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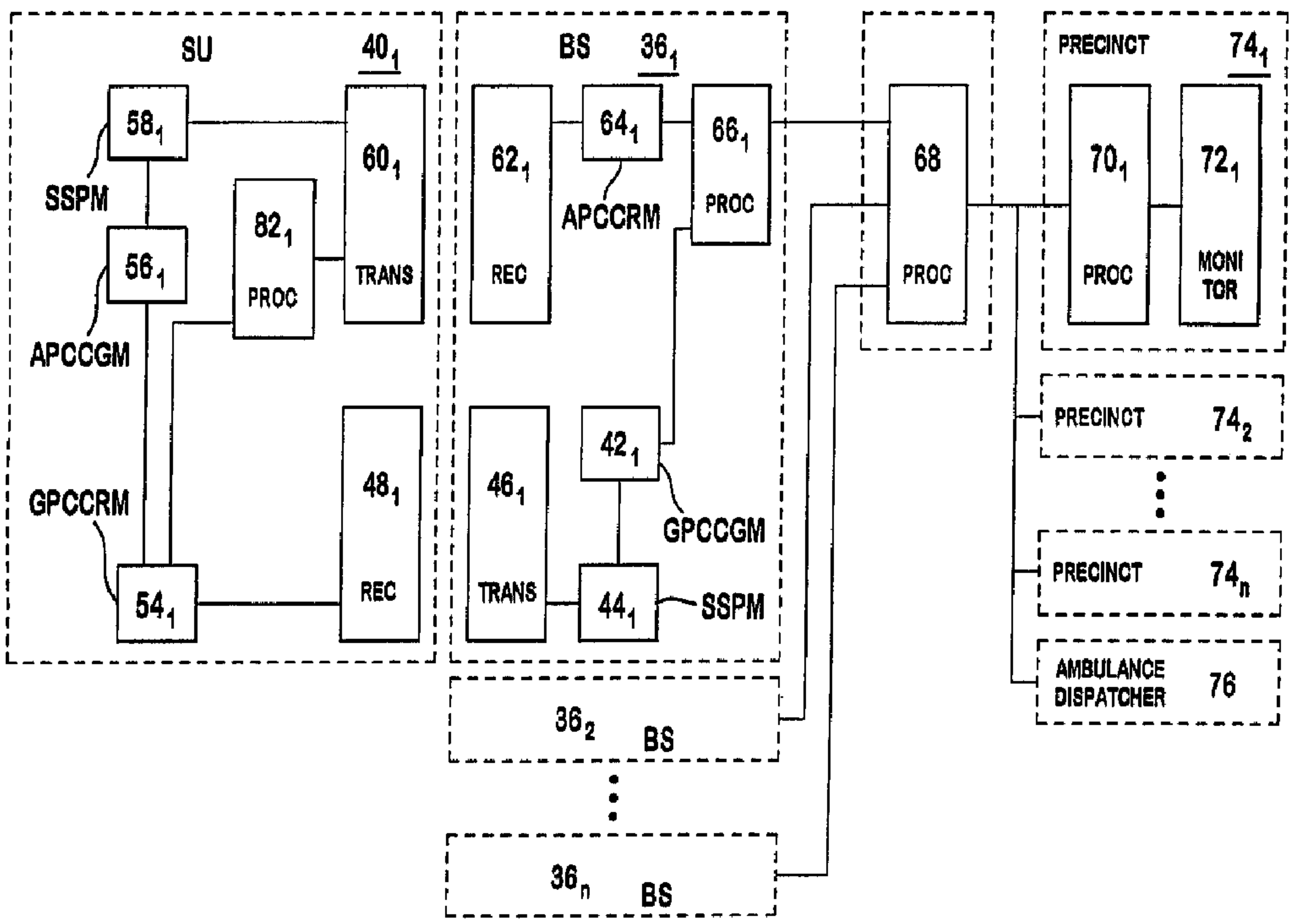
(72) Inventeur/Inventor:
MESECHER, DAVID K., US

(73) Propriétaire/Owner:
INTERDIGITAL TECHNOLOGY CORPORATION, US

(74) Agent: RIDOUT & MAYBEE LLP

(54) Titre : PROCEDE ET SYSTEME DE LOCALISATION D'UN ABONNE MOBILE DANS UN SYSTEME DE TELECOMMUNICATIONS AMDC
(54) Title: METHOD AND SYSTEM FOR LOCATING A MOBILE SUBSCRIBER IN A CDMA COMMUNICATION SYSTEM



(57) Abrégé/Abstract:
The invention determines the geographic location of a subscriber unit within a CDMA communication system. At least one base station transmits a spread spectrum signal with a chip code sequence unique to that base station. A subscriber unit receives the

(57) Abrégé(suite)/Abstract(continued):
base station signal and transmits a spread spectrum signal with a unique chip code sequence time synchronized with the chip code sequence of the received base station signal. The base station receives the subscriber unit signal and compares the chip code sequence of the received subscriber unit signal with the chip code sequence signal transmitted by the base station to determine the location of the subscriber unit.

ABSTRACT

The invention determines the geographic location of a subscriber unit within a CDMA communication system. At least one base station transmits a spread spectrum signal with a chip code sequence unique to that base station. A subscriber unit receives the base station signal and transmits a spread spectrum signal with a unique chip code sequence time synchronized with the chip code sequence of the received base station signal. The base station receives the subscriber unit signal and compares the chip code sequence of the received subscriber unit signal with the chip code sequence signal transmitted by the base station to determine the location of the subscriber unit.

TITLE OF THE INVENTION

METHOD AND SYSTEM FOR LOCATING A MOBILE SUBSCRIBER IN A CDMA COMMUNICATION SYSTEM

This application is a divisional of Canadian patent application Serial No. 2,367,572 filed internationally on September 3, 1999 and entered nationally on September 21, 2001.

BACKGROUND OF THE INVENTION

Field of the Invention

This invention generally relates to spread spectrum code division multiple access (CDMA) communication systems. More particularly, the present invention relates to a system and method that determines the geographic location of a subscriber unit within a CDMA communication system.

Description of the Prior Art

Wireless systems capable of locating a subscriber are presently known in the art. One wireless technique uses the global positioning system (GPS). In GPS, the communication handset receives data transmitted continuously from the 24 NAVSTAR satellites. Each satellite transmits data indicating the satellite's identity, the location of the satellite and the time the message was sent. The handset compares the time each signal was received with the time it was sent to determine the distance to each satellite. Using the determined distances between the satellites and the handset along with the location of each satellite, the handset can triangulate its location and provide the information to a communication base station. However, the incorporation of a GPS within a subscriber unit increases its cost.

Another subscriber location technique is disclosed in U.S. Patent No. 5,732,354. A mobile telephone using time division multiple access (TDMA) as the air interface is located within a plurality of base stations. The mobile telephone measures the received signal strength from each of the base stations and transmits each strength to each respective base station. At a mobile switching center, the received signal strengths from the base stations are compared and processed. The result yields the distance between the mobile telephone and each base station. From these distances, the location of the mobile telephone is calculated.

Wireless communication systems using spread spectrum modulation techniques are increasing in popularity. In code division multiple access (CDMA) systems, data is transmitted using a wide bandwidth (spread spectrum) by modulating the data with a pseudo random chip code sequence. The advantage gained is that CDMA systems are more resistant to signal distortion and interfering frequencies in the transmission path than communication systems using the more common time division multiple access (TDMA) or frequency division multiple access (FDMA) techniques.

EP 0 865 223 A2 is a position estimation scheme for a cellular mobile system. A first and a second signal sequence are exchanged between the mobile station and the base station. These signals may be CDMA signals. A phase difference between the first and second sequence is used to determine a distance between the mobile and base station. Using multiple base stations, the position is estimated using triangulation.

U.S. Patent No. 5,600,706 is a position system using a range determination in a CDMA system. The system uses pilot signals and time difference of arrival (TDOA) and absolute time of arrival (TOA) in the position determination.

WO 98/18018 discloses locating a mobile terminal using two antennas of an array in a time division multiple access communication system. A phase difference in the signals received by the two antennas is used to determine an angle from the centerline of the antennas to the mobile terminal. Received signal strength is used to estimate the terminal's distance. The terminal's location is determined using the determined angle and distance.

WO 97/47148 discloses determining a position of a mobile terminal within a cellular system. A signal is transmitted at a low power level. The power level is temporarily increased. The signal transmitted at the increased power level is used to make a position measurement of the terminal.

U.S. Patent No. 5,736,964 discloses a CDMA system for locating a communication unit. A base station transmits a location request to the unit. The unit transmits a receive time of the message to the base station. A group of base stations also determine a receive time of a symbol sequence in the unit's transmissions. Using the time measurements, the location of the unit is determined.

U.S. Patent No. 5,506,864 discloses a system for determining a distance between a base station and a remote unit in a CDMA system. The base station transmits a base CDMA signal to the remote unit. The remote unit transmits a remote CDMA signal to the base station. The remote CDMA signal has its timing synchronized to the received base CDMA signal. The base station determines the distance to the remote unit by comparing the chip code sequences of the transmitted base CDMA signal and the received remote CDMA signal.

There exists a need for an accurate mobile subscriber unit location system that uses data already available in an existing CDMA communication system.

SUMMARY OF THE INVENTION

A subscriber unit is geographically located using a plurality of base stations in a wireless CDMA communication system. Each base station transmits a first spread spectrum signal having a first code. For each received first signal, the subscriber unit transmits a second spread spectrum signal having a second code. The second spread spectrum signal is time synchronized with its received first signal. An impulse response of each received first signal is analyzed to determine a first received component. At each base station, an impulse response of that base station's received second signal is analyzed to determine a first received component. A distance between each base station and the subscriber unit is determined. The distance determination is based on in part a timing difference between the received signal and the transmitted signal and the determined first received component for the second signals. The location of the subscriber unit is based on in part the determined distances, a fixed location of each base station and a maximum likelihood estimation.

According to an embodiment of the present disclosure there is provided a base station comprising a plurality of antennas, each of the antennas separated by a known distance; means for transmitting a first spread spectrum signal having a first code; means for receiving, using the plurality of antennas, a second spread spectrum signal having a second code, the second spread spectrum signal time synchronized with the first spread spectrum signal; means for making a distance determination based on in part a timing difference between the second code and the first code; means for comparing a phase difference of a carrier signal of the second spread spectrum signal as received by each of the plurality of antennas; means for determining an angle of the second spread spectrum signal using the known distance between the antennas and the phase difference; means for determining a location of a source of the second spread spectrum signal using the determined angle and the distance determination; and means for analyzing an impulse response of multipath components of the second spread spectrum signal to determine a first received component of the second spread spectrum signal, wherein the determined first received component is used to make the distance determination

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is an illustration of a simplified, prior art CDMA system.

Figure 2 is an illustration of a prior art CDMA system.

Figure 3 is a block diagram of major components within a prior art CDMA system.

Figure 4 is a block diagram of components within a prior art CDMA system.

Figure 5 is an illustration of a global pilot signal and an assigned pilot signal being communicated between a base station and a subscriber unit.

Figure 6 is a block diagram of a first embodiment of the present invention using at least three base stations.

Figure 7 is an illustration of locating a subscriber unit using the first embodiment of the present invention with at least three base stations.

Figure 8 is a block diagram of a second embodiment of the present invention showing components used in a subscriber unit.

Figure 9 is an illustration of locating a subscriber unit using the second embodiment of the present invention with two base stations.

Figure 10 is an illustration of locating a subscriber unit using the second embodiment of the present invention with more than two base stations.

Figure 11 is a detailed illustration of the third embodiment of the present invention having a base station with multiple antennas.

Figure 12 is an illustration of the third embodiment having a base station with multiple antennas.

Figure 13 is a block diagram of components used in the third embodiment.

Figure 14 is an illustration of multipath.

Figure 15 is a graph of a typical impulse response of multipath components.

Figure 16 is a block diagram of components within a fourth embodiment correcting for multipath.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The preferred embodiments will be described with reference to the drawing figures where like numerals represent like elements throughout.

Shown in **Figure 1** is a simplified CDMA communication system. A data signal with a given bandwidth is mixed with a spreading code generated by a pseudo random chip code sequence generator producing a digital spread spectrum signal. Upon reception, the data is reproduced after correlation with the same pseudo random chip code sequence used to transmit the data. Every other signal within the transmission bandwidth appears as noise to the signal being despread.

For timing synchronization with a receiver, an unmodulated pilot signal is required for every transmitter. The pilot signal allows respective receivers to synchronize with a given transmitter, allowing despreading of a traffic signal at the receiver.

In a typical CDMA system, base stations send global pilot signals to all subscriber units within their communicating range to synchronize transmissions in a forward direction. Additionally, in some CDMA systems, for example a B-CDMA™ system, each subscriber unit sends a unique assigned pilot signal to synchronize transmissions in a reverse direction.

