(54) Title: APPARATUS AND METHOD FOR LOCATING CELLULAR TELEPHONES AND SIMILAR TRANSMITTERS
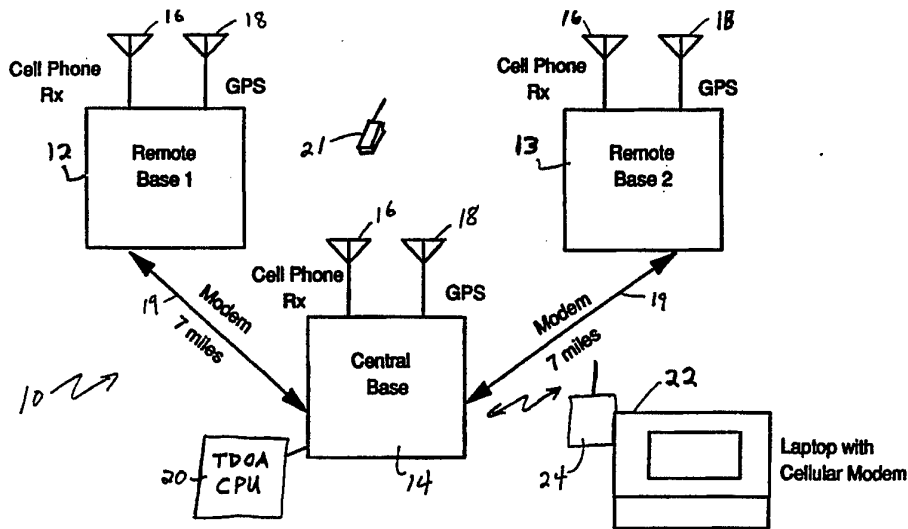
(57) Abstract

The field of locating cellular telephones suffers from high multipath city environments which affect accuracy. This problem can be overcome by a method for determining location by the time difference of arrival, tdoa, of signals from a cellular telephone (21) or other transmitter at cellular based stations (12-14). The method (20) includes determining tdoas for a plurality of channels, averaging the tdoas from the channels, subtracting the average tdoa from the individual channel tdoas to determine residual channel tdoas and determining an overall residual tdoa from the residual channel tdoas. Applications include emergency calls and criminal investigations.

APPARATUS AND METHOD FOR LOCATING CELLULAR TELEPHONES
AND SIMILAR TRANSMITTERS

Background of the Invention
Field of the Invention

The present invention generally relates to the function of locating cellular telephones and similar mobile transmitters, and particularly, to a method and apparatus which use time-difference-of-arrival techniques and which take advantage of the multiple channels used by cellular telephones and similar transmitters for this purpose.

Statement of the Prior Art

The proliferation of cellular telephones, or cell phones, and their technology and usage, has revealed various applications for the ability to locate cell phones. These applications include "911" calls, tourist and travel information, tracking of unauthorized cell phone usage and illegal activities, and the locating of commercial and government vehicles, to name a few. The basic cell phone systems can only determine the nearest cell phone base station, which locates the cell phone to within 3 to 10 miles.

A goal of any such system for use with cellular phones is the use of as much existing equipment as possible or at least compatibility with existing equipment. Examples of this are use with unmodified cellular phones and compatibility with existing cellular base stations.

A great deal of technology already exists concerning the tracking or locating of radio transmitters. One known method for locating transmitters is time difference of arrival, tdoa, which has been used for many years, at least in such applications as LORAN and GPS. The

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application of this process to cell phones includes
measuring the time of arrival of the same signal at a
multiplicity of base stations and comparing the times to
determine the difference between times of arrival and
5   thereby the differences in transmission time from the
cell phone or transmitter. Because it operates on the
ordinary signal transmitted, it does not require any
modifications of the transmitter. One such application
of tdoa technology combined with direction finding and
10   applied to cellular phones is described in U.S. Patent
No. 5,317,323. The system described therein uses GPS
timing signals at the receivers to determine the time of
signal reception. Direction finding is used to help
eliminate multipath and co-channel interference.
15   Unfortunately, the use of direction finding requires the
use of a steerable antenna or array and is thus not
compatible with existing omnidirectional antenna
structures. The patent does show the importance of
removing multipath interference. Thus, it is a goal of
20   any such locating system for cellular telephones to
distinguish between a direct signal from a cell phone and
multipath reflections of the same signal from buildings
and other reflectors. Reflected signals, which take a
longer and unknown path to the receiver, provide less
25   accurate location information.

SUMMARY OF THE INVENTION

Accordingly, it is a object of the present invention
to provide an apparatus and method for determining the
30   location of cellular telephones by using time difference
of arrival measurements at a multiplicity of cell phone
base stations.

It is a further object of the present invention to
perform such location finding even when the signals

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received at one or more of the base stations are
indistinguishable from noise and other co-channel
interference.

