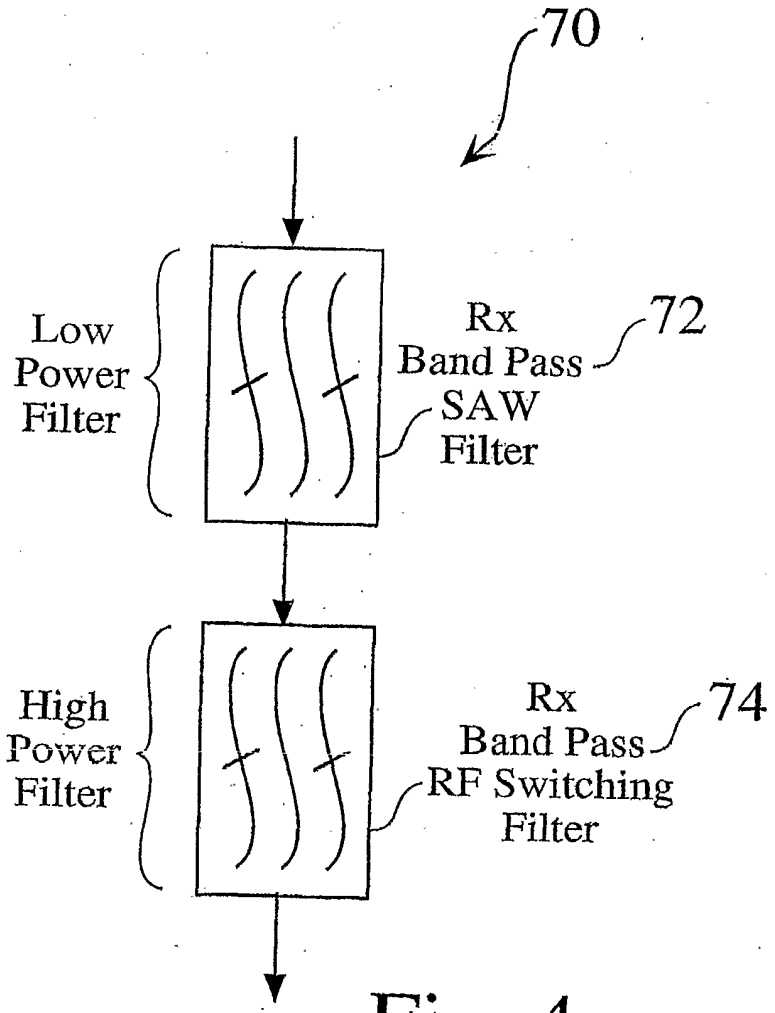

70
Low
Power
Filter
Rx
Band Pass
SAW
Filter
72
High
Power
Filter
Rx
Band Pass
RF Switching
Filter
74

Fig. 4

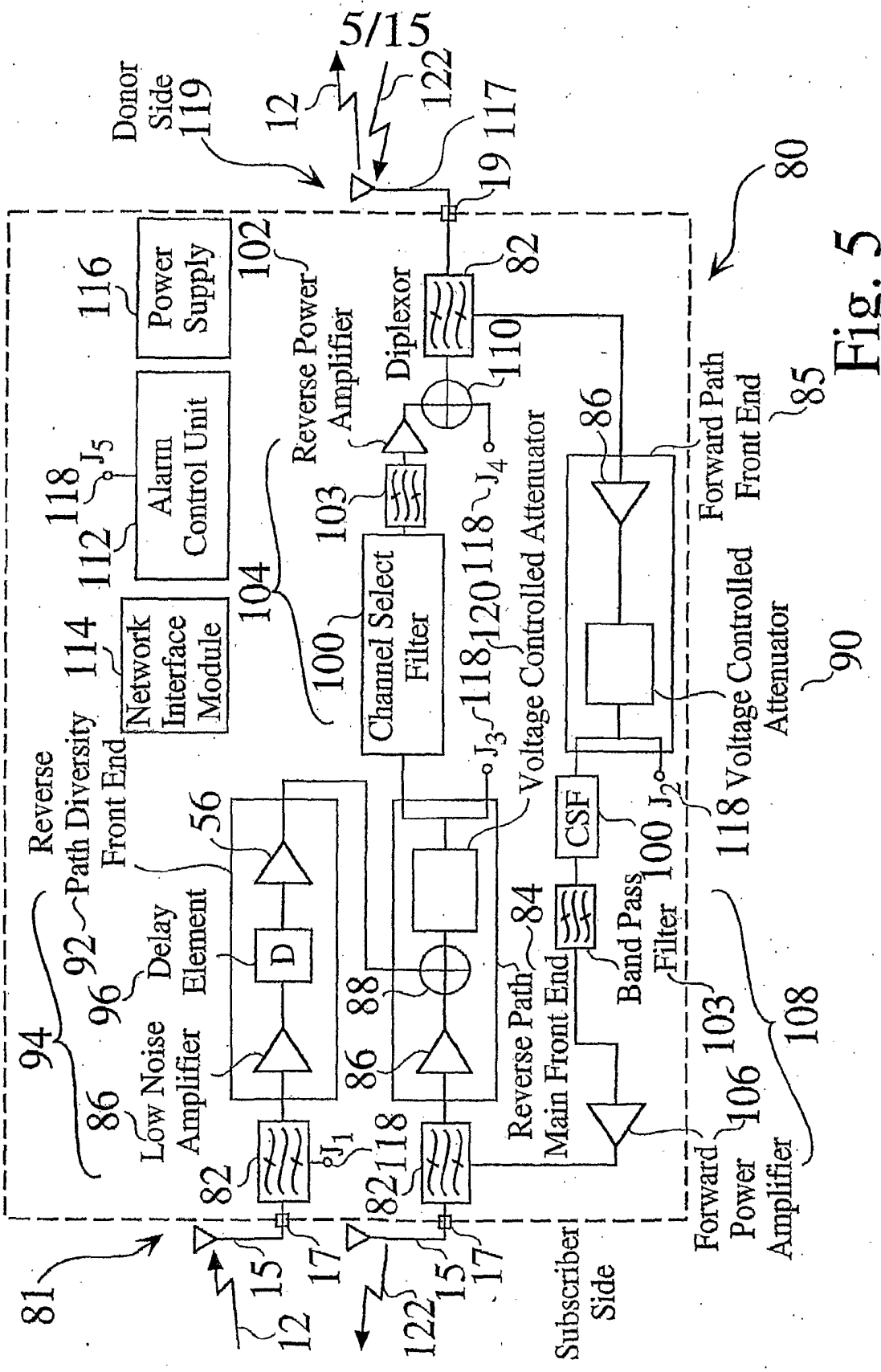

5/15
Donor Side 119
12
122
19
117
80
Power Supply
116
102
Reverse Power Amplifier
Diplexor
82
110
86
Forward Path Front End
85
Alarm Control Unit
118
J_5
112
103
J_4
Network Interface Module
114
104
100
Channel Select Filter
118
120
118
Voltage Controlled Attenuator
90
Reverse Path Diversity Front End
92
94
96
Delay Element
56
D
J_3
J_2
118
Voltage Controlled Attenuator
Low Noise Amplifier
86
88
84
CSF
Band Pass Filter
100
Reverse Path Main Front End
103
106
108
Forward Power Amplifier
82
J_1
118
81
15
17
12
122
15
17
Subscriber Side