Figure 2 illustrates a CDMA communication system **30**. The communication system **30** comprises a plurality of base stations $\mathbf{36_1}$, $\mathbf{36_2}$ ... $\mathbf{36_n}$. Each base station $\mathbf{36_1}$, $\mathbf{36_2}$ ... $\mathbf{36_n}$ is in wireless communication with a plurality of subscriber units $\mathbf{40_1}$, $\mathbf{40_2}$ ... $\mathbf{40_n}$, which may be fixed or mobile. Each subscriber unit $\mathbf{40_1}$, $\mathbf{40_2}$ ... $\mathbf{40_n}$ communicates with either the closest base station $\mathbf{36_1}$ or the base station $\mathbf{36_1}$ which provides the strongest communication signal. Each base station $\mathbf{36_1}$, $\mathbf{36_2}$ ... $\mathbf{36_n}$ is in communication with other components within the communication system **30** as shown in **Figure 3**.

A local exchange **32** is at the center of the communications system **30** and communicates with a plurality of network interface units (NIUs) $\mathbf{34_1}$, $\mathbf{34_2}$ ... $\mathbf{34_n}$. Each NIU is in communication with a plurality of radio carrier stations (RCS) $\mathbf{38_1}$, $\mathbf{38_2}$ ... $\mathbf{38_n}$ or base stations $\mathbf{36_1}$, $\mathbf{36_2}$ ... $\mathbf{36_n}$. Each (RCS) $\mathbf{38_1}$, $\mathbf{38_2}$ ... $\mathbf{38_n}$ or base station $\mathbf{36_1}$, $\mathbf{36_2}$ ... $\mathbf{36_n}$ communicates with a plurality of subscriber units $\mathbf{40_1}$, $\mathbf{40_2}$ ... $\mathbf{40_n}$ within its communicating range.

Figure 4 depicts a block diagram of the pertinent parts of an existing spread spectrum CDMA communication system. Each independent base station **36_1**, **36_2** ... **36_n** generates a unique global pilot signal using a global pilot chip code generating means **42_1** and spread spectrum processing means **44_1**. The global pilot chip code generating means **42_1** generates a unique pseudo random chip code sequence. The unique pseudo random chip code sequence is used to spread the resultant signals bandwidth such as to 15 MHZ as used in the B-CDMA™ air interface. The spread spectrum processing means modulates the global pilot chip code sequence up to a desired center frequency. The global pilot signal is transmitted to all subscriber units **40_1** by the base station's transmitter **46_1**.

A receiver **48_1** at a subscriber unit **40_1** receives available signals from a plurality of base stations **36_1**, **36_2** ... **36_n**. As shown in **Figure 5**, the global pilot **50_1** travels from the base station **36_1** to the subscriber unit **40_1** and can be represented as:

$$\tau_1 = \frac{d_1}{c}. \qquad \textbf{Equation (1)}$$

The time the signal travels from the base station **36_1** to the subscriber unit **40_1**, τ_1, equals the distance between the base station **36_1** and subscriber unit **40_1**, d_1, divided by the speed of light, **c**.

Referring back to **Figure 4**, a global pilot chip code recovery means **54_1** within the subscriber unit **40_1** can receive global pilot chip code sequences from a plurality of base stations **36_1**, **36_2** ... **36_n**. The subscriber unit **40_1** generates a replica of a global pilot chip code sequence and synchronizes the generated replica's timing with the received global pilot **50_1**. The subscriber unit **40_1** also has a processor **82_1** to perform the many analysis functions of the subscriber unit **40_1**.

The subscriber unit $\mathbf{40_1}$ generates an assigned pilot signal $\mathbf{52_1}$ using assigned pilot chip code generating means $\mathbf{56_1}$ and spread spectrum processing means $\mathbf{58_1}$. The assigned pilot chip code generating means $\mathbf{56_1}$ generates a pseudo random chip code sequence with its timing synchronized with the recovered global pilot chip code sequence. As a result, the assigned pilot chip code sequence is delayed by τ_1 with respect to the base station $\mathbf{36_1}$, $\mathbf{36_2}$ ... $\mathbf{36_n}$. The spread spectrum processing means $\mathbf{58_1}$ generates the assigned pilot signal $\mathbf{52_1}$ by modulating the assigned pilot chip code sequence up to a desired center frequency. The assigned pilot signal $\mathbf{52_1}$ is transmitted to all base stations $\mathbf{36_1}$, $\mathbf{36_2}$ ... $\mathbf{36_n}$ within range to receive the assigned pilot signal $\mathbf{52_1}$.

The base station $\mathbf{36_1}$ receives the assigned pilot signal $\mathbf{52_1}$ with the base station's receiver $\mathbf{62_1}$. The received assigned pilot $\mathbf{52_1}$ travels the same distance d_1 as the global pilot signal $\mathbf{50_1}$ as shown in **Figure 5**. Accordingly, the received assigned pilot signal will be delayed by τ_1 with respect to the mobile unit $\mathbf{40_1}$ and by $2\tau_1$ with respect to the global pilot $\mathbf{50_1}$ generated at the base station $\mathbf{36_1}$.

Since the chip code sequence of the assigned pilot $\mathbf{52_1}$ received at the base station $\mathbf{36_1}$ will be delayed by $2\tau_1$ with respect to the chip code sequence of the global pilot signal $\mathbf{50_1}$ generated at the base station $\mathbf{36_1}$, the round trip propagation delay, $2\tau_1$, can be determined by comparing the timing of the two chip code sequences. Using the round trip propagation delay, $2\tau_1$, the distance d_1 between the base station $\mathbf{36_1}$ and subscriber unit $\mathbf{40_1}$ can be determined by:

$$d_1 = c \cdot \frac{2\tau_1}{2} \qquad \textbf{Equation (2)}$$

If a spreading sequence having a chipping rate of at least 80ns is used and the communication system has the ability to track 1/16th of a chip, the distance d_1 can be measured to within 2 meters.

Figure 6 is a block diagram of a first embodiment of the present invention. No additional hardware is required in the subscriber unit $\mathbf{40_1}$. The only changes are implemented by software within the subscriber unit's processor $\mathbf{82_1}$ and the processors $\mathbf{66_1}$, $\mathbf{66_2}$ ... $\mathbf{66_n}$, **68**, $\mathbf{70_1}$, $\mathbf{70_2}$ ... $\mathbf{70_n}$ located within the base station $\mathbf{36_1}$, NIU $\mathbf{34_1}$ or Local Exchange $\mathbf{32_1}$, Precincts $\mathbf{74_1}$, $\mathbf{74_2}$ ... $\mathbf{74_n}$ and Ambulance Dispatcher **76**.

The subscriber unit $\mathbf{40_1}$ is sent a signal by a base station $\mathbf{36_1}$ indicating that a 911 call was initiated and to begin the subscriber location protocol. Upon receipt, the subscriber unit $\mathbf{40_1}$ will sequentially synchronize its transmission chip code sequence to at least three base stations' chip code sequences. To allow reception by the base stations $\mathbf{36_2}$, $\mathbf{36_3}$ ... $\mathbf{36_n}$ outside of the subscriber unit's normal communicating range, these transmissions will be sent at a higher than normal power level temporarily over-riding any adaptive power control algorithms.

A processor $\mathbf{66_1}$ within each base station $\mathbf{36_1}$, $\mathbf{36_2}$ ... $\mathbf{36_n}$ is coupled to the assigned pilot chip code recovery means $\mathbf{64_1}$ and the global pilot chip code generator $\mathbf{42_1}$. The processor $\mathbf{66_1}$ compares the two chip code sequences to determine the round trip propagation delay τ_1, τ_2 ... τ_n and the respective distance d_1, d_2 ... d_n between the subscriber unit $\mathbf{40_1}$ and the respective base station **36_1, 36_2 ... 36_n**. Within either a NIU **34_1** or the local exchange **32**, a processor **68** receives the distances d_1, d_2 ... d_n from the processors **66_1, 66_2 ... 66_n** within all the base stations **36_1, 36_2 ... 36_n**. The processor **68** uses the distances d_1, d_2 ... d_n to determine the location of the subscriber unit **40_1** as follows.

By using the known longitude and latitude from three base stations **36_1, 36_2, 36_3** and distances d_1, d_2, d_3, the location of the subscriber unit **40_1** is determined. As shown in **Figure 7** by using the three distances d_1, d_2, d_3, three circles **78_1, 78_2, 78_3** with radiae **80_1, 80_2, 80_3** are constructed. Each circle **78_1, 78_2, 78_3** is centered around a respective base station **36_1, 36_2, 36_3**. The intersection of the three circles **78_1, 78_2, 78_3** is at the location of the subscriber unit **40_1**.

Using the Cartesian coordinates, the longitude and latitude corresponding with each base station **36_1, 36_2 ... 36_n** is represented as X_n, Y_n, where X_n is the longitude and Y_n is the latitude. If X, Y represents the location of the subscriber unit **40_1**, using the distance formula the following equations result:

$$(X_1-X)^2 + (Y_1-Y)^2 = d_1^2 \qquad \textbf{Equation (3)}$$

$$(X_2-X)^2 + (Y_2-Y)^2 = d_2^2 \qquad \textbf{Equation (4)}$$

$$(X_3-X)^2 + (Y_3-Y)^2 = d_3^2 \qquad \textbf{Equation (5)}$$

In practice due to small errors in calculating the distances d_1, d_2, d_3, **Equations 3**, **4** and **5** cannot be solved using conventional algebra. To compensate for the errors, a maximum likelihood estimation is used to determine the location and are well known to those skilled in the art. For increased accuracy, additional base stations **36_4, 36_5 ... 36_n** can be used to calculate additional distances for inclusion in the estimation analysis.

The subscriber unit's location is sent through the communication system **30** to at least one precinct **74_1, 74_2 ... 74_n** and an ambulance dispatcher **76**. A processor **70_1** within each precinct **74_1, 74_2 ... 74_n** and the ambulance dispatcher **76** receives the location of all 911 calls originating in the system and displays the location on a conventional computer monitor **72_1**. The display comprises a listing of all 911 calls and addresses on a geographic map.

An alternate approach reduces the number of processors by transmitting raw data through the communication system **30** and processing the raw data at a single site.

Figure 8 is a second embodiment of a location system. At least two base stations **36_1, 36_2 ... 36_n** have their internal timing synchronized with each other and transmit their respective global pilot signals **52_1, 52_2 ... 52_n** with time synchronized chip code sequences. The subscriber unit. **40_1** receives the global pilots **52_1, 52_2 ... 52_n**. However, the received global pilots **52_1, 52_2 ... 52_n** are not synchronized. The global pilot **52_1** from a first base station **36_1** will travel distance d_1 and is delayed by T_1. The global pilot **52_2** from a second base station **36_2** travels distance d_2 and is delayed by T_2. The subscriber unit **40_1** recovers each base station's global pilot chip code sequence with its global pilot chip code recovery means **54_1**. A processor **82_1** within the subscriber unit **40_1** is coupled to each global pilot chip code recovery means **54_1, 54_2 ... 54_n**. The processor **82_1** compares the chip code sequences of each pair of pilot chip code sequences and calculates the time differences Δt_1, Δt_2 ... Δt_n between the sequences as follows.

Within the subscriber unit **40_1**, the chip code sequences used by each base station **36_1**, **36_2** ... **36_n** are stored. After synchronizing with the first base station's pilot **36_1**, the processor **82_1** will store where within the sequence synchronization was obtained. This process is repeated for the other base stations **36_2**, **36_3** ... **36_n**. The synchronization process can be done sequentially (synchronizing to the first base station's chip code sequence then the second, etc.) or in parallel (synchronizing to all base stations at the same time).

By using the relative time difference between τ_1, τ_2, ... τ_n each base station's chip code sequence and knowing that each base station's pilot was sent at the same time, with two base stations the time differences are calculated as follows:

$$\Delta t_1 = \tau_2 - \tau_1 \qquad \textbf{Equation (6)}$$

$$\Delta t_2 = \tau_3 - \tau_2 \qquad \textbf{Equation (7)}$$

The time differences Δt_1, Δt_2 ... Δt_n are transmitted to at least one of the base stations **36_1**.

At least one base station **36_1** recovers the time difference data from the received signals using time difference recovery means **84_1**. The time difference data is sent with the distance data d_1 through the communications system to a processor **68**. The processor 68 determines the location of the subscriber unit **40_1** using the time difference data Δt_1, Δt_2 ... Δt_n and the distance data d_1, d_2 ... d_n as follows.

Using information from only two base stations **36_1, 36_2** as shown in **Figure 9**, the processor uses distances ***d_1, d_2*** to create two circles **78_1, 78_2**. Using the time difference, **Δt_1**, a hyperbola **86_1** can be constructed as follows.

All the points along the hyperbola **86_1** receive the global pilot signals **52_1, 52_2** from the synchronized base stations **36_1, 36_2** with the same time difference, **Δt_1**. The time difference **Δt_1** can be converted to a distance difference **Δd_1** by substituting **Δt_1** for ***t_1*** and **Δd_1** for ***d_1*** in **Equation 1**. Using the distance formula and **X, Y** as the location of the subscriber unit **40_1**, the following equation results:

Equation (8)

$$\Delta d_1 = \sqrt{(X_1 - X)^2 + (Y_1 - Y)^2} - \sqrt{(X_2 - X)^2 + (Y_2 - Y)^2}$$

By using **Equation 8** with **Equations 3** and **4** in a maximum likelihood estimation, the location of the subscriber unit **40_1** can be determined. The subscriber unit's location is subsequently sent to the nearest police precinct **74_1, 74_2 ... 74_n** and ambulance dispatcher **76** in the cellular area.