It is still a further object of the present
5   invention to perform such location finding in the
presence of high levels of multipath reflected signals.

It is yet a further object of the present invention
to perform such location finding while taking advantage
of the frequency separation of a plurality of cell phone
10   channels to improve the accuracy of the location finding.

It is yet a further object of the present invention
to perform such location finding using antennas and
antenna structures which are normally used for typical
cell phone operation.

15   In one form, the present invention provides a method
for determining the time difference of arrival, tdoa, of
signals from a cellular telephone, cell phone, or similar
transmitter at a pair of base stations, comprising the
steps of: substantially simultaneously sampling
20   transmission signals from the cell phone or similar
transmitter at the pair of base stations in a plurality
of channels having different frequencies; correlating the
corresponding signals sampled at the base stations for
each channel to determine a tdoa therebetween for each
25   channel; averaging the tdoas determined for each channel;
subtracting the average tdoa from each of the determined
channel tdoas to determine a residual phase tdoa for each
channel; determining an overall phase tdoa between the
pair of base stations based upon the residual phase tdoas
30   for each channel; and adding the average tdoa to the
overall phase tdoa to determine an overall tdoa between
the pair of base stations.

In another form, the present invention provides a
method for collecting transmission signals at a first

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cell phone base station from a particular cell phone for
the purpose of determining location of the cell phone
using time difference of arrival, tdoa, comprising the
steps of: receiving signals transmitted over all channels
5   of a wideband, cell phone base station, operating
spectrum including a known reverse control channel
thereof; digitizing the received wideband spectrum
signals; storing the digitized signals as digitized data
in a delay memory; monitoring the known reverse control
10   channel signal for a cell phone transmission including a
predetermined number of either a cell phone to be located
or a phone number being called; identifying a
predetermined number from the monitoring of the reverse
control channel; and storing data from the delay memory
15   in response to the identifying of the predetermined
number, including the portion of the received signal
bearing identifying data of the predetermined number.

        In yet another form, the present invention provides
an apparatus for collecting transmission signals at a
20   first cell phone base station from a particular cell
phone for the purpose of determining location of the cell
phone using time difference of arrival, tdoa, comprising:
means for receiving signals transmitted over all channels
of a wideband, cell phone base station, operating
25   spectrum including a known reverse control channel
thereof; means for digitizing the received wideband
spectrum signals; means for storing the digitized signals
as digitized data in a delay memory; means for monitoring
the known reverse control channel signal for a cell phone
30   transmission including a predetermined number of either a
cell phone to be located or a number being called; means
for identifying a predetermined number from the
monitoring of the reverse control channel; and means for
storing data from the delay memory in response to the

identifying of the predetermined number, including the
portion of the received signal bearing the identifying
data of the predetermined number.

5   **BRIEF DESCRIPTION OF THE DRAWINGS**
         The present invention is illustratively described in
reference to the appended drawings in which:
         Fig. 1 is a system block diagram of an apparatus
constructed in accordance with one embodiment of the
10 present invention;
         Fig. 2 is a block diagram of one embodiment of a
portion of Fig. 1;
         Fig. 3 is a block diagram of a second embodiment of
a portion of Fig. 1;
15   Fig. 4 is a signal diagram of some of the results of
the tdoa determination process;
         Fig. 5 is a diagram of additional results of the
tdoa process; and
         Fig. 6 is another signal diagram of additional
20 results of the tdoa process.

         DETAILED DESCRIPTION OF THE DRAWINGS
         Fig. 1 shows one embodiment of a cell phone locating
system 10 which would take advantage of existing cell
25 phone base stations and antennas. System 10 generally
includes a multiplicity of existing cellular base
stations 12-14, to which the apparatus of the present
invention is added. Base stations 12-14 make use of
existing transmit and receive antennas 16 which may be
30 identical in form and function. Added to each base
station is an additional GPS (Global Positioning System)
antenna 18 which receives timing signals from the
existing civilian GPS for use in the locating function.
Each of the base stations also includes further equipment

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for performing the locating function as described below.
Communication lines 19 are shown connecting at least two
remote base stations 12,13 with a central base station
14. Central base station 14 includes equipment not
5   present in the remote base stations 12,13 in the form of
tdoa CPU 20 for processing signals received by all base
stations 12-14. Tdoa CPU 20 may be located at any one of
the base stations or may be located separately from such
base stations. Such separate location would include the
10   interconnection of all comm. lines 19 directly between
the base stations and tdoa CPU 20. A cell phone 21,
located within the range of the base stations 12-14, may
be located by the equipment of the present embodiment.
      The base station 14, having tdoa CPU 20, is shown
15   being accessed by a computer 22, such as a portable
computer, using a telecommunications link, such as a
cellular telephone modem 24, for the purpose of
requesting location information or the performance of a
locating operation on a cell phone such as 21.
20   ·   Fig. 2 shows a system block diagram for installation
at one of the remote base stations 12-14 of Fig. 1. The
system 30 shown generally includes a receiver section 32,
a processing section 34 and a control and communication
section 36. Receiver section 32 is coupled to the
25   existing cell phone antenna 16 and the GPS antenna 18.
Signals from the existing cell phone antenna 16 are
coupled through a Filter and Low Noise Amplifier 40 to a
frequency down converter 42 and a receiver 44 for the
reverse control channel of the cell phone system. Down
30   converter 42 outputs signals from the full cell phone
bandwidth being received. The analog output of receiver
44 is nominally fed through a TTL converter 45 for
providing a digital format to the control section 36.