Fig. 5

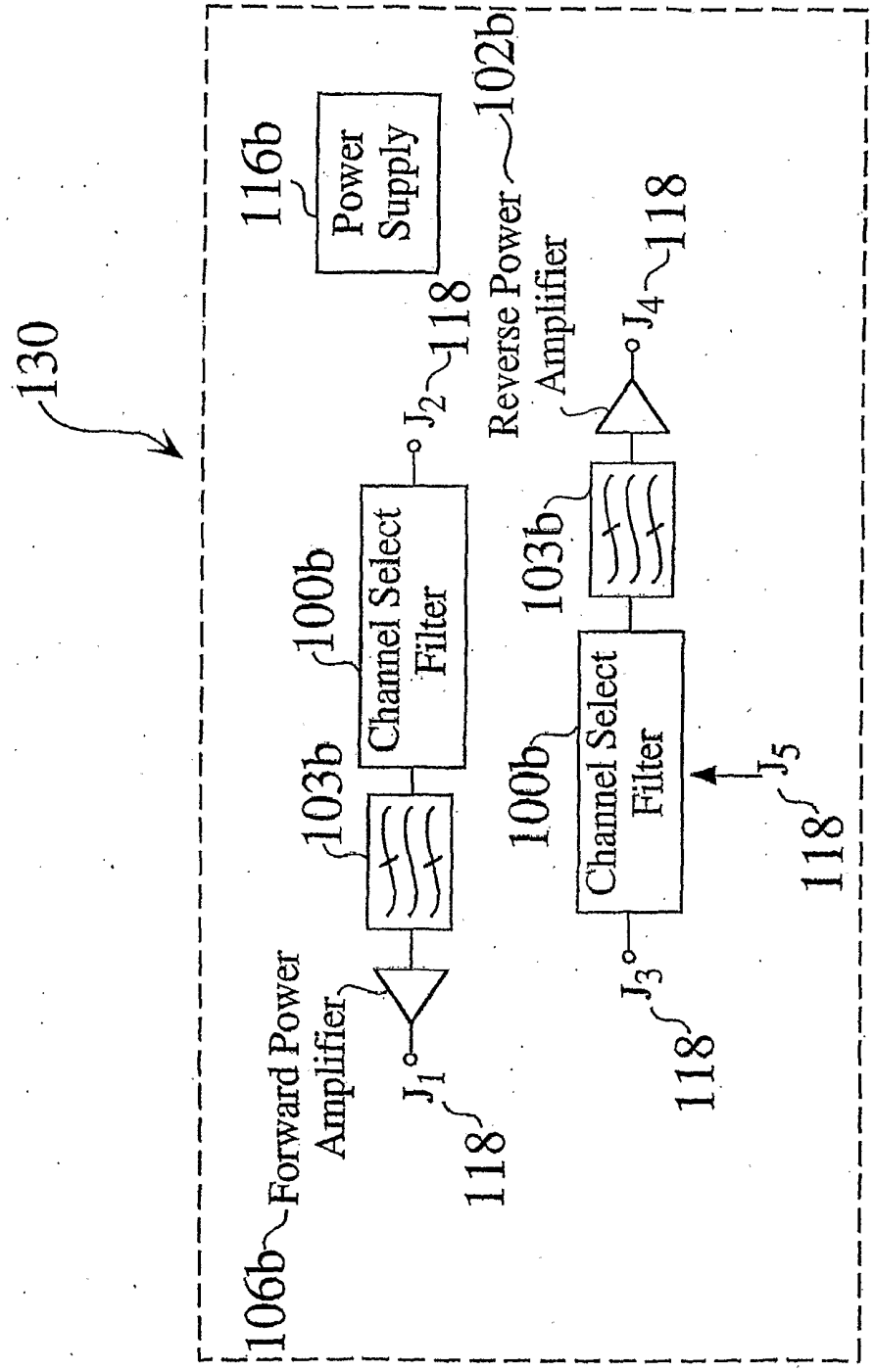

130
106b
Forward Power Amplifier
118
J1
103b
100b
Channel Select Filter
J2
118
116b
Power Supply
102b
Reverse Power Amplifier
J4
118
103b
100b
Channel Select Filter
J3
118
J5
118