For improved accuracy, additional base stations **36_1, 36_2 ... 36_n** are used. **Figure 10** shows the invention used with three base stations **36_1, 36_2, 36_3**. The distances ***d_1, d_2, d_3*** are used to create three circles **78_1, 78_2, 78_3**. Using time differences **Δt_1, Δt_2**, two intersecting hyperbolas **86_1, 86_2** are constructed. With maximum likelihood estimation, the subscriber units' location calculated with two hyperbolas $\mathbf{86_1}$, $\mathbf{86_2}$, and three circles $\mathbf{78_1}$, $\mathbf{78_2}$, $\mathbf{78_3}$ yields greater accuracy.

As shown in **Figure 8**, the subscriber unit $\mathbf{40_1}$ is required to process each global pilot chip code sequence to determine the time differences $\mathbf{\Delta t_1}$, $\mathbf{\Delta t_2}$ ... $\mathbf{\Delta t_n}$. An alternate approach removes the processing from the subscriber unit $\mathbf{40_1}$.

With reference to **Figure 6**, the mobile unit $\mathbf{40_1}$ will synchronize the assigned pilot to one of the base station's global pilot chip code sequences, such as the nearest base station $\mathbf{36_1}$ with a delay of τ_1. The assigned pilot $\mathbf{50_1}$ is transmitted to all base stations $\mathbf{36_1}$, $\mathbf{36_2}$ ... $\mathbf{36_n}$. The assigned pilot $\mathbf{50_1}$ will be received at each base station with a respective delay, $\tau_1 + \tau_1$, $\tau_1 + \tau_2$, $\tau_1 + \tau_3$. Each base station $\mathbf{36_1}$, $\mathbf{36_2}$ ... $\mathbf{36_n}$ will send the delayed chip code sequence along with the calculated distance to a processor **68** located in a NIU $\mathbf{34_1}$ or local exchange **32**. The processor **68** will calculate the time differences $\mathbf{\Delta t_1}$, $\mathbf{\Delta t_2}$ ... $\mathbf{\Delta t_n}$ by comparing the received assigned pilot chip code sequences. Since all received assigned pilot chip code sequences are delayed by τ_1, the τ_1 delay will cancel out of the resultant time differences $\mathbf{\Delta t_1}$, $\mathbf{\Delta t_2}$ ... $\mathbf{\Delta t_n}$. Accordingly, the subscriber unit $\mathbf{40_1}$ can be located using hyperbolas $\mathbf{86_1}$, $\mathbf{86_2}$ as previously described.

Another embodiment shown in **Figures 11**, **12** and **13** uses a base station $\mathbf{36_1}$ with multiple antennas $\mathbf{88_1}$, $\mathbf{88_2}$ ... $\mathbf{88_n}$. Two of the antennas $\mathbf{88_1}$, $\mathbf{88_2}$ lie along a centerline **92** at a known distance, ***l***, apart as shown in **Figure 11**. Both antennas $\mathbf{88_1}$, $\mathbf{88_2}$ receive the assigned pilot signal $\mathbf{90_1}$, $\mathbf{90_2}$ from the subscriber unit $\mathbf{40_1}$. However, the antenna $\mathbf{88_2}$ further away from the subscriber unit $\mathbf{40_1}$ receives the signal over a slightly longer distance d_1' and with a slight delay with respect to the nearer antenna **88_1**. This delay results in a carrier phase difference, **φ**, between the signals received at each antenna as shown on **Figure 13**. A processor **66** using the received carrier phase difference and the chip code sequence recovered by each assigned pilot chip code recovery means **96_1**, **96_2** ... **96_n** can determine the location of the subscriber unit **40_1** as follows.

As shown in **Figure 12**, the subscriber unit **40_1** is located at distance d_1 at angle **α** from the centerline **92** of the antennas **88_1**, **88_2**. As seen at the scale of **Figure 12** both received assigned pilot signals **90_1**, **90_2** appear to be coincident. However, as shown in **Figure 11**, the received assigned pilot signals **90_1**, **90_2** are slightly separated. The received assigned pilot signal **90_1** returning to the first antenna **88_1** travels a distance d_1. The received assigned pilot signal **90_2** returning to the second antenna **88_2** travels a slightly longer distance d_1'. As shown in **Figure 11**, the difference between the two distances d_1, d_1' is a distance m.

Since the distances d_1, d_1' between the antennas **88_1**, **88_2** and the subscriber unit **40_1** are much larger than the distance l between the antennae **88_1**, **88_2** both received assigned pilot signals **90_1**, **90_2** follow approximately parallel paths. By constructing a right triangle using a point **94** which is distance d_1 from the subscriber unit **40_1** as shown in **Figure 11**, the angle ∝ can be determined by the following geometric relationship:

$$\propto = \cos^{-1}(m/l). \qquad \textbf{Equation (9)}$$

The distance m can be determined by using the carrier phase difference, **φ**, between the two received signals **90_1**, **90_2** as follows:

$$m = \frac{\phi \cdot \lambda}{2\pi}$$ **Equation (10)**

The distance ***m*** equals the phase difference between the two signals, **φ**, in radians multiplied by the wavelength of the signal, **λ**, divided by **2π**. The wavelength, **λ**, can be derived from the known frequency ***f*** of the assigned pilot signal as follows:

$$\lambda = c/f.$$

Equation (11)

The processor **68** also compares the chip code sequences of the global pilot generating means **42_1** with the recovered assigned pilot chip code sequence to determine the distance ***d_1*** as shown in **Figure 6**. Using both the angle ∝ and distance ***d_1***, the processor **66_1** locates the subscriber unit **40_1** using simple geometry. There are many techniques well known to those skilled in the art to eliminate the ambiguity between locations above and below the antennas **88_1**, **88_2**. One such technique is using antennas employing sectorization. Subsequently, the subscriber unit's location is sent to the precincts **74_1**, **74_2** ... **74_n** and ambulance dispatcher **76**. Additional antennas may be used to improve on the accuracy of the system.

An alternate embodiment uses more than one base station **36_1**, **36_2** ... **36_n**. A processor **68** located within either a NIU **34_1** or the local exchange **32** collects distance and angle information from more than one base station **36_1, 36_2 ... 36_1** as well as the time differences **Δt_1, Δt_2 ... Δt_n**, between the base stations **36_1, 36_2 ... 36_n**. Using the maximum likelihood estimation technique, the processor **68** determines a more accurate location of the subscriber unit **40_1**.

A fourth embodiment corrects for multipath. **Figure 14** illustrates multipath. A signal such as a global pilot signal is transmitted from a base station **36_1**. The signal follows a multitude of paths **98_1, 98_2 ... 98_n** between the base station **36_1** and subscriber unit **40_1**.

Figure 13 is a graph showing the impulse response **136** of the received multipath components. Since each received multipath component travels a unique path, it arrives at a receiver with a propagation delay determined by the length of the path **98_1, 98_2 ... 98_n**. The impulse response **106** shows the collective signal magnitude of all the multipath components received at each propagation delay.

The previously described subscriber unit location techniques assumed the subscriber unit **40_1** synchronizes with the line of sight multipath component **98_1** traveling distance d_1. However, if the subscriber unit synchronizes with a non-line of sight multipath component **98_1, 98_2 ... 98_n**, the distance calculation will be in error due to the delay **MD_1** as shown in **Figure 15**.

Figure 16 is a system correcting for errors resulting from multipath. The global pilot **50_1** is sent from the base station **36_1** to subscriber unit **40_1**. The subscriber unit **40_1** collects all of the multipath components using a multipath receiver **102_1** such as disclosed in U.S. Patent No. 5,796,776

Lomp et al. A processor **82_1** within the subscriber unit **40_1** analyzes the impulse response **100** of the received global pilot signal **50_1**.

Since the line of sight multipath component **98_1** travels the shortest distance d_1, the first received component **98_1** is the line of sight component. If the line of sight component is not received, the first received component **98_1** will be the closest and, accordingly, the best available estimate for the line of sight component. The processor **82_1** compares the chip code sequence of the first received component **98_1** with the chip code sequence used to synchronize the assigned pilot chip code sequence. This comparison determines the delay due to multipath, **MD_1**. The multipath delay, **MD_1**, is transmitted to the base station **36_1**.

A processor **66_1** and multipath receiver **104_1** within the base station **36_1** perform the same analysis on the received assigned pilot signal. As a result, the multipath delay, **MD_2**, of the assigned pilot signal is determined. Additionally, multipath delay recovery means **106_1** recovers the transmitted global pilot signal's multipath delay **MD_1** for use by the processor **66_1**. The processor **66_1** compares the generated global pilot chip code sequence to the recovered assigned pilot chip code sequence to determine the round trip propagation delay **$2T_1$**. To correct for multipath, the processor **66_1** subtracts both the global pilot signal's multipath delay **MD_1** and the assigned pilot signals multipath delay **MD_2** from the calculated round trip propagation delay, **$2T_1$**. The corrected round trip propagation delay is used to determine the subscriber unit's location in one of the techniques as previously described.

Although the invention has been described in part by making detailed reference to certain specific embodiments, such detail is intended to be instructive rather than restrictive. It will be appreciated by those skilled in the art that many variations may be made in the structure and mode of operation without departing from the scope of the invention as disclosed in the teachings herein.

WHAT IS CLAIMED IS:

1. A base station comprising:

a plurality of antennas, each of the antennas separated by a known distance;

means for transmitting a first spread spectrum signal having a first code;

means for receiving, using the plurality of antennas, a second spread spectrum signal having a second code, the second spread spectrum signal time synchronized with the first spread spectrum signal;

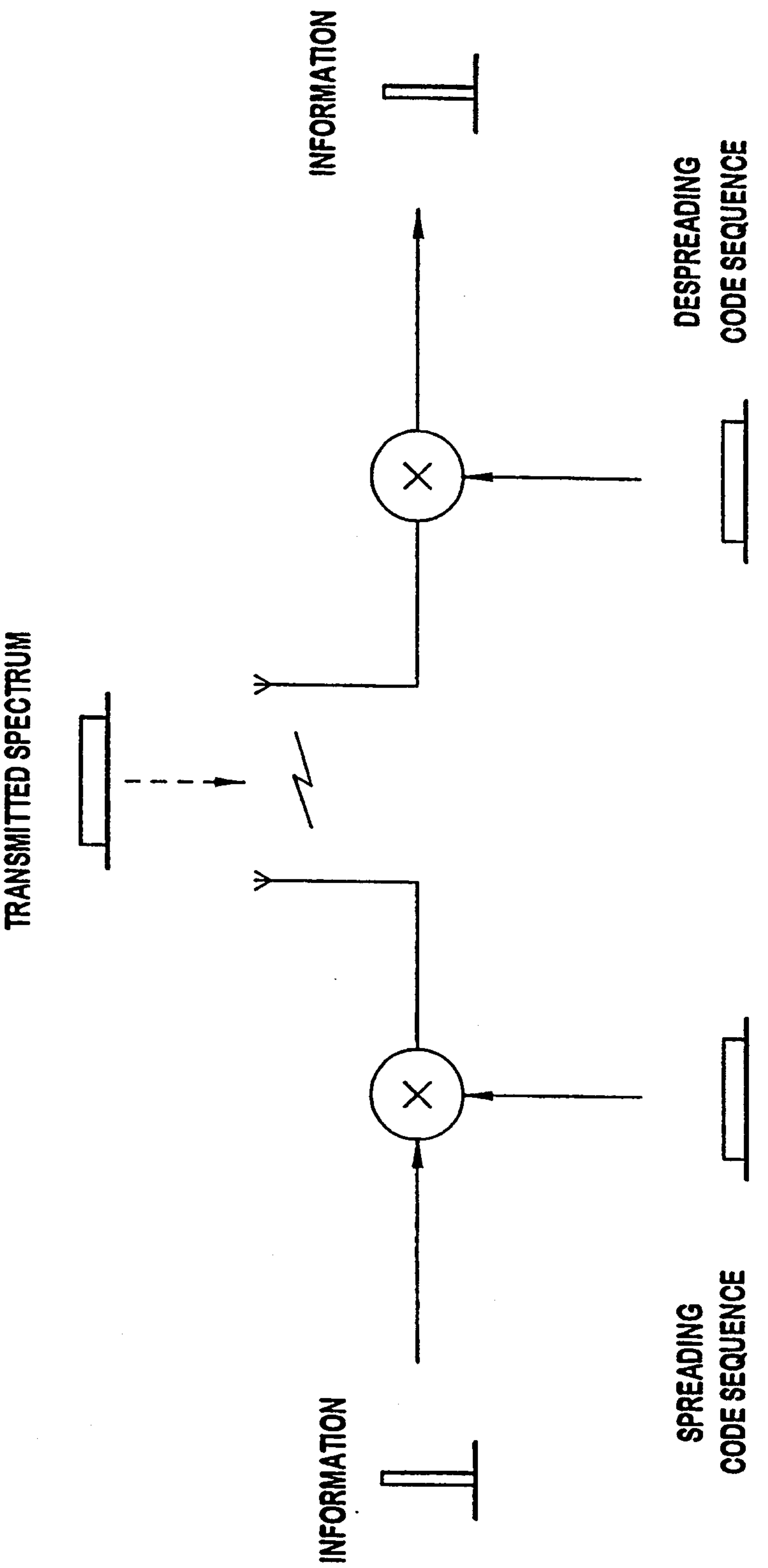
means for making a distance determination based on in part a timing difference between the second code and the first code;

means for comparing a phase difference of a carrier signal of the second spread spectrum signal as received by each of the plurality of antennas;

means for determining an angle of the second spread spectrum signal using the known distance between the antennas and the phase difference;

means for determining a location of a source of the second spread spectrum signal using the determined angle and the distance determination; and means for analyzing an impulse response of multipath components of the second spread spectrum signal to determine a first received component of the second spread spectrum signal, wherein the determined first received component is used to make the distance determination.