Down converter 42 also receives demodulated GPS
timing signals or time tags at one pulse per second and
one kilopulse per second from a GPS receiver 46 connected
to GPS antenna 18. Down converter 42 includes a counter
5   (not shown) which is clocked by the kilopulse signal and
reset by the pulse per second signal, thus producing a
time tag for association with the received cell phone
signals. Thus, the GPS time tags, which are
substantially the same at all local base stations are
10   used to measure the time of arrival of signals received
by antenna 16 on both the reverse control channels and
the reverse voice channels. The received cell phone
signals from down converter 42 are synchronously fed
through an analog-to-digital, A/D, converter 48 to the
15   processing section 34 along with the time tag signals on
line 49. Additionally, A/D converter 48 is triggered in
response to the GPS signals so that the time tags
correspond to the exact points in time that A/D converter
48 performs sampling.
20   Processing section 34 generally includes a delay
memory 50, a filter/decimator 52, a FIFO buffer 54 and a
time tag decoder 56. Memory 50 receives digitized data
from the cell phone bandwidth being received along with
corresponding time tag data. Buffer 54 and decoder 56
25   output data to a control CPU 60 in control section 36 and
receive an alarm or trigger signal therefrom.
Filter/decimator 52 receives a tuning signal from CPU 60.
The purpose of delay memory 50 is to store data from the
cell phone bandwidth while control CPU 60 determines if a
30   portion of that data and its corresponding time tag
should be recorded. Because delay memory 50 temporarily
stores all data in the cell phone spectrum, it must
operate at a fairly high speed such as 25MHz to cover a
cell phone bandwidth of 10MHz. The purpose of

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filter/decimator 52 is to digitally tune to only a single
channel, 30KHz, and filter out the remainder of the cell
phone spectrum being fed from delay memory 50. Because
the data then recorded in FIFO buffer 54 only corresponds
5 to the single channel bandwidth, it can run at a much
lower speed, i.e. 100KHz, than delay memory 50.

Control section 36 includes the control CPU 60 along
with a communications CPU 62 which communicate with each
other and with the remainder of the locator system 10
10 using an Ethernet connection 64 over comm. lines 19.
Comm. CPU 62 is also coupled to a cell phone receiver 66
of sorts which solely monitors the forward control and
voice channels and records voice channel assignments sent
from the base station to individual cell phones. In
15 another implementation voice channel assignment data may
be hard wired or reported via a direct computer link from
the cell phone system thereby making receiver 66
unnecessary.

In operation, comms. CPU 62 receives data over the
20 Ethernet 64 to monitor for a specific predetermined phone
number to be located. Cell phone calls to specific
telephones number may also be so designated and
monitored. Comms. CPU 62 passes this information to
control CPU 60 which monitors the reverse control channel
25 signal from receiver 44. Control CPU 60 also sends a
tuning signal to filter/decimator 52 so that the data
exiting therefrom is the contents of the reverse control
channel. Whenever a cell phone places a call, it
transmits both its own number and the number to be called
30 over the reverse control channel. Likewise whenever a
cell phone is called, its number is transmitted over the
forward control channel and it responds over the reverse
control channel using its phone number.

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Whenever control CPU 60 matches a cell phone transmission number with either a predetermined number to be located or a specific number being called, such as '911', control CPU 60 generates an alarm or trigger

5   signal for FIFO buffer 54 and time tag decoder 56. This trigger causes buffer 54 to begin collecting data and decoder 56 to identify the specific time tag corresponding to the beginning of the data being so stored. The trigger signal is simultaneously sent to all

10   of the immediately surrounding base stations so that simultaneously received signals are collected. Surrounding base stations will collect data even though the reverse control channel signals they received may not have been strong enough to enable identification of the

15   predetermined cell phone number or number being called.

The delay in time between the receipt of a reverse control channel signal and the decoding of that signal by control CPU 60 to generate a trigger in the present embodiment amounts to approximately 20 ms. of data or

20   less. This corresponds to the amount of data stored in delay memory 50 which can therefore be captured in buffer 54 even after the number being monitored has been decoded therefrom. In response to a trigger, buffer 54 collects 82 milliseconds of data which may then be passed as a

25   block or packet to control CPU 62 along with the corresponding decoded initial time tag from decoder 56.