Fig. 6

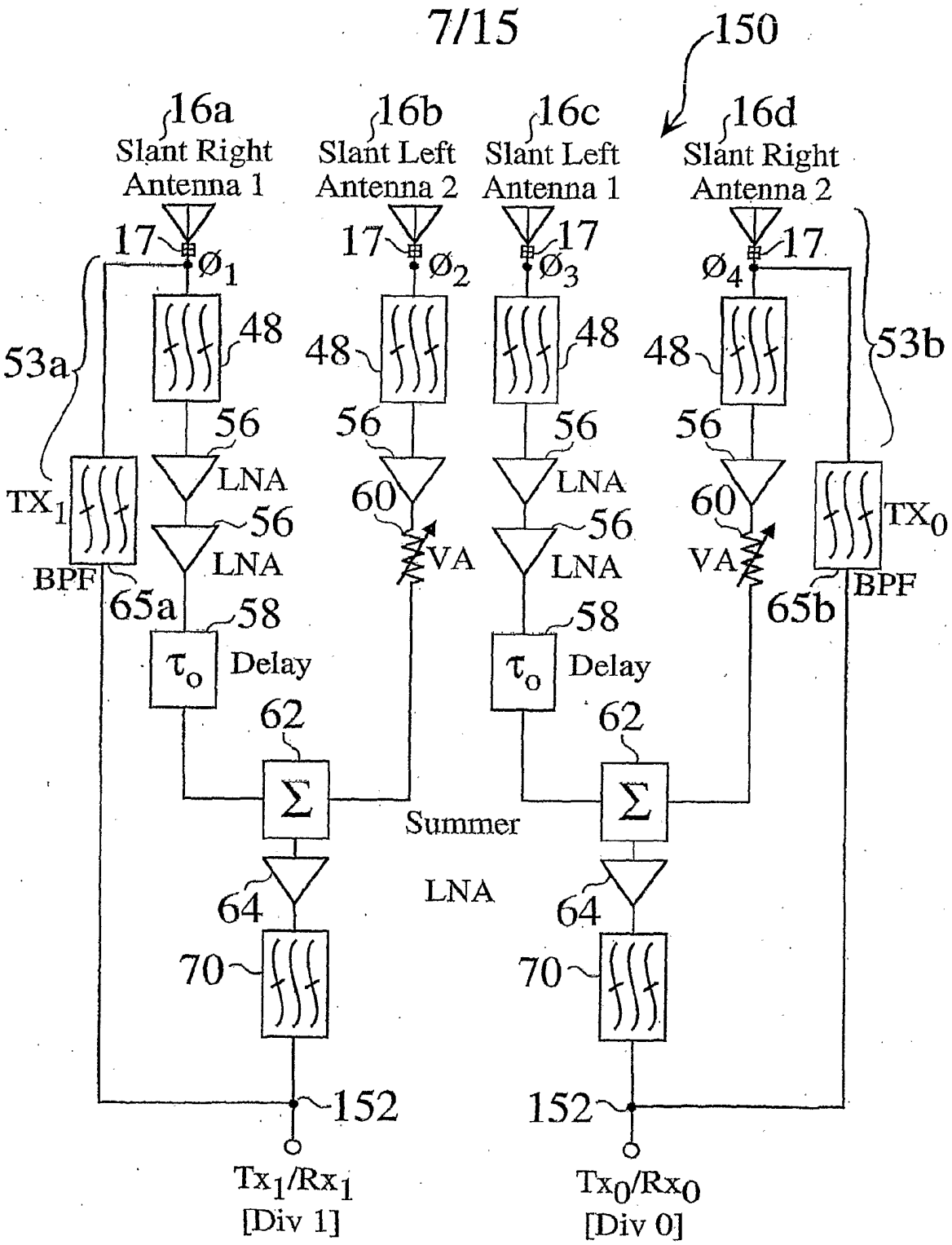

150
16a
Slant Right
Antenna 1
16b
Slant Left
Antenna 2
16c
Slant Left
Antenna 1
16d
Slant Right
Antenna 2
17
Ø1
Ø2
Ø3
Ø4
48
53a
53b
56
LNA
TX1
TX0
60
VA
BPF
65a
65b
58
τo
Delay
62
Σ
Summer
LNA
64
70
152
Tx1/Rx1
[Div 1]
Tx0/Rx0
[Div 0]

Fig. 7

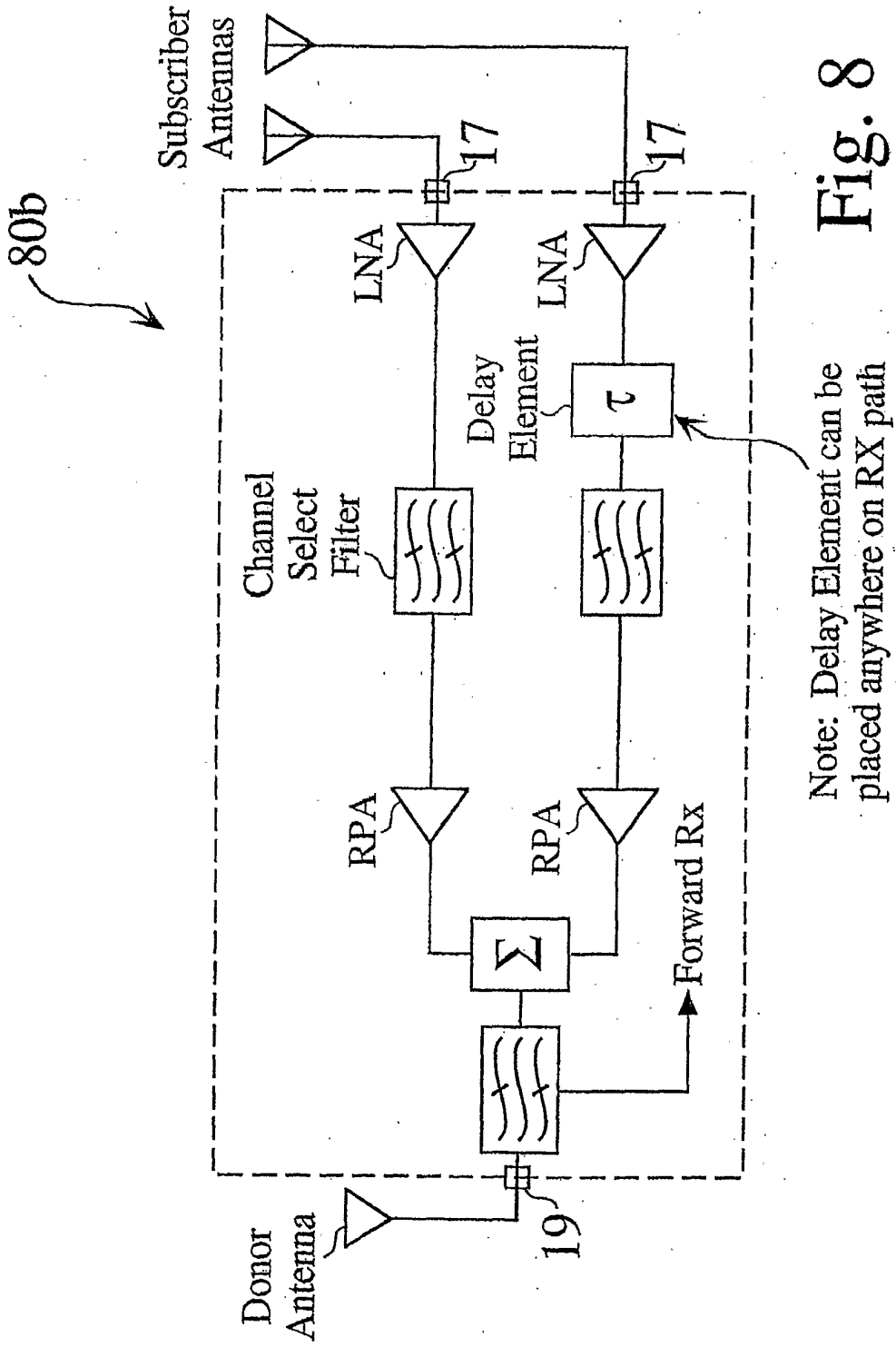

80b
Subscriber Antennas
17
17
LNA
LNA
Delay Element
τ
Channel Select Filter
RPA
RPA
Σ
Forward Rx
Donor Antenna
19
Note: Delay Element can be placed anywhere on RX path prior to Combiner