2. The base station of claim 1 wherein the first spread spectrum signal is a pilot signal.



PRIOR ART

FIG. 1

FIG. 2

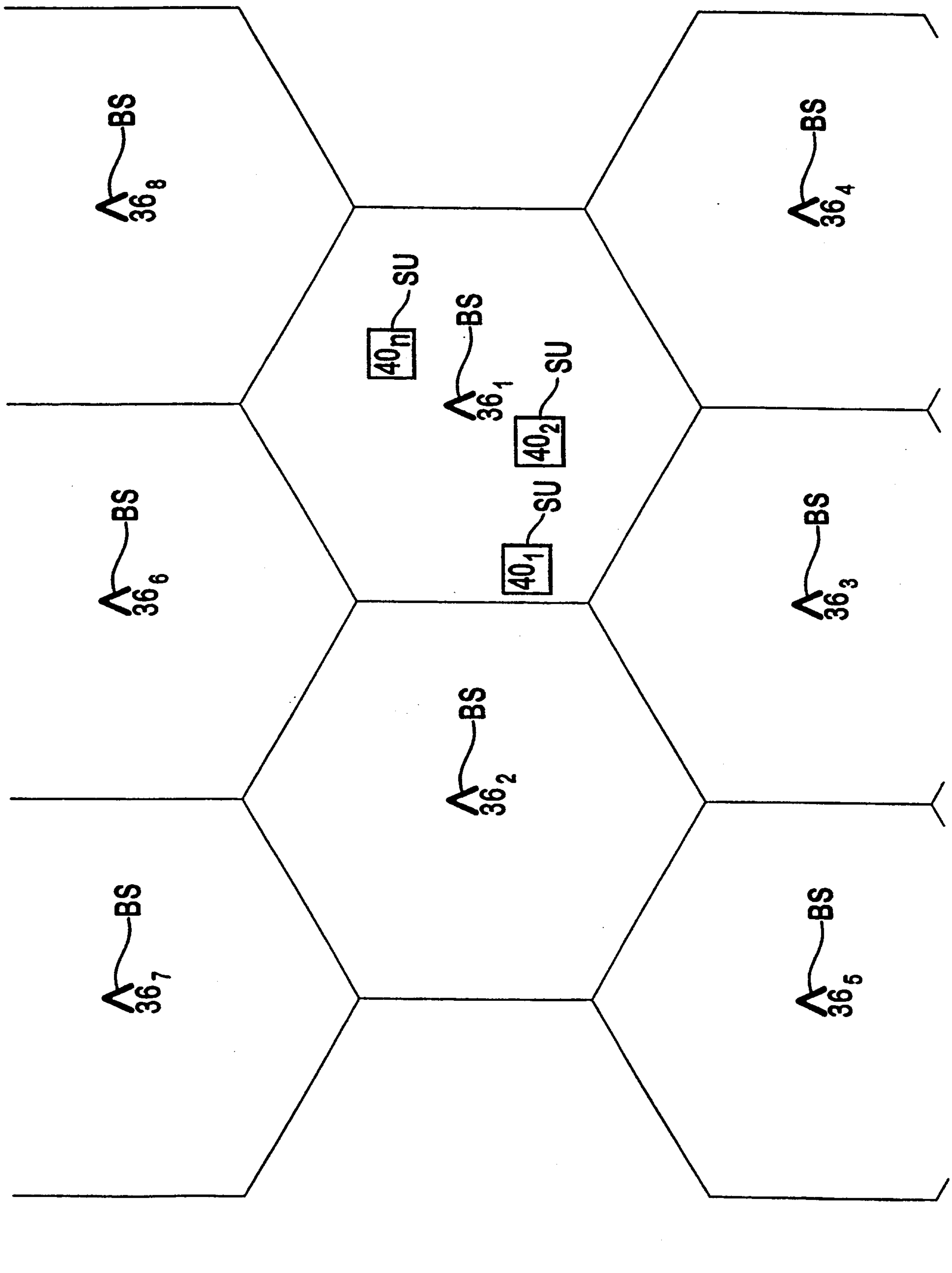
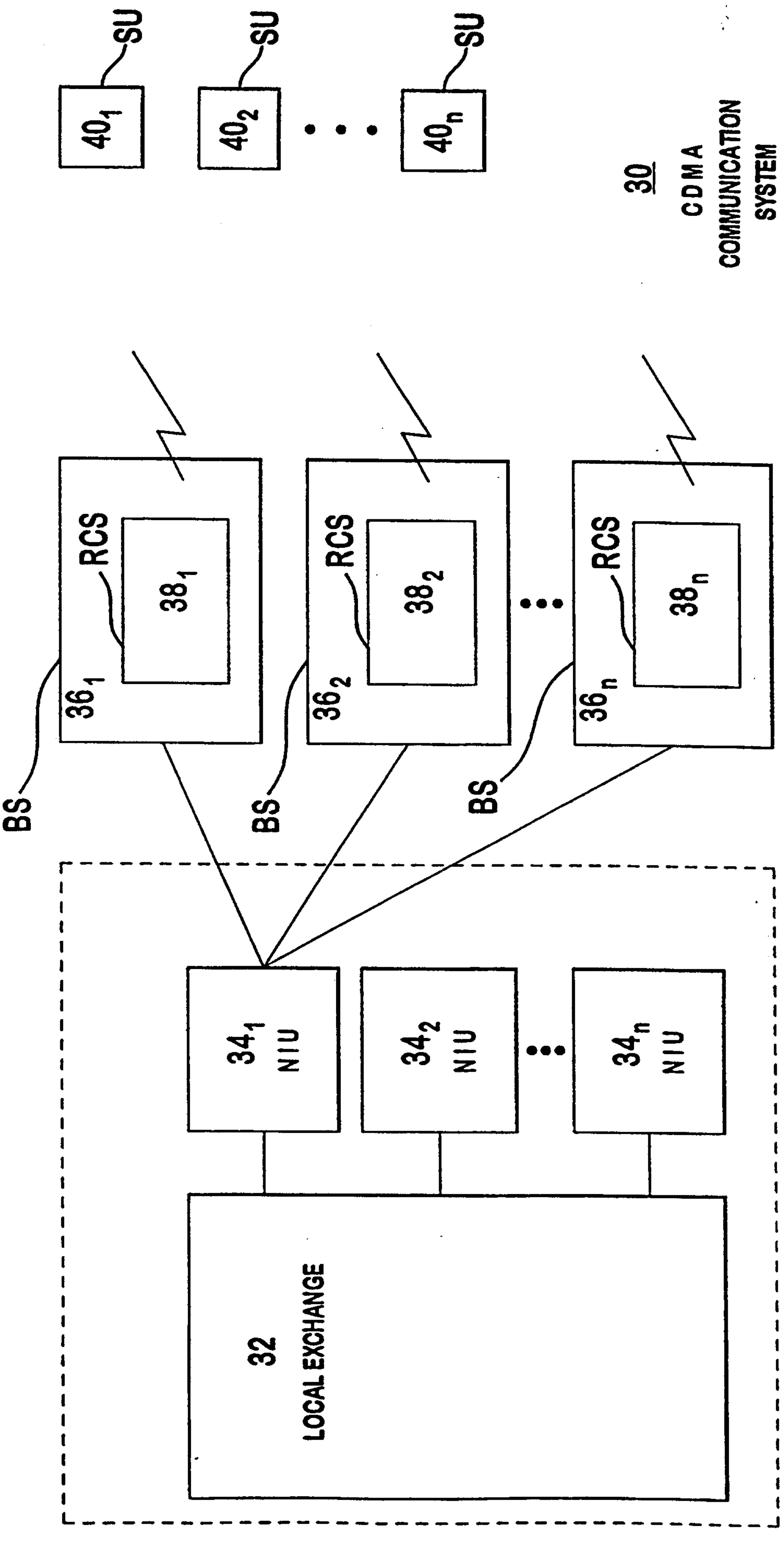

BS
36 8
BS
36 4
SU
40 n
BS
36 1
SU
40 2
SU
40 1
BS
36 6
BS
36 3
BS
36 2
BS
36 7
BS
36 5

FIG. 3


SU
40_1
40_2
40_n
30
CDMA COMMUNICATION SYSTEM
RCS
38_1
38_2
38_n
36_1
36_2
36_n
BS
34_1 NIU
34_2 NIU
34_n NIU
32
LOCAL EXCHANGE