Once a monitored phone or a called number is identified from the reverse control channel from receiver 44, the forward control channel is further monitored by

30   comms. CPU 62 and receiver 66 to determine the voice channel assignment from the base station. This assignment is passed to control CPU 60. After the 82 milliseconds of reverse control channel data is collected in buffer 54, control CPU 60 re-tunes filter/decimator 52

to the assigned reverse voice channel and re-triggers
buffer 54 and time tag decoder 56 to collect another 82
milliseconds of data from the assigned reverse voice
channel. This data is likewise passed with its initial
5   time tag to control CPU 60 and the locator system for
processing.

        During and after data collection from the reverse
voice channel, receiver 66 and comms. CPU 62 also monitor
the forward voice channel to detect further voice channel
10   assignments. When such assignments are detected, control
CPU 60, as well as surrounding base stations, are
notified to change data collection channels. This
subsequent reverse voice channel switching both insures
that sufficient data is collected for each collection
15   period and also provides additional data for improving
the accuracy of the location function performed by tdoa
CPU 20.

        This process of recording reverse control and voice
channel data with its corresponding time tags is
20   performed simultaneously at each of the base stations
receiving the cell phone transmission. This may be done
in response to identification of the reverse control
channel signal at each base station or it may be done in
response to trigger signals generated from one or more of
25   the base stations and passed to surrounding base stations
via comms. CPU 62 and the Ethernet connection 64. The
latter triggering avoids the necessity that each of the
base stations receive a signal of sufficient strength
from which to identify the predetermined number or the
30   called number. The 82 milliseconds of recorded data at
each base station provides sufficient identity between
the three recorded sets of data to determine comparable
times of arrival. Thereafter the recorded data is passed
to tdoa CPU 20 where calculations are made to determine

relative transmission time to the base stations 12-14 and
to apply that data to mapping software. These tdoa
calculations are described in greater detail below.

5   Fig. 3 shows an alternate system embodiment 70 of
the base station system 30 of Fig. 2. Sections and
components in Fig. 3 bearing the same reference numbers
as those in Fig. 2 are identical in form and function.
Generally included are a receiver section 72, processing
section 74 and control and communication section 76.
10   Receiver section 72 differs from Fig. 2 in that it
includes a dual down converter 78 and a pair of A/D
converters 80,81. The purpose for this is to cover the
entire 25 MHz cell phone spectrum with available A/D
converters 80,81 which only operate at 30 MHz. This is
15   accomplished by splitting the cell phone spectrum into a
pair of 12.5 MHz. base band signals with the dual down
converter 78 and then feeding each base band signal
through a separate 30 MHz. A/D 80,81 to provide adequate
sampling. To control the A/D converters 80,81 and time
20   tag generation, a 10 MHz. signal from the GPS receiver 46
is converted to a 30 MHz clock signal by the down
converter and fed to converters 80,81 and a time tag
generator 82 in processor section 74.

          Processor section 74 further includes a delay memory
25   84, a filter/decimator 54, FIFO buffer 84 and an FM
demodulator 86. Control and communications section 76
includes a single CPU 88 to perform the functions of both
CPUs of Fig. 2. The type of signals passed between
processor section 74 and control and comm. section 76 are
30   the same as Fig. 2.

          In operation, all of the channels in the wideband
cell phone spectrum are received, down converted and
digitized in receiver section 72 and fed to processor
section 74 as a pair of base band signals 90,91 along

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with clock and time tag signals synchronized to the
digitization process. Processor section 74 receives one
of the digitized data signals 90,91, under the control of
CPU 88 depending upon the spectrum location of the
5   reverse control channel being monitored. The received
signal 90,91 is fed directly into delay memory 82 and
into the filter/decimator 54 through a shunt 92 around
delay memory 82. Filter/decimator 54 is initially set to
separate the reverse control channel and feeds that data
10   to FM demodulator 86, which separates the data contained
therein from the carrier signal so that the data can be
monitored by CPU 88. This data is passed through a small
portion of buffer 84 and fed to CPU 88 for monitoring.

When CPU 88 detects a response from a predetermined
15   cell phone, or a predetermined called number, over the
demodulated reverse control channel, it generates a
trigger which switches the input of filter/decimator 54
from shunt 92 to the output of delay memory 82. Delay
memory 82 holds sufficient data so that the predetermined
20   number may be detected by CPU 88 while the same data is
still present in delay memory 82. The trigger signal
also causes a time tag signal to be sent to CPU 88 to
mark the beginning of the data being collected and causes
the data output of filter/decimator to be stored in FIFO
25   buffer 84. Once an amount of data (nominally 320
milliseconds) has been collected in buffer 84, it is
passed to CPU 88. CPU 88 then re-tunes the
filter/decimator to the reverse voice channel assigned to
the cell phone and detected from receiver 66 and also
30   triggers another time tag. This causes data to be
collected in buffer 84 from the reverse voice channel.
Similar data collections are also made from subsequent
reverse voice channel assignments. Once data has been
collected and sent to CPU 88, the data is sent with its

respective time tags to tdoa CPU 20 for tdoa
calculations.