Fig. 8

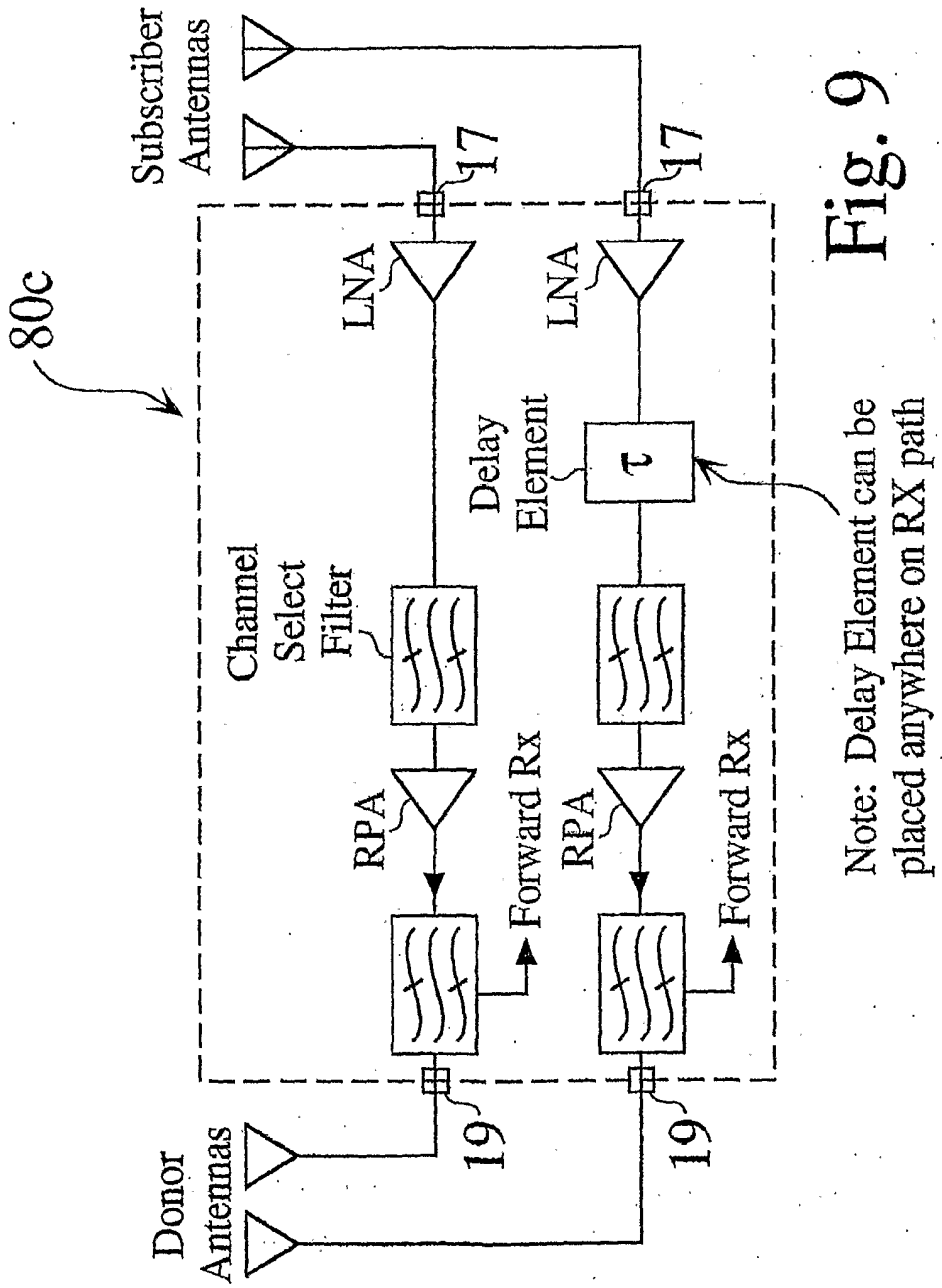

80c
Subscriber Antennas
17
17
LNA
LNA
Delay Element
τ
Channel Select Filter
RPA
RPA
Forward Rx
Forward Rx
Note: Delay Element can be placed anywhere on RX path
19
19
Donor Antennas

Fig. 9

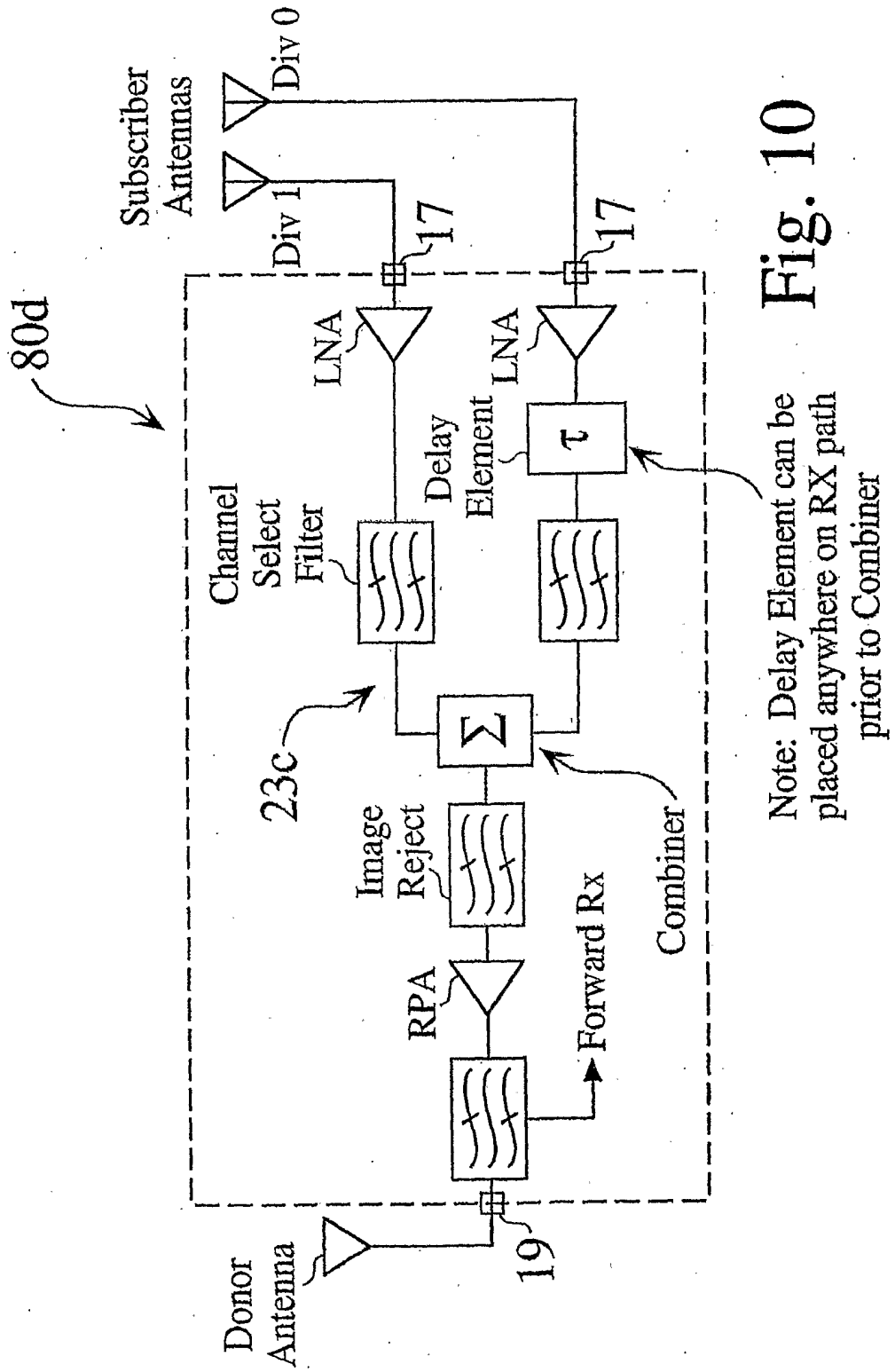

80d
Subscriber Antennas
Div 0
Div 1
17
17
LNA
LNA
Delay Element
τ
Channel Select Filter
23c
Σ
Image Reject
RPA
Forward Rx
Combiner
Donor Antenna
19
Note: Delay Element can be placed anywhere on RX path prior to Combiner