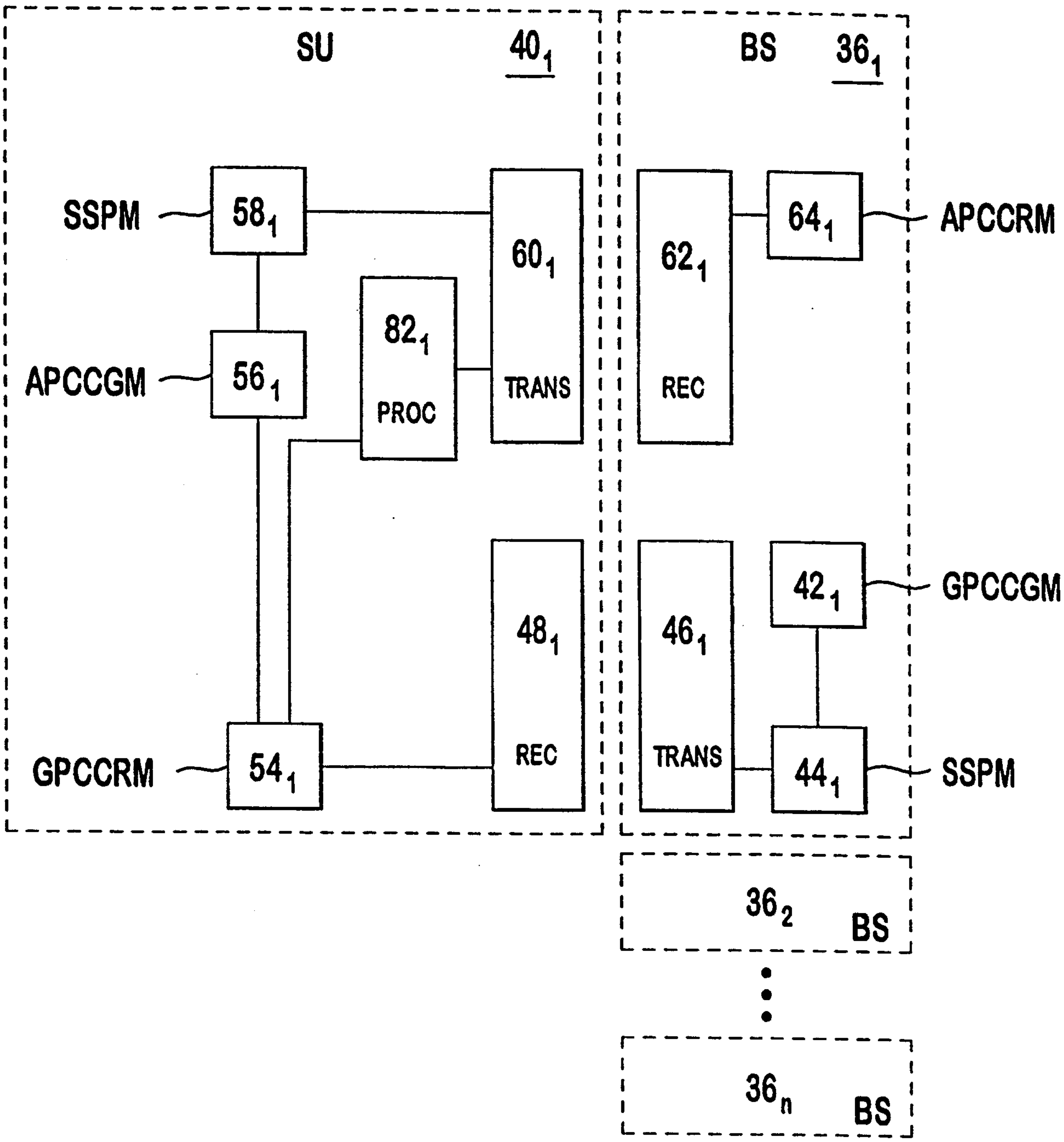
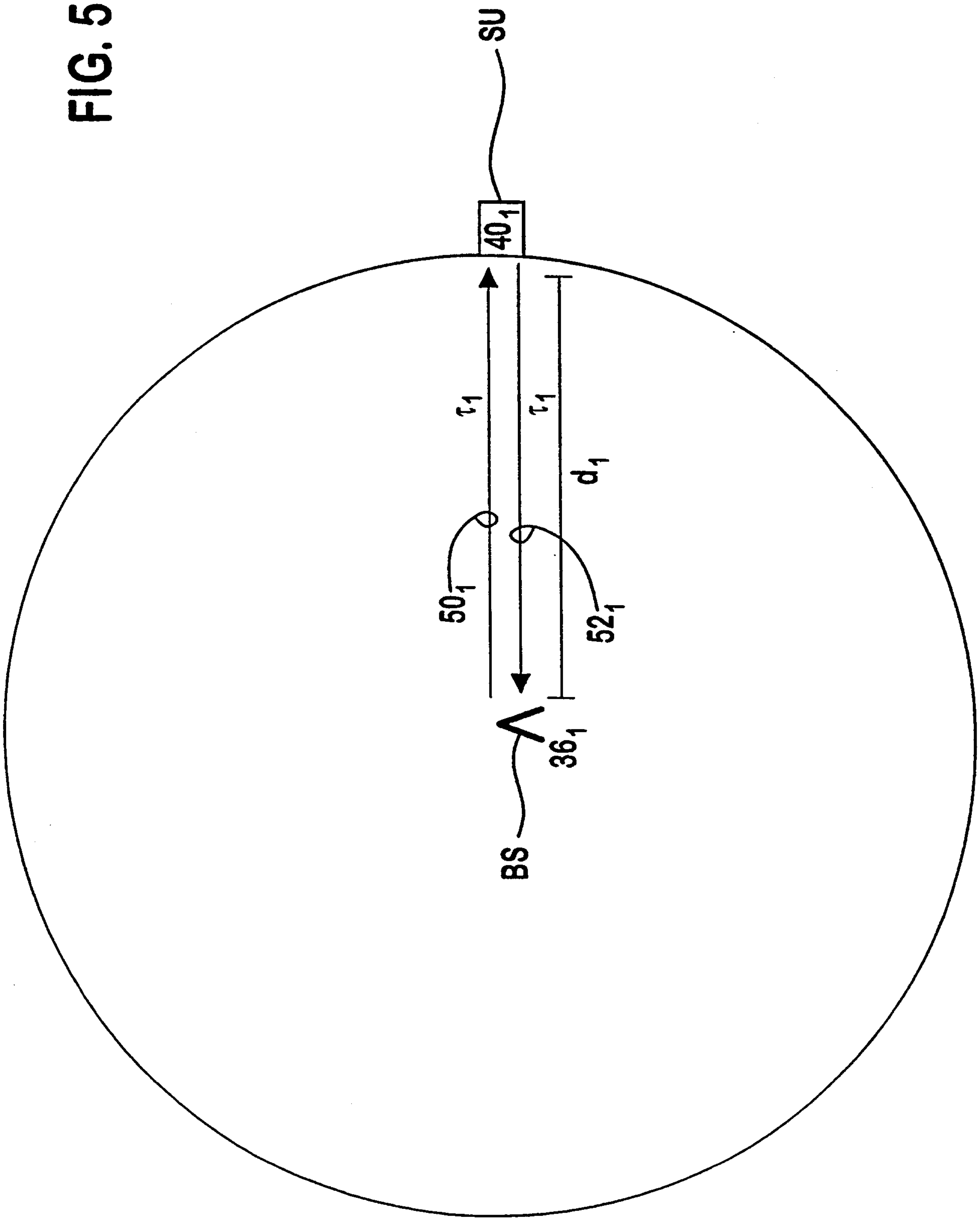
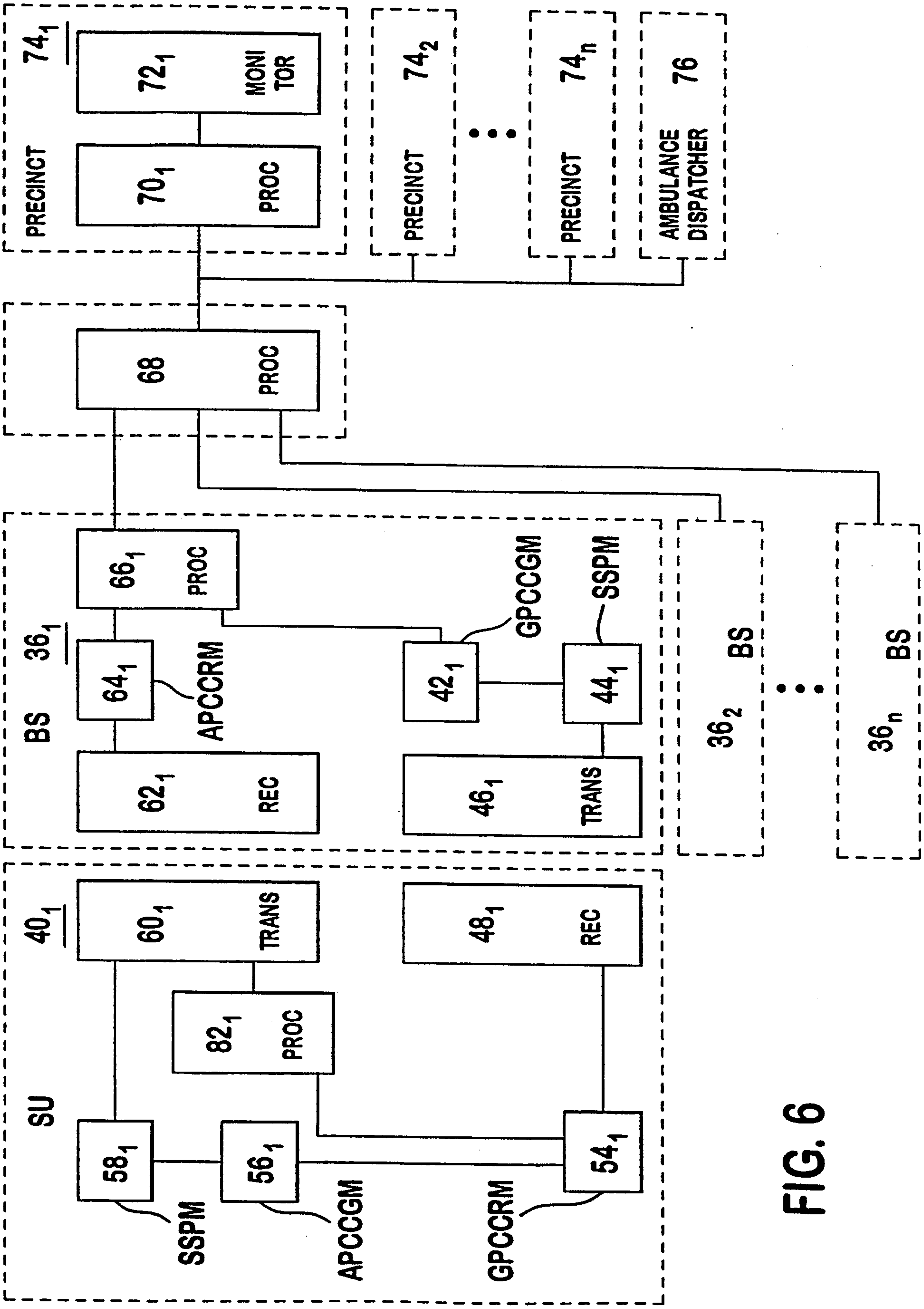

SU
40_1
SSPM
58_1
APCCGM
56_1
82_1
PROC
60_1
TRANS
GPCCRM
54_1
48_1
REC
BS
36_1
62_1
REC
64_1
APCCRM
46_1
TRANS
42_1
GPCCGM
44_1
SSPM
36_2
BS
36_n
BS

FIG. 4

FIG. 5

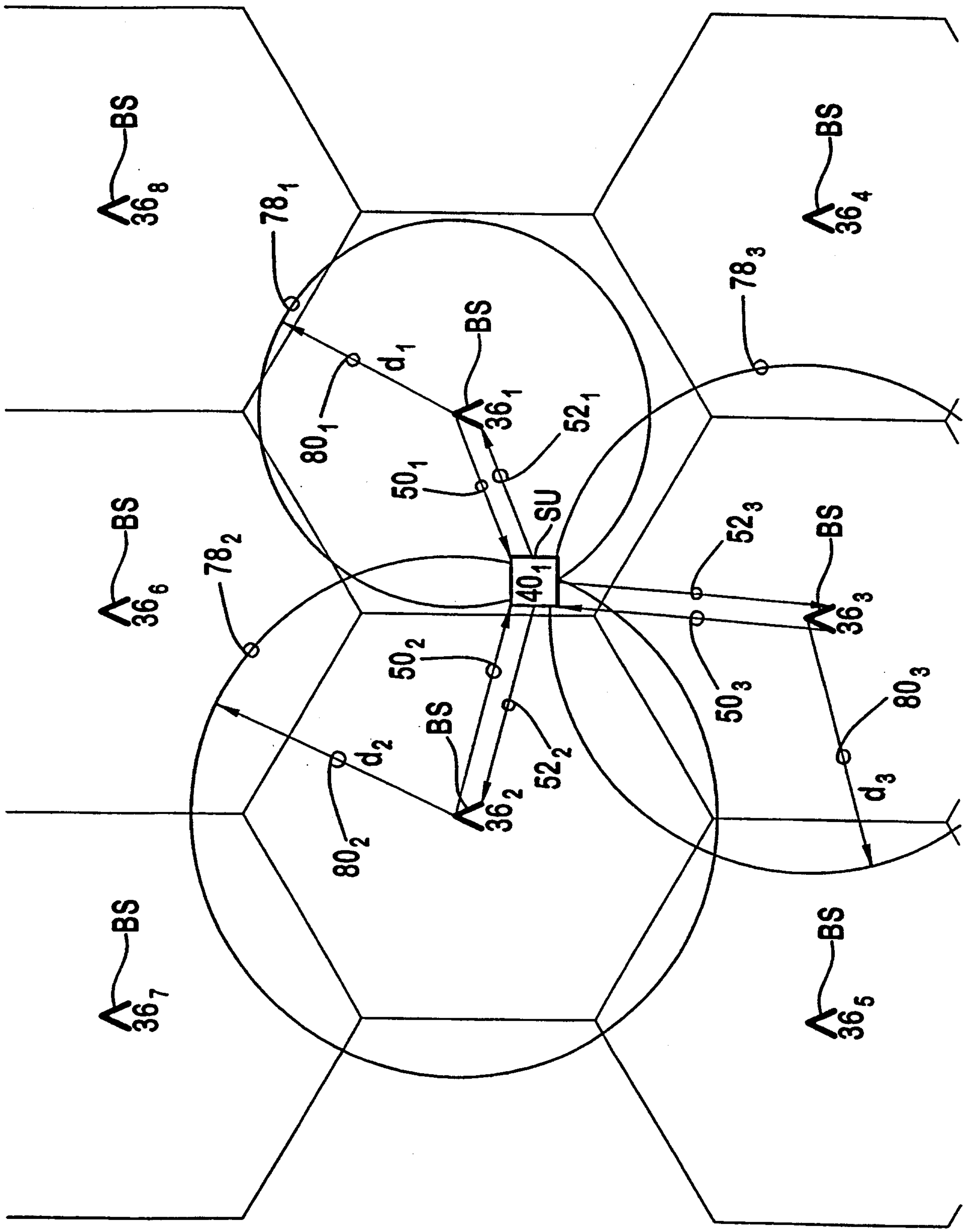




PRECINCT
74_1
70_1
PROC
72_1
MONI TOR
PRECINCT
74_2
PRECINCT
74_n
AMBULANCE DISPATCHER
76
68
PROC
BS
36_1
66_1
PROC
64_1
APCCRM
62_1
REC
42_1
GPCCGM
44_1
SSPM
46_1
TRANS
36_2
BS
36_n
BS
SU
40_1
60_1
TRANS
82_1
PROC
48_1
REC
58_1
SSPM
56_1
APCCGM
54_1
GPCCRM

FIG. 6

FIG. 7


BS
36_1
36_2
36_3
36_4
36_5
36_6
36_7
36_8
40_1
SU
50_1
50_2
50_3
52_1
52_2
52_3
78_1
78_2
78_3
80_1
80_2
80_3
d_1
d_2
d_3