   The method and apparatuses which function in
accordance with the present invention are robust in that
5   only one of the base stations monitoring the reverse
control channel needs to clearly receive a signal
identifying either a predetermined cell phone or a called
phone. Because it is possible to simply trigger all
surrounding base stations to record and transmit data
10   based upon one or more identified control and voice
channels, even signals received by several of the base
stations which are too weak for identification can still
be used for tdoa measurements. The remote triggering is
facilitated by the wideband nature of the data which is
15   received and stored in the delay memory of each base
station.

   The purpose of analyzing the signal data from each
of the base stations is to calculate the tdoa between at
least two pairs out of at least three base stations.
20   This tdoa data is then converted to relative distance
data and the location of the transmitter can be
calculated from the known locations of the base stations
and coordinated with map software. For purposes of
identification and notation, base stations are referred
25   to as a,b,c and cell phone transmission channels located
at different frequencies in the cell phone spectrum are
referred to as x,y,z.

   The signal data, S(t) for tdoa calculations comes in
packets of digitized signals. Each packet, S,
30   corresponds to one transmission channel x,y,z received at
one base station, a,b,c as in $S_{ax}, S_{ay}, S_{az}, S_{bx}....$ Each
packet also includes a time tag, nominally for the first
sample in the packet, and the sampling frequency or time
between samples is known. Two or more channel

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transmissions are sampled at each base station. Each
channel transmission is sampled at three base stations or
more.

5   The first step in the tdoa determination process is
the transformation of each packet of data into the
frequency domain by performing an FFT to produce $S(f)$ as
in $S_{ax}, S_{ay}, S_{az}, S_{bx}, S_{by}, S_{bz} \ldots$.

           The overall tdoa between any two base stations, r_{ab},
is determined by first determining the tdoa function in
10   each separate transmission channel, $R_{abx}, R_{aby}, R_{abz}$. This
is done in the frequency domain by multiplying the signal
data received at a base station in a transmission
channel, S_{ax}, by the complex conjugate of the same
channel data received at another base station, S_{bx}^{*},

15               $R_{abx} = S_{ax} \times S_{bx}^{*}$

           The same correlation is performed for each
transmission channel, x,y,z, between the two base
stations a,b.

           These calculated tdoa functions are converted back
20   into the time domain by an inverse FFT and show an
amplitude peak, as seen in Fig. 4, at the tdoa of the two
correlated signals. The precise peak is usually not
aligned with one of the points produced by the inverse
FFT, so a quadratic interpolation is performed using the
25   adjacent points to make a more accurate determination of
the peak amplitude and the exact time delay, or tdoa,
thereof for each transmission channel.

           The tdoa signals plotted in Fig. 4 vary between
transmission channels for each pair of base stations
30   because of phase differences at the different
frequencies. However, the tdoa amplitudes in the time
domain are substantially equal in the absence of
substantial multipath signal reception. Thus, variation

of the tdoa amplitudes between transmission channels is
an indication of multipath problems.

The interpolated time delay or tdoa values for all
transmission channels measured between two base stations
5   are averaged to determine Avg.r_{ab}.

The average tdoa is subtracted from each of the
correlated tdoa functions in the frequency domain by
using a multiplication factor to determine a residual
phase tdoa, $Ph.R_{abx}$, due to phase in each channel.

10            $$Ph.R_{abx} = R_{abx} \times e^{j2pift}, \quad \text{where } t = Avg.r_{ab},$$

and f is the center frequency of the respective channel,
x.

The resulting phase vectors in each of the frequency
bins of the residual tdoa function, $Ph.R_{abx}$, $Ph.R_{aby}$, ...,
15   are summed to determine the residual phase tdoa, $Ph.R_{ab}$,
for each transmission channel, x,y,z.

The amplitude of the residual phase tdoas from all
of the transmission channels between two base ations
are plotted, as shown in Fig. 5, against their respective
20   transmission channel frequencies and the angle of the
plot determines the overall residual tdoa, $Ph.r_{ab}$,
between two base stations. This residual phase tdoa is
added to the average tdoa, Avg.r_{ab}, for the respective
pair of base stations to determine the overall tdoa, r_{ab},
25   between those stations.