Fig. 10

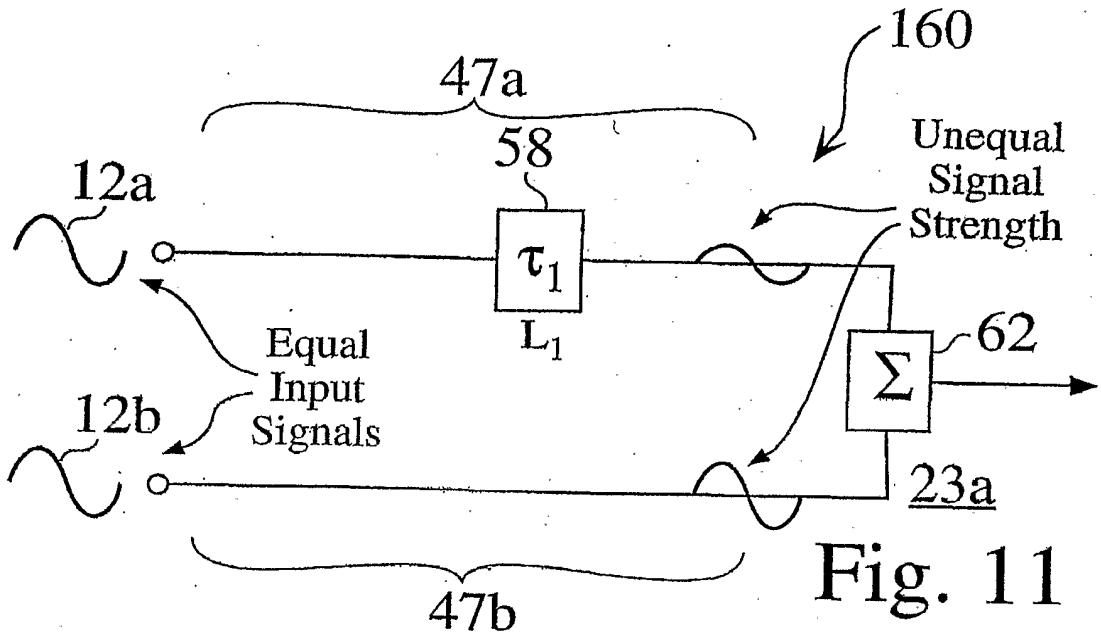

160
47a
58
Unequal
Signal
Strength
12a
τ_1
L_1
62
Equal
Input
Signals
12b
Σ
23a
47b

Fig. 11

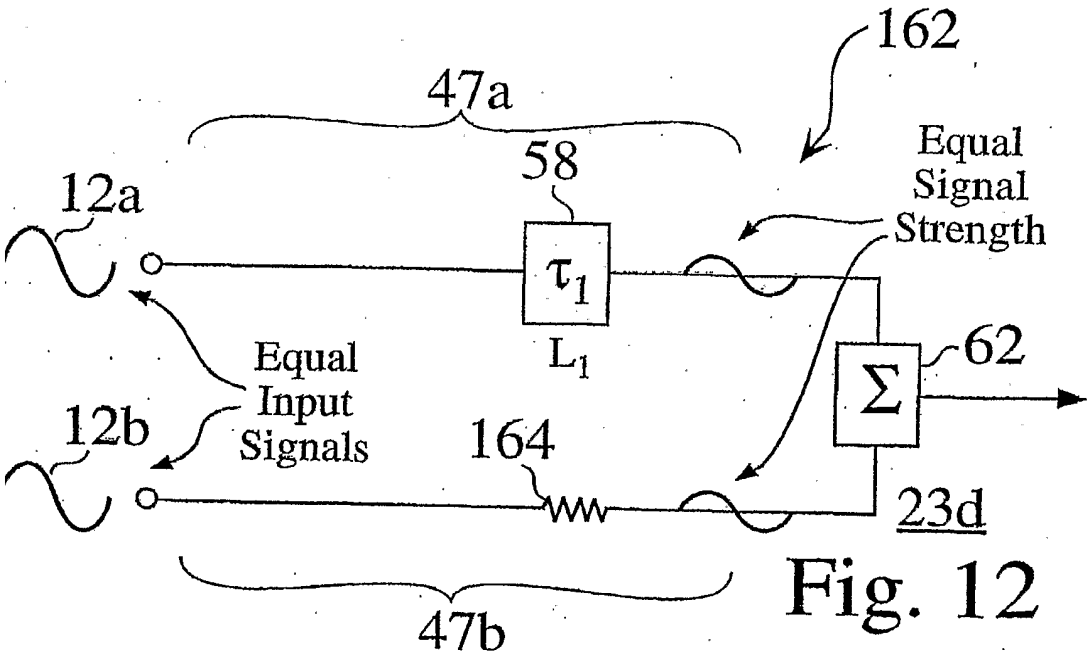

162
47a
58
Equal
Signal
Strength
12a
τ_1
L_1
62
Equal
Input
Signals
12b
164
Σ
23d
47b