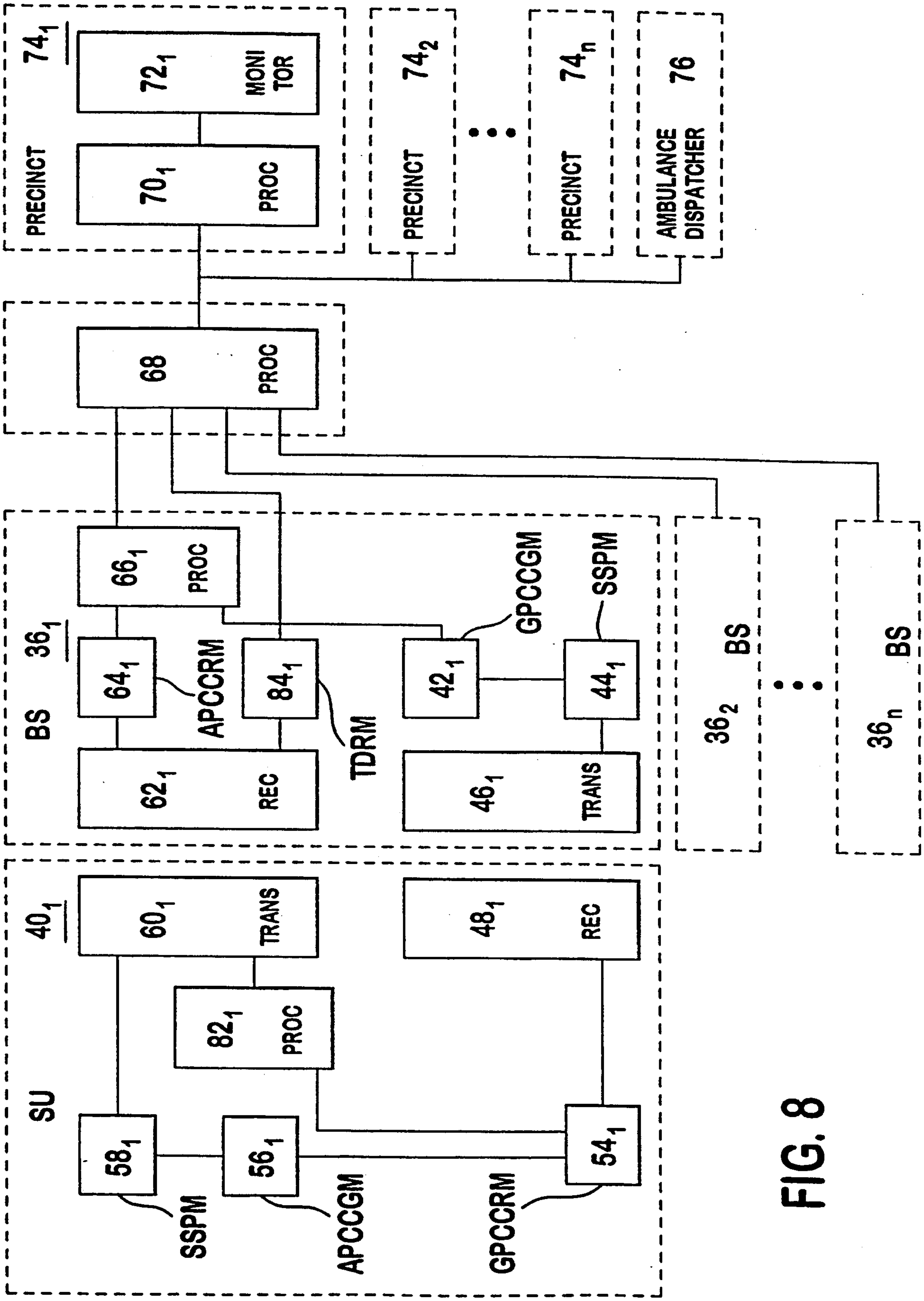

PRECINCT
74_1
72_1
MONI TOR
70_1
PROC
PRECINCT
74_2
PRECINCT
74_n
AMBULANCE DISPATCHER
76
68
PROC
BS
36_1
66_1
PROC
64_1
APCCRM
84_1
TDRM
62_1
REC
42_1
GPCCGM
44_1
SSPM
46_1
TRANS
BS
36_2
BS
36_n
SU
40_1
60_1
TRANS
48_1
REC
82_1
PROC
58_1
SSPM
56_1
APCCGM
54_1
GPCCRM

FIG. 8

FIG. 9

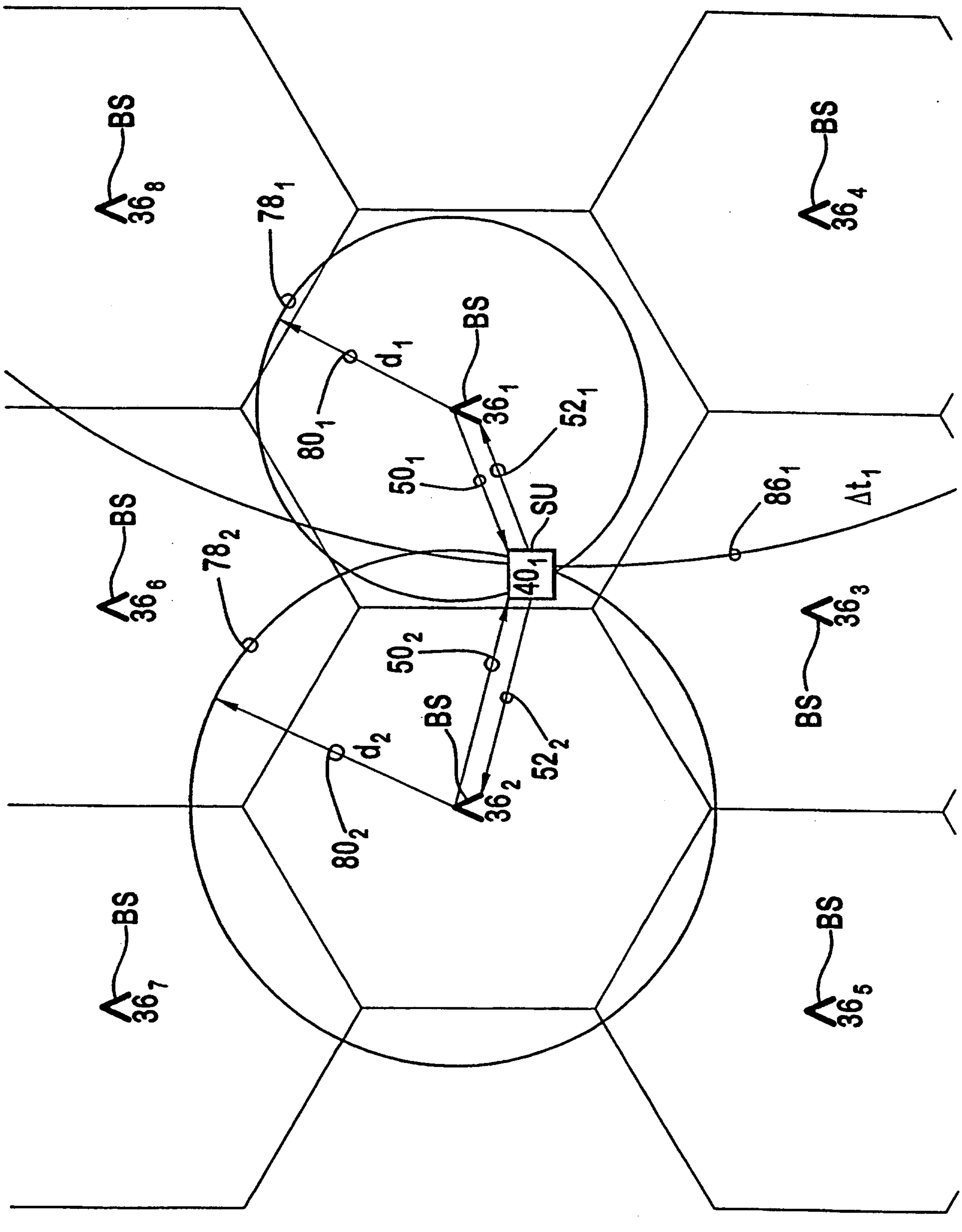
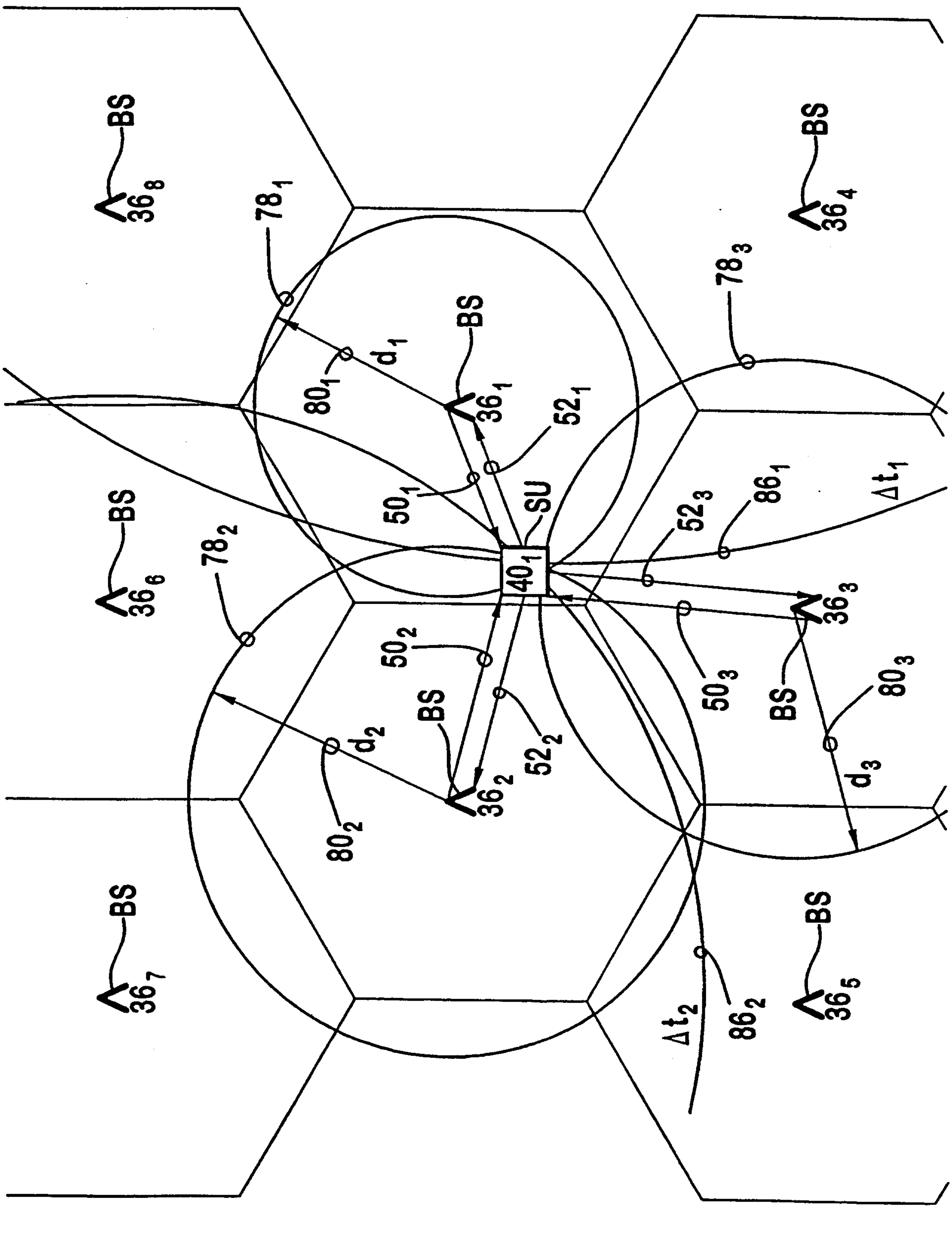

BS
36_8
78_1
BS
36_4
BS
d_1
36_1
80_1
52_1
50_1
SU
86_1
Δt_1
BS
36_6
78_2
40_1
36_3
BS
50_2
BS
d_2
52_2
36_2
80_2
BS
36_7
BS
36_5

FIG. 10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78_1
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d_1
80_1
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52_1
50_1
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52_3
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78_2
40_1
36_3
50_2
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d_3
80_2
36_7
36_5
86_2
Δt_2