If the plot of phase tdoa vs. frequency of Fig. 5 is
not linear or if the peak values of the tdoa functions in
the time domain of Fig. 4 are not equal between a pair of
base stations, multipath, or multiple signal reception is
30   indicated. In such case, the residual phase tdoa values
for each frequency channel, as shown in Fig. 5, are
combined with their respective interpolated amplitude
values from R_{abx},... of Fig. 4 and are noted in the
frequency domain. All nonsample frequencies are set to a

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zero amplitude and zero phase. The resulting frequency
domain data is converted back into the time domain by an
inverse FFT and the resulting time domain data will show
the receipt of multiple signals as shown in Fig. 7. The
5   earlier signal 94 is used as the overall residual phase
delay, Ph.r$_{ab}$, even though the later signal 96 may be
stronger. With a minimum of three transmission channels
unevenly spaced within the cell phone band, the earlier
arrival may be readily ascertained. Distinguishing the
10   various multipath signals received is also enhanced by
zero padding in the frequency domain before taking the
inverse FFT.

The embodiments described above are intended to be
taken in an illustrative and not a limiting sense.
15   Various modifications and changes may be made to the
above embodiments by persons skilled in the art without
departing from the scope of the present invention as
defined in the appended claims. For example, the present
invention may be applied for locating similar
20   transmitters other than cellular phones and transmitters
using different transmission formats. These include
personal communication system transmitters, or PCS, and
code division packet data, or CDPD.

WHAT IS CLAIMED IS:

1. A method for determining the time difference of
arrival, tdoa, of signals from a cellular telephone, cell
phone, or similar transmitters at a pair of base
5   stations, comprising the steps of:

        substantially simultaneously sampling transmission
signals from the cell phone or similar transmitter at the
pair of base stations in a plurality of channels having
different frequencies;

10   correlating the corresponding signals sampled at the
base stations for each channel to determine a tdoa
therebetween for each channel;

        averaging the tdoas determined for each channel;

        subtracting the average tdoa from each of the
15 determined channel tdoas to determine a residual phase
tdoa for each channel;

        determining an overall phase tdoa between the pair
of base stations based upon the residual phase tdoas for
each channel; and

20   adding the average tdoa to the overall phase tdoa to
determine an overall tdoa between the pair of base
stations.

        2.   The method of claim 1, wherein the step of
25 correlating produces a tdoa function for each channel and
further wherein the step of subtracting the average tdoa
from each of the channel tdoas includes multiplication of
the correlated tdoa functions for each channel by a
factor in the frequency domain and vectorally summing the
30 results thereof to produce a residual phase measurement
for each channel.

        3.   The method of claim 2, wherein the step of
determining an overall phase tdoa includes deriving an

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overall relationship between the residual phase
measurements of all channels and their respective channel
frequencies.

5   4.   The method of claim 3, wherein the step of
deriving an overall relationship includes
        plotting the residual phase measurements of all
channels in the frequency domain against their respective
channel frequencies,
10   determining the angle of the plotted phase
measurements with respect to the frequency axis, and
        determining the overall phase tdoa from the
determined angle.

15   5.   The method of claim 4, further comprising
evaluating the presence of multipath signals from
amplitudes of the correlated tdoa functions or from the
derived overall relationship between the residual phase
measurements of all channels and their respective
20 frequencies.

        6.   The method of claim 2, wherein the step of
determining an overall phase tdoa, comprises the steps
of:
25   creating a frequency domain function from the
residual phase measurements for each channel frequency
and respective amplitudes of the correlated tdoa
relationships for each channel;
        inverse Fourier transforming the created frequency
30 domain function into a time domain function; and
        choosing the overall phase tdoa from a peak
occurrence in the transformed time domain function.

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7.   The method of claim 6, wherein the step of
inverse Fourier transforming results in a time domain
function having multiple peaks occurring at sequential
points in time representing multiple signal reception,
5   and further wherein the step of choosing the overall
phase tdoa includes using a point in time of an earlier
occurring peak as the overall phase tdoa.

8.   The method of claim 6, wherein the step of
10   creating a frequency domain signal includes setting
amplitude and phase values of frequencies outside of the
sampled plurality of channels equal to zero.

9.   A method for collecting transmission signals at
15   a first base station from a particular cell phone for the
purpose of determining location of the cell phone using
time difference of arrival, tdoa, comprising the steps
of:
      receiving signals transmitted over all channels of a
20   wideband, cell phone base station operating spectrum
including a known reverse control channel thereof;
      digitizing the received wideband spectrum signals;
      storing the digitized signals as digitized data in a
delay memory;
25   monitoring the known reverse control channel signal
for a cell phone transmission including a predetermined
number of either a cell phone to be located or a phone
number being called;
      identifying a predetermined number from the
30   monitoring of the reverse control channel; and
      storing data from the delay memory in response to
the identifying of the predetermined number, including
the portion of the received signal bearing identifying
data of the predetermined number.

10. The method of claim 9, wherein the steps of base signals, digitizing received signals, storing digitized signals, and storing data from the delay memory are performed at a plurality of additional base stations, and further wherein the step of storing data from the delay memory at the plurality of addition base stations is performed in response to the step of identifying a predetermined number performed at the first base station.

11. The method of claim 10, wherein the storing of data from the delay memory includes digitally filtering data stored in the delay memory to retain data from only a single selectable cell phone channel.