Fig. 12

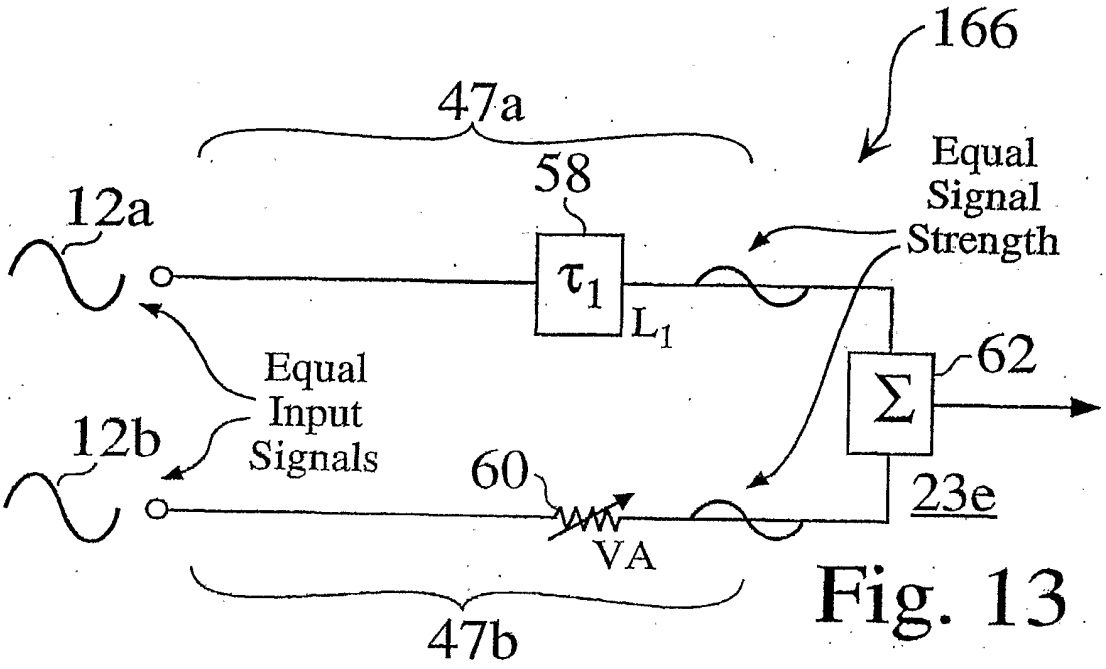

166
47a
58
Equal
Signal
Strength
12a
τ_1
L_1
62
Σ
Equal
Input
Signals
12b
60
VA
23e
47b

Fig. 13

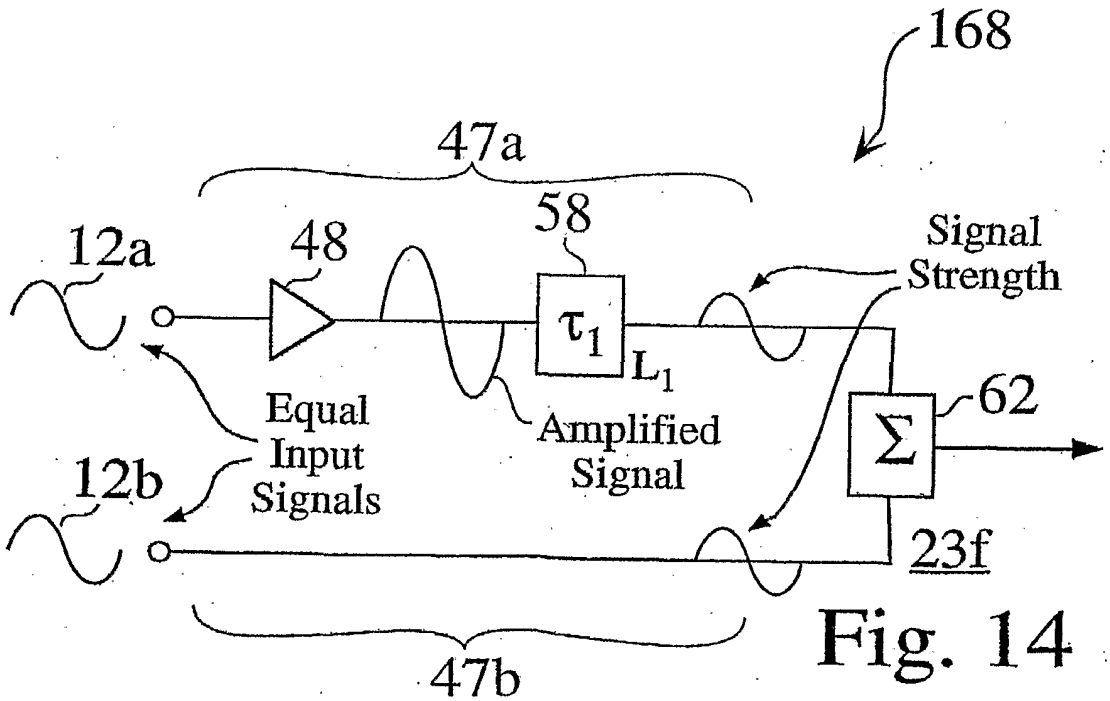

168
47a
58
Signal
Strength
12a
48
τ_1
L_1
62
Σ
Equal
Input
Signals
Amplified
Signal
12b
23f
47b

Fig. 14

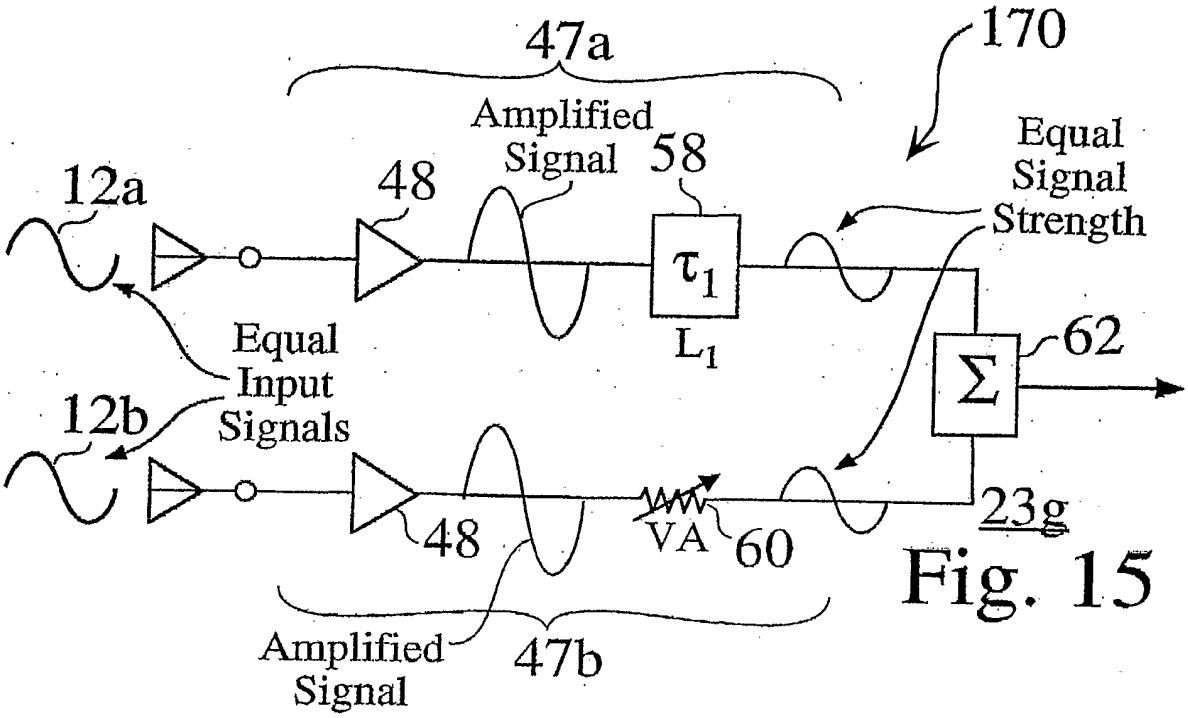

47a
170
Amplified
Signal
58
Equal
Signal
Strength
12a
48
τ_1
L_1
62
Equal
Input
Signals
12b
Σ
23g
48
VA
60
Amplified
Signal
47b