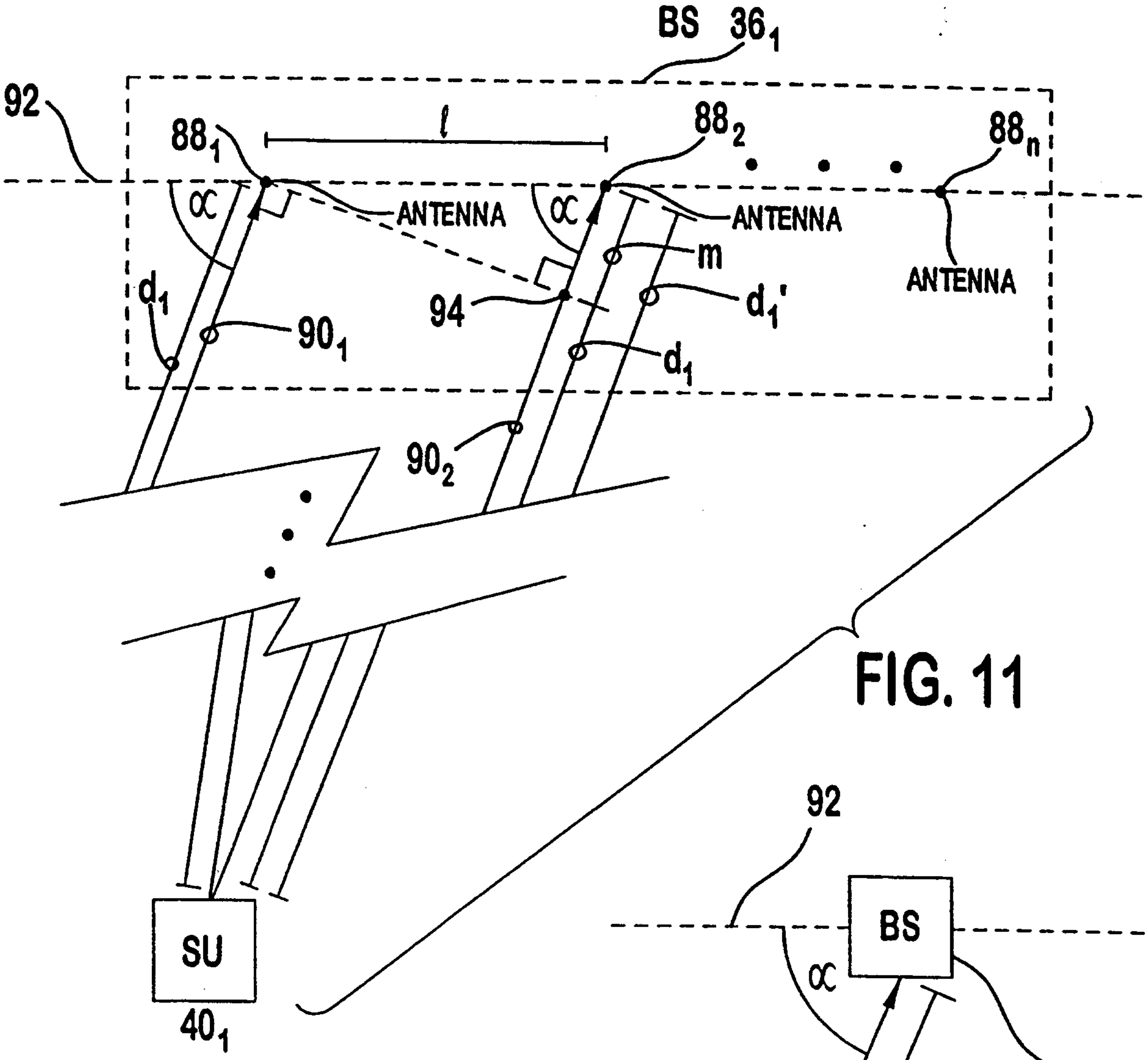

BS 36₁
92
88₁
l
88₂
88ₙ
ANTENNA
ANTENNA
ANTENNA
∝
∝
m
d₁
90₁
94
d₁'
d₁
90₂
SU
40₁

FIG. 11

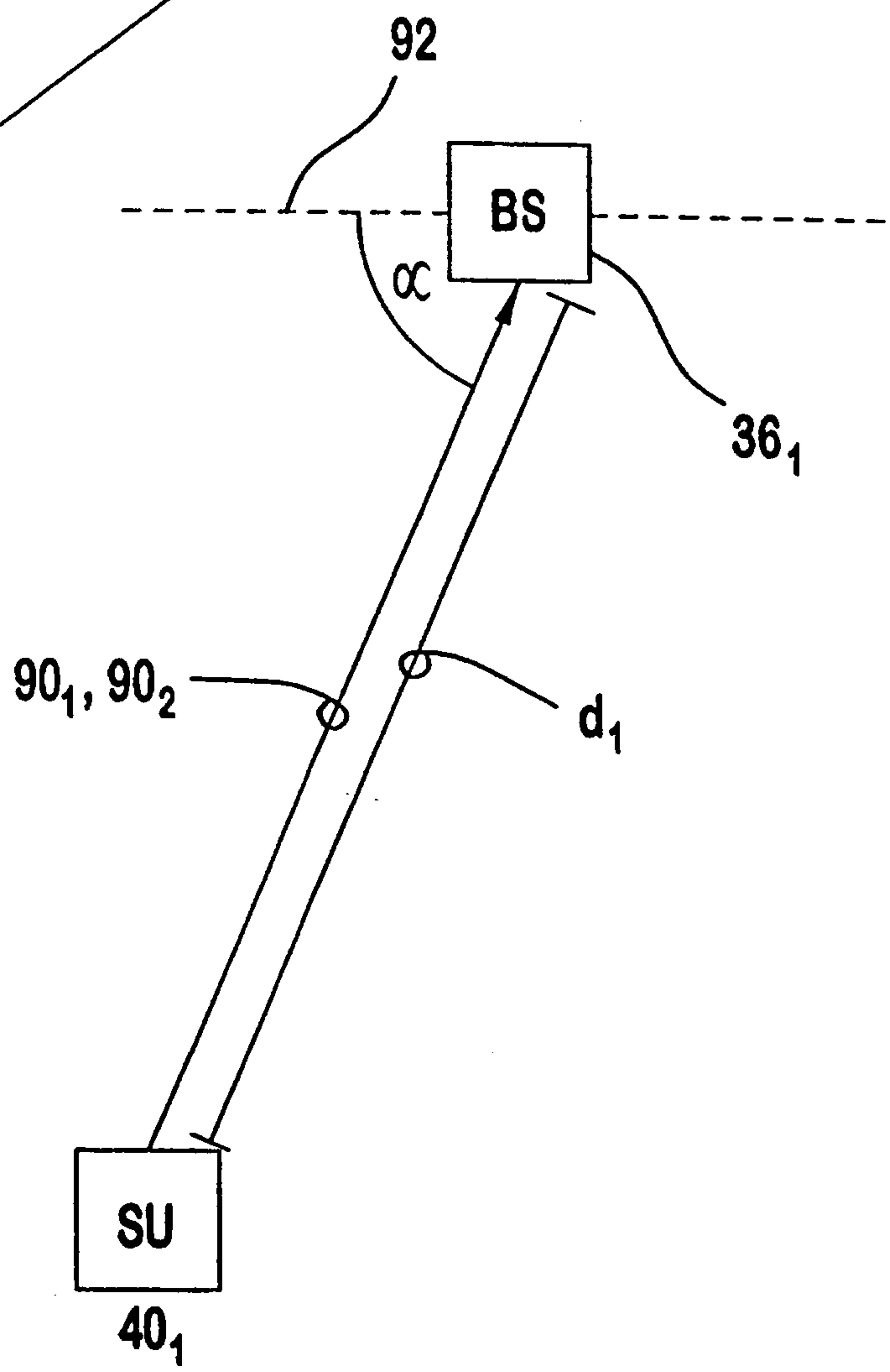
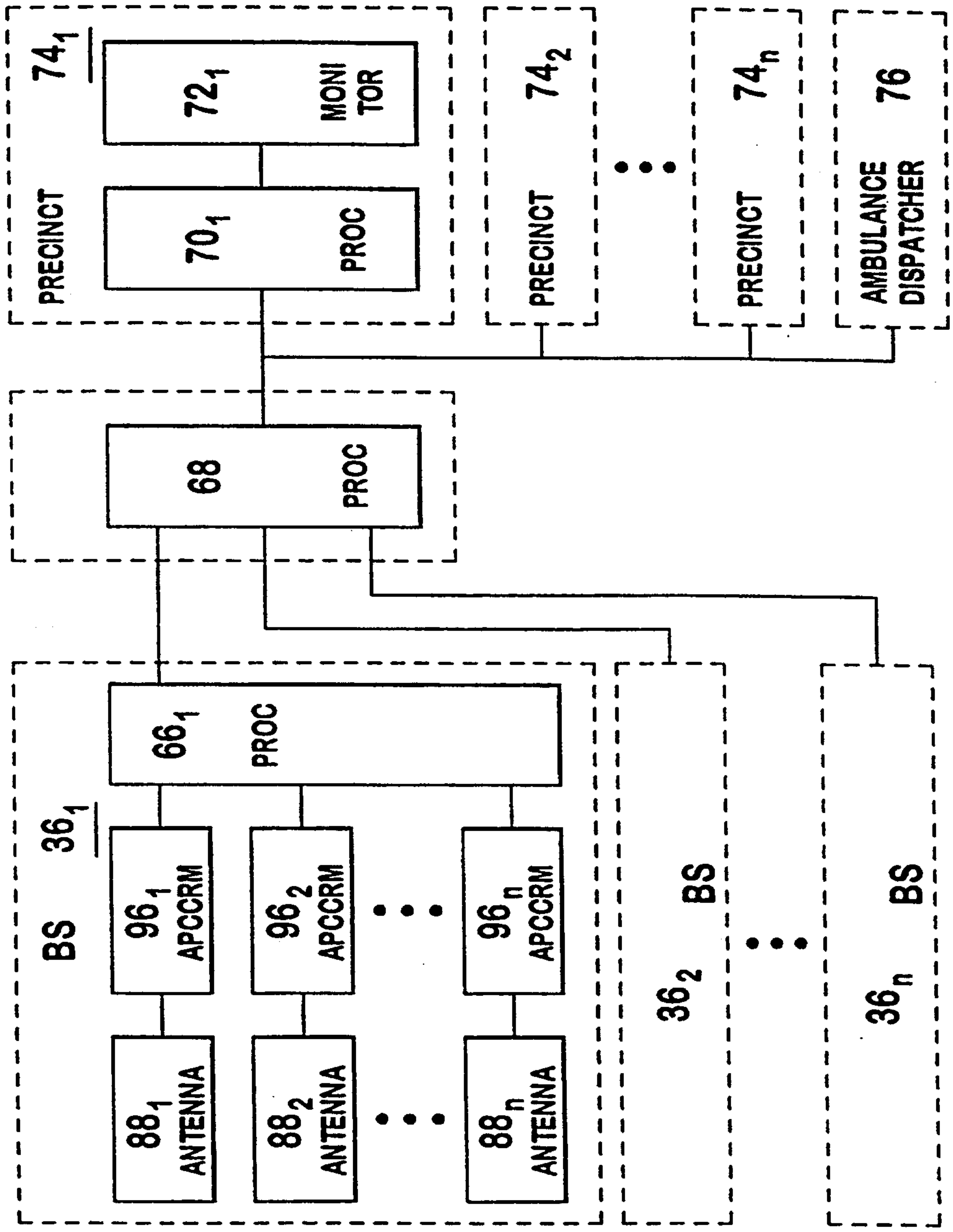

92
BS
∝
36₁
90₁, 90₂
d₁
SU
40₁

FIG. 12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74_1
70_1
PROC
72_1
MONI TOR
PRECINCT
74_2
PRECINCT
74_n
AMBULANCE DISPATCHER
76
68
PROC
BS
36_1
66_1
PROC
96_1
APCCRM
96_2
APCCRM
96_n
APCCRM
88_1
ANTENNA
88_2
ANTENNA
88_n
ANTENNA
36_2
BS
36_n
BS