12. The method of claim 11, further comprising the steps of generating a sampling signal for the digitizing of the received signals along with corresponding time tag signals for the stored digitized data, and storing the corresponding time tag signals in the delay memory with the digitized data.

13. The method of claim 12, further comprising the steps of determining reverse voice channel assignments and storing data from one or more reverse voice channel assignments by digitally filtering data from the delay memory to retain only digitized reverse voice channel data and its corresponding time tag.

14. An apparatus for collecting transmission signals at a first cell phone base station from a particular cell phone for the purpose of determining location of the cell phone using time difference of arrival, tdoa, comprising the steps of:

means for receiving signals transmitted over all
channels of a wideband, cell phone base station,
operating spectrum including a known reverse control
channel thereof;

5   means for digitizing the received wideband spectrum
signals;

means for storing the digitized signals as digitized
data in a delay memory;

means for monitoring the known reverse control

10   channel signal for a cell phone transmission including a
predetermined number of either a cell phone to be located
or a phone number being called;

means for identifying the predetermined number from
the monitoring of the reverse control channel; and

15   means for storing data from the delay memory in
response to the identifying of the predetermined number,
including the portion of the received signal bearing the
identifying data of the predetermined number.

20   15. The method of claim 14, wherein the means for
storing data from the delay memory includes means for
digitally filtering data stored in the delay memory for
retaining data from only a single selectable cell phone
channel.

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16. The method of claim 15, further comprising
means for generating a sampling signal for the means for
digitizing along with corresponding time tag signals for
the stored digitized data, and means for storing the

30   corresponding time tag signals in the delay memory with
the digitized data.