Fig. 15

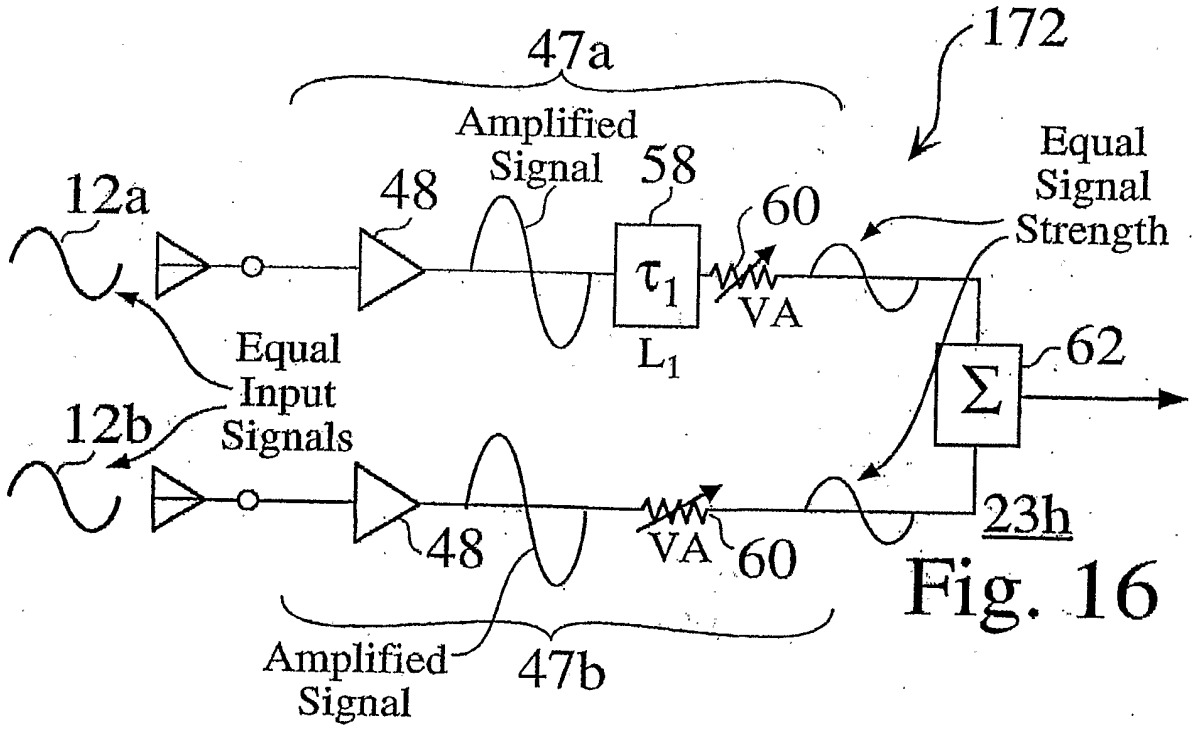

47a
172
Amplified
Signal
58
Equal
Signal
Strength
12a
48
60
τ_1
VA
L_1
62
Equal
Input
Signals
12b
Σ
23h
48
VA
60
Amplified
Signal
47b

Fig. 16

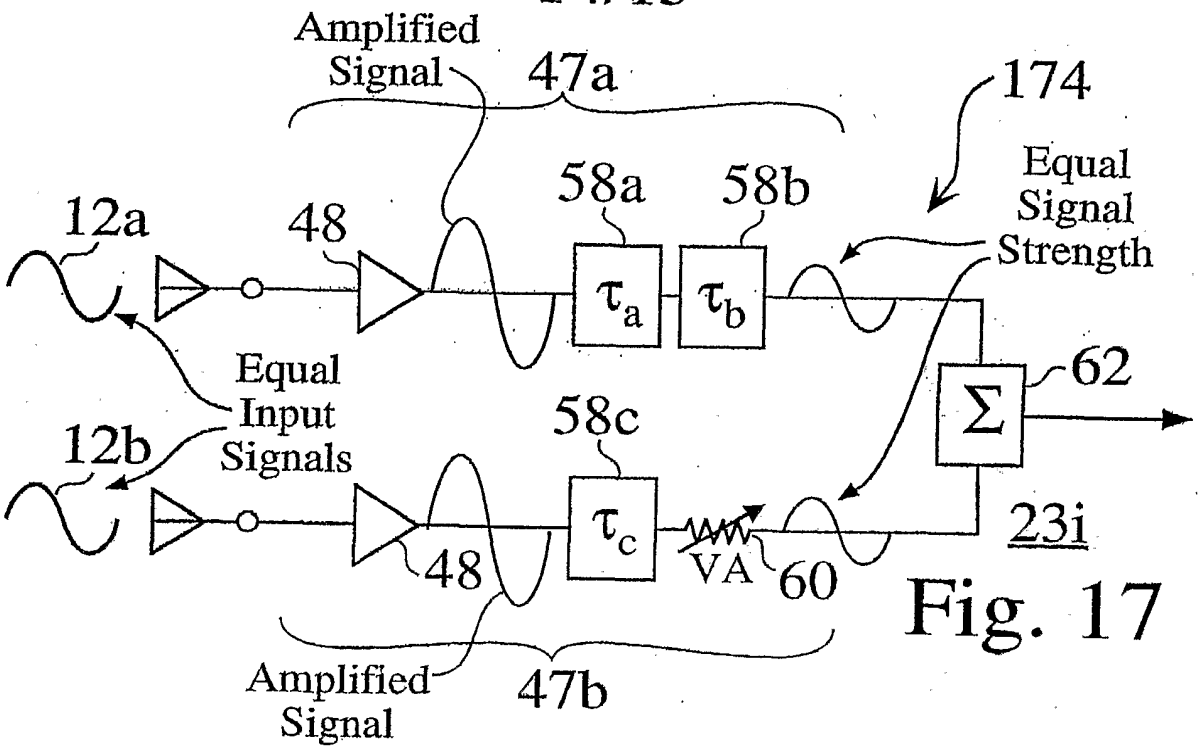

Amplified Signal
47a
174
Equal Signal Strength
58a
58b
12a
48
τ_a
τ_b
Equal Input Signals
62
Σ
58c
12b
τ_c
VA
60
23i
48
Amplified Signal
47b