FIG. 13

FIG. 14

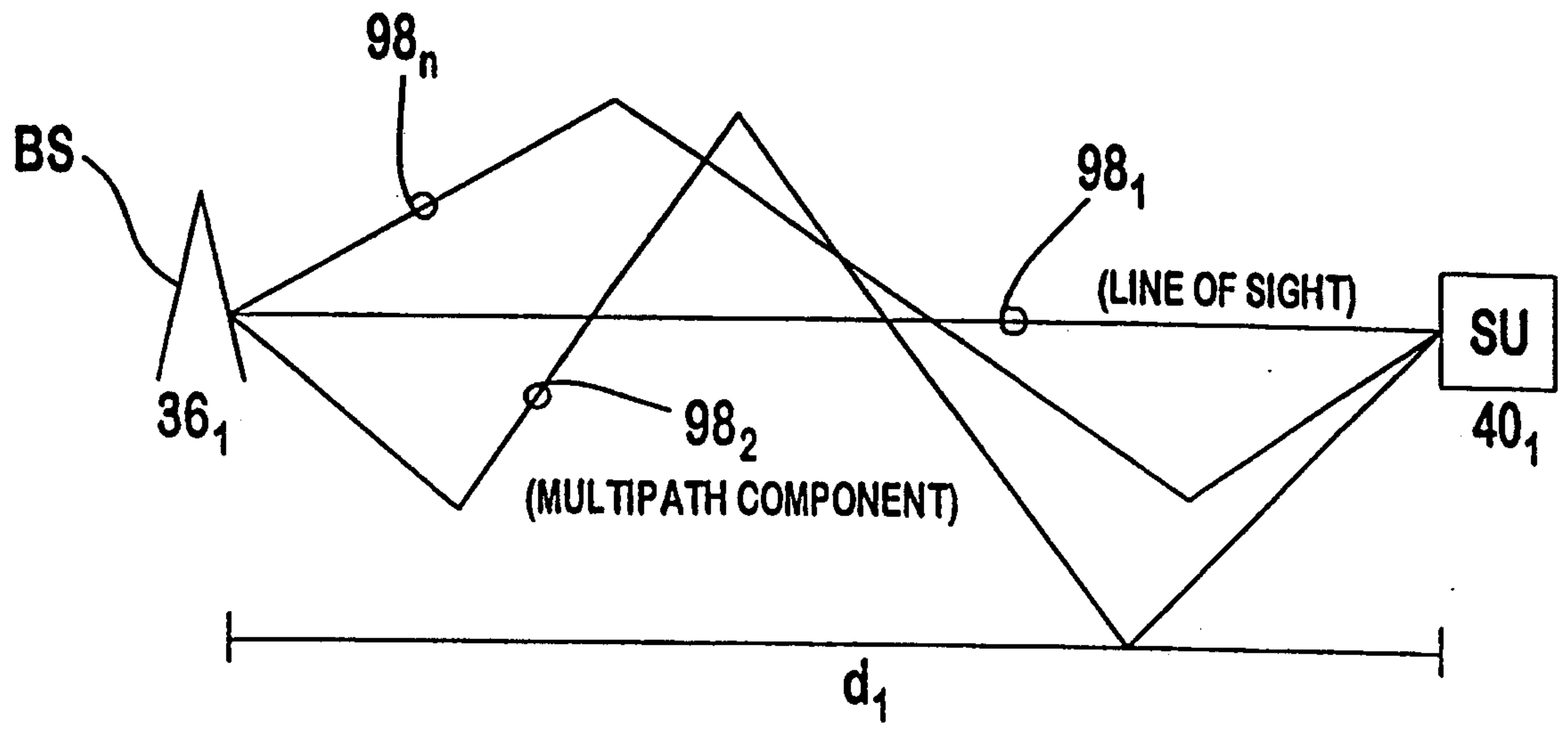
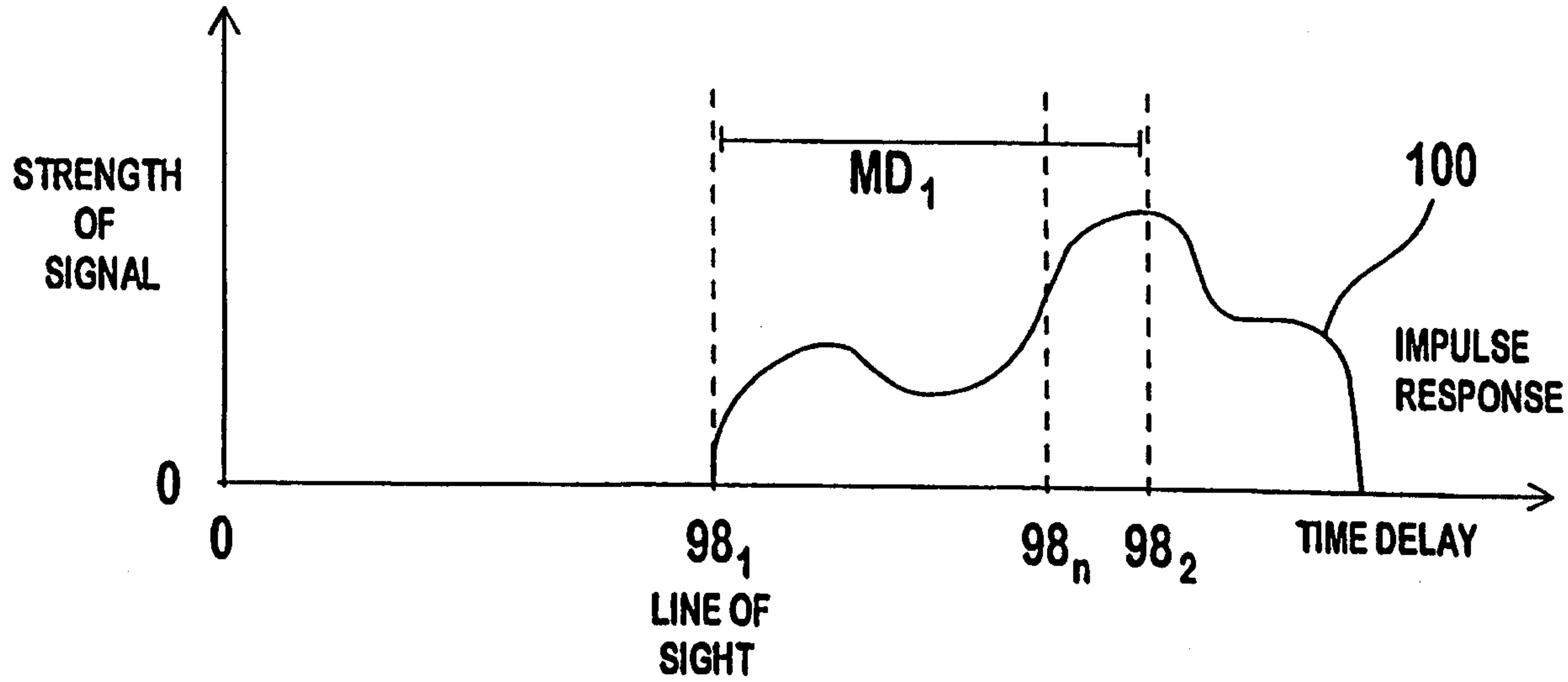
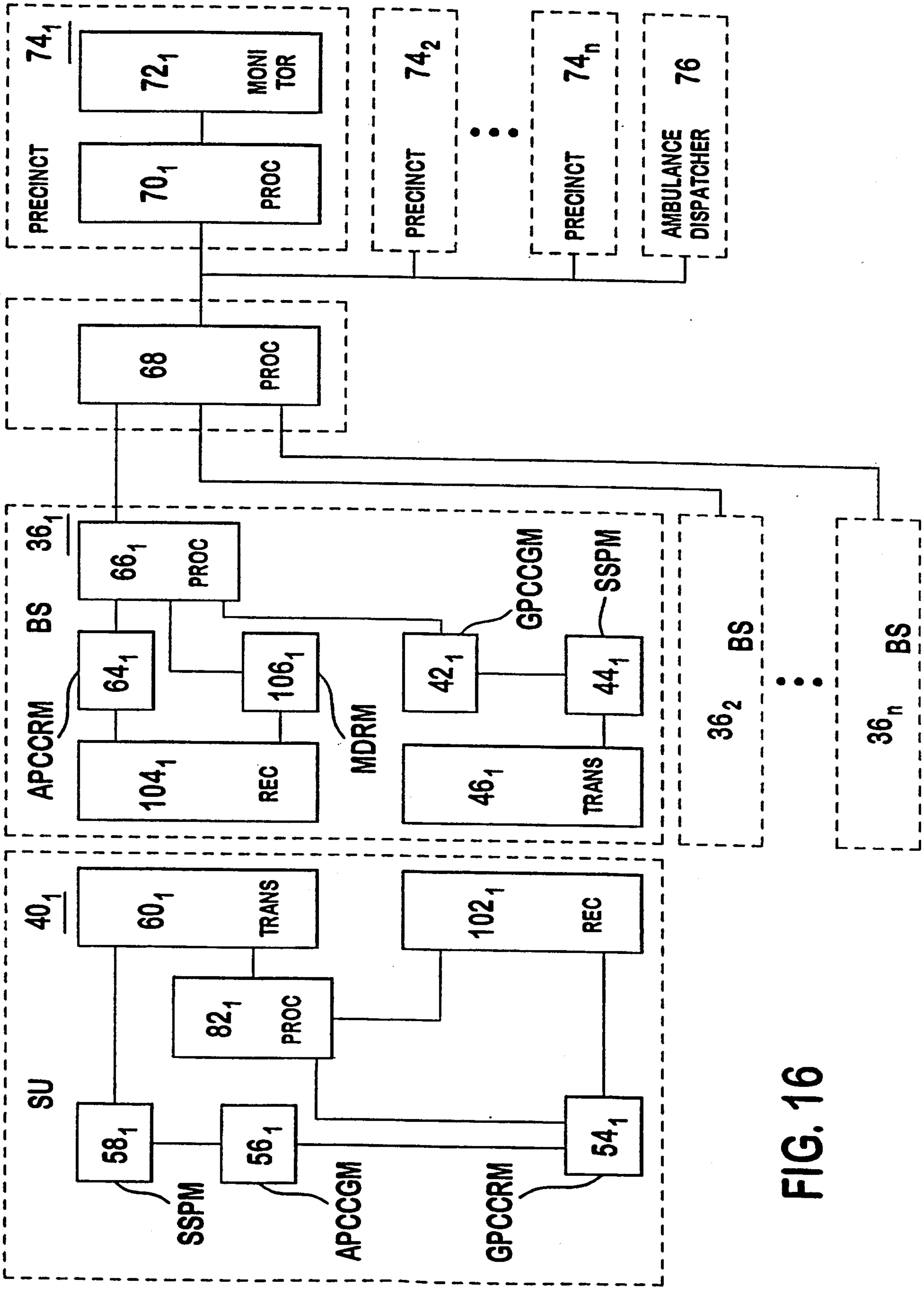

98n
BS
981
(LINE OF SIGHT)
SU
361
982
(MULTIPATH COMPONENT)
401
d1

FIG. 15


STRENGTH
OF
SIGNAL
MD1
100
IMPULSE
RESPONSE
0
0
981
LINE OF
SIGHT
98n
982
TIME DELAY


PRECINCT
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PROC
72_1
MONI TOR
PRECINCT
74_2
PRECINCT
74_n
AMBULANCE DISPATCHER
76
68
PROC
BS
36_1
66_1
PROC
APCCRM
64_1
106_1
MDRM
104_1
REC
GPCCGM
42_1
SSPM
44_1
46_1
TRANS
36_2
BS
36_n
BS
SU
40_1
60_1
TRANS
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PROC
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REC
58_1
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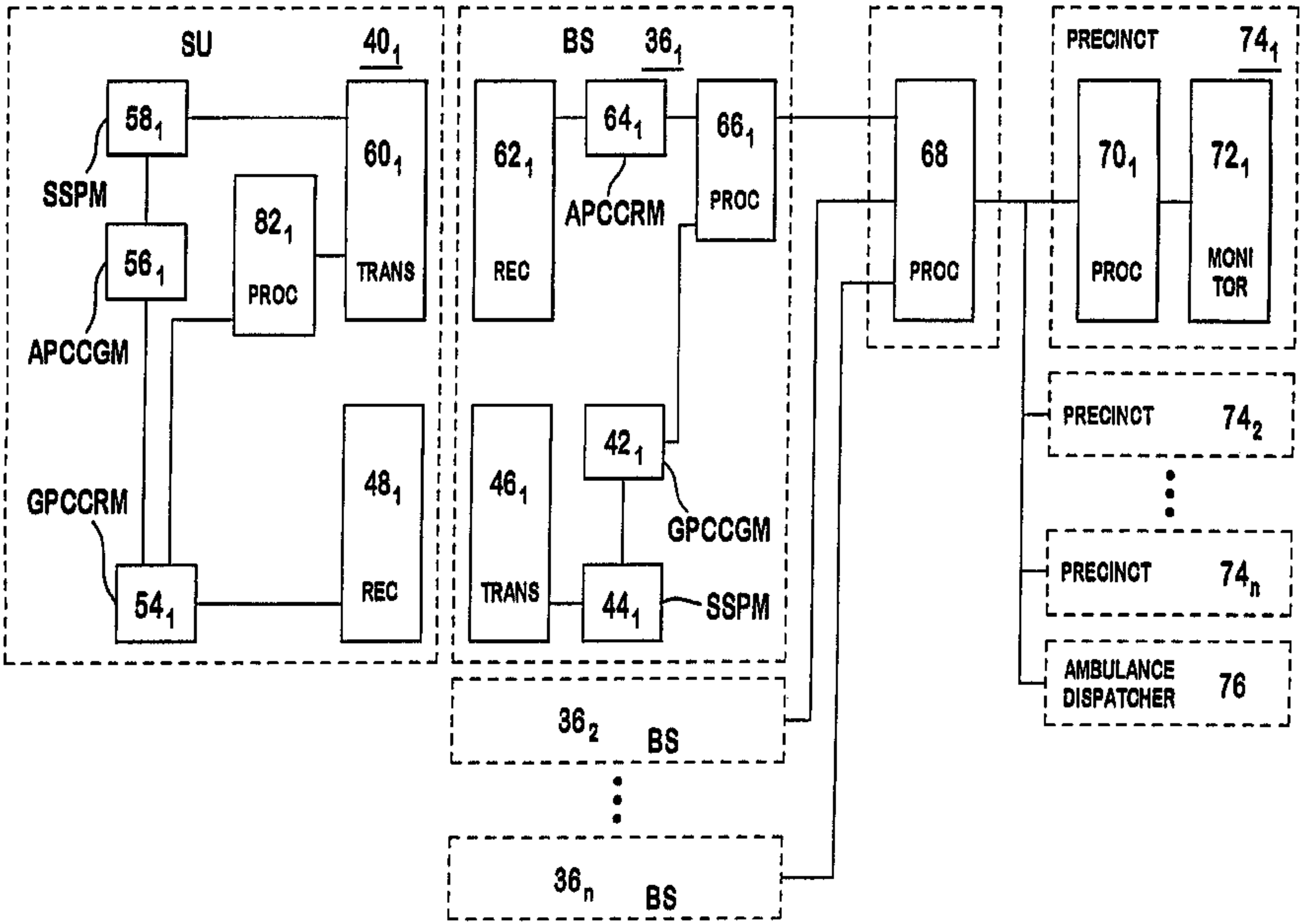
APCCGM
54_1
GPCCRM

FIG. 16



SU
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PROC
60_1
TRANS
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REC
BS
36_1
62_1
REC
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66_1
PROC
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TRANS
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GPCCGM
44_1
SSPM
36_2 BS
36_n BS
68
PROC
PRECINCT
74_1
70_1
PROC
72_1
MONI TOR
PRECINCT 74_2
PRECINCT 74_n
AMBULANCE DISPATCHER 76