Fig. 17

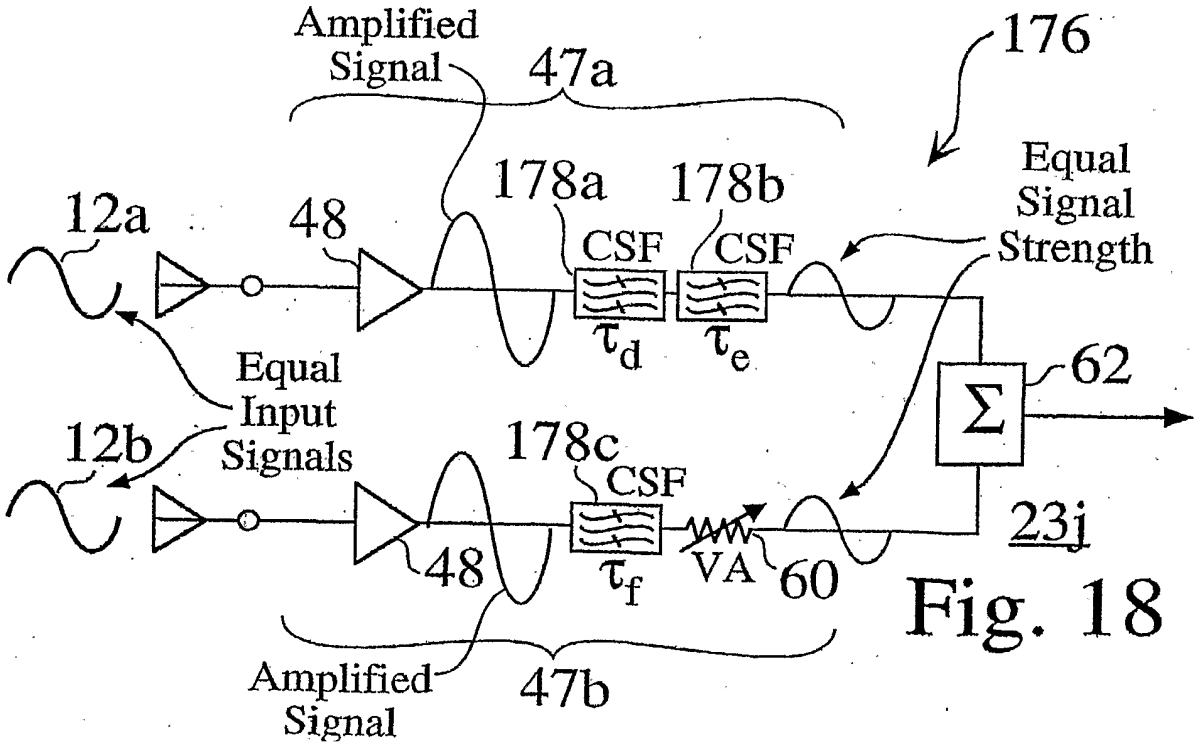

Amplified Signal
47a
176
Equal Signal Strength
178a
178b
12a
48
CSF
CSF
τ_d
τ_e
Equal Input Signals
62
Σ
178c
12b
CSF
τ_f
VA
60
23j
48
Amplified Signal
47b

Fig. 18

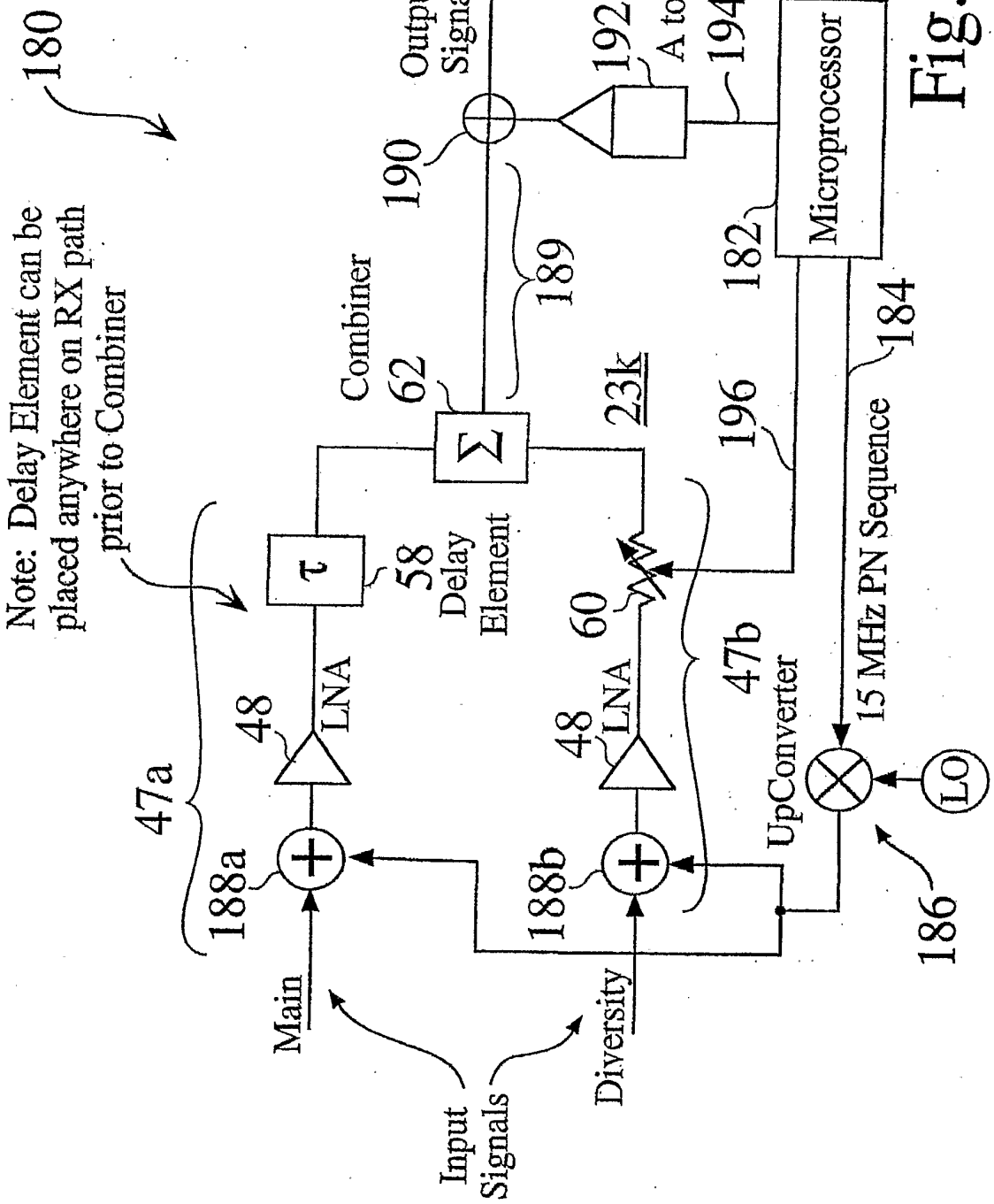

180
Note: Delay Element can be placed anywhere on RX path prior to Combiner
47a
188a
188b
47b
48
LNA
48
LNA
τ
58
Delay Element
60
Σ
62
Combiner
23k
Main
Diversity
Input Signals
UpConverter
LO
186
15 MHz PN Sequence
184
196
189
190
Output Signal
192
A to D
194
Microprocessor
182

Fig. 19