17. The method of claim 16, further comprising
means for determining reverse voice channel assignments

and means for enabling the storing of data from one or
more reverse voice channels assignments by controlling
the means for digitally filtering data from the delay
memory to retain only digitized reverse voice channel
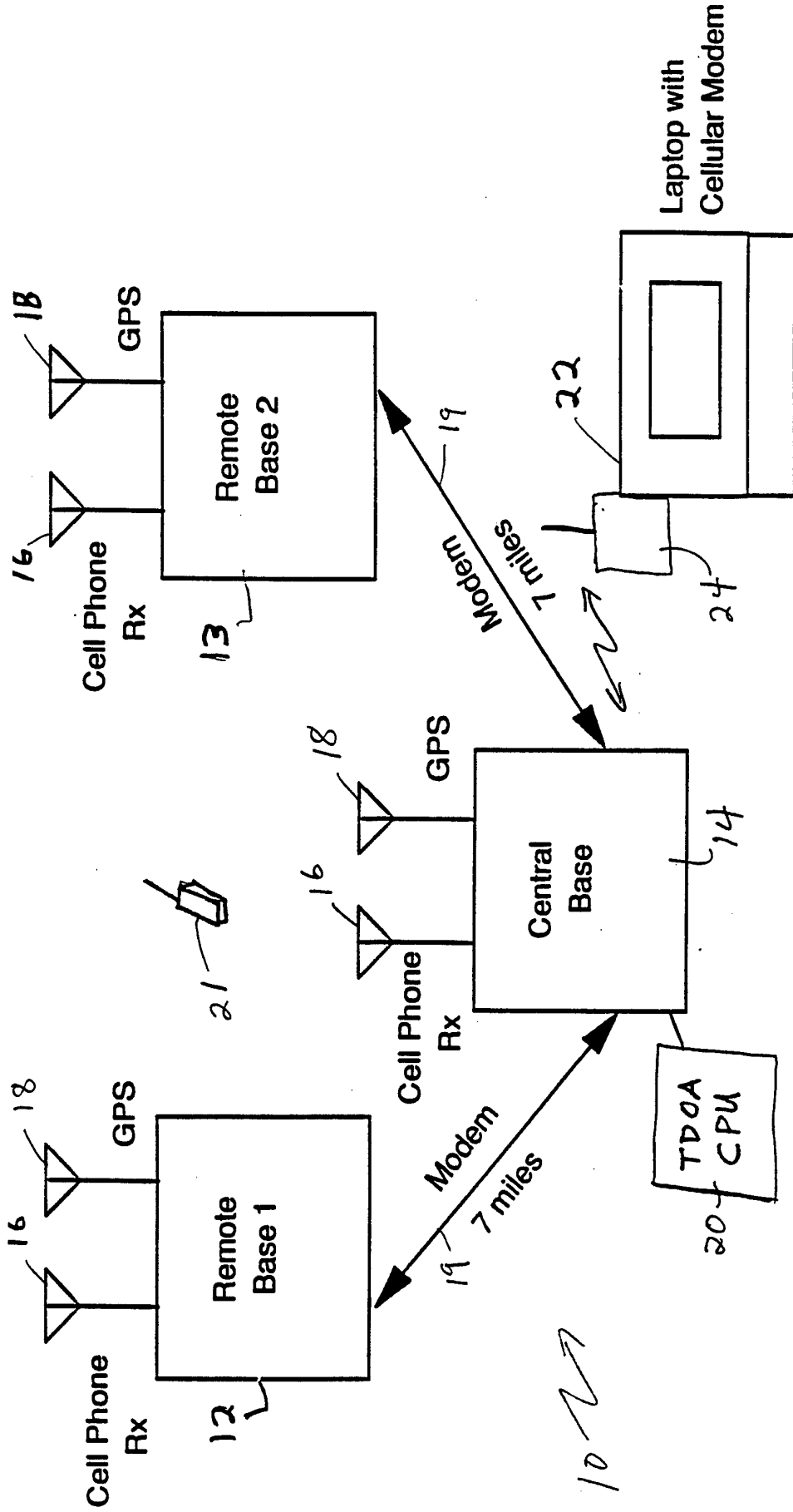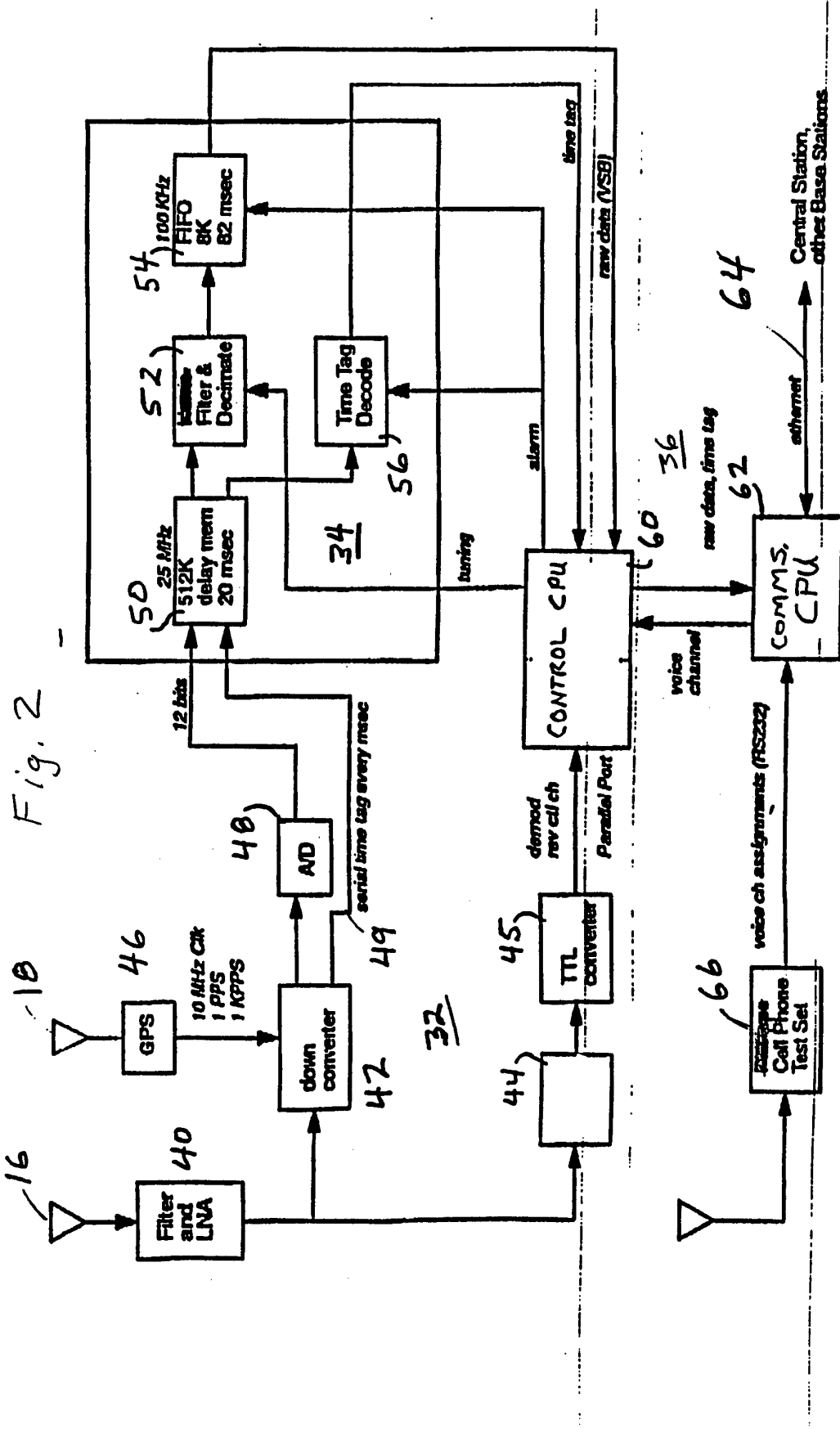5   data and its corresponding time tag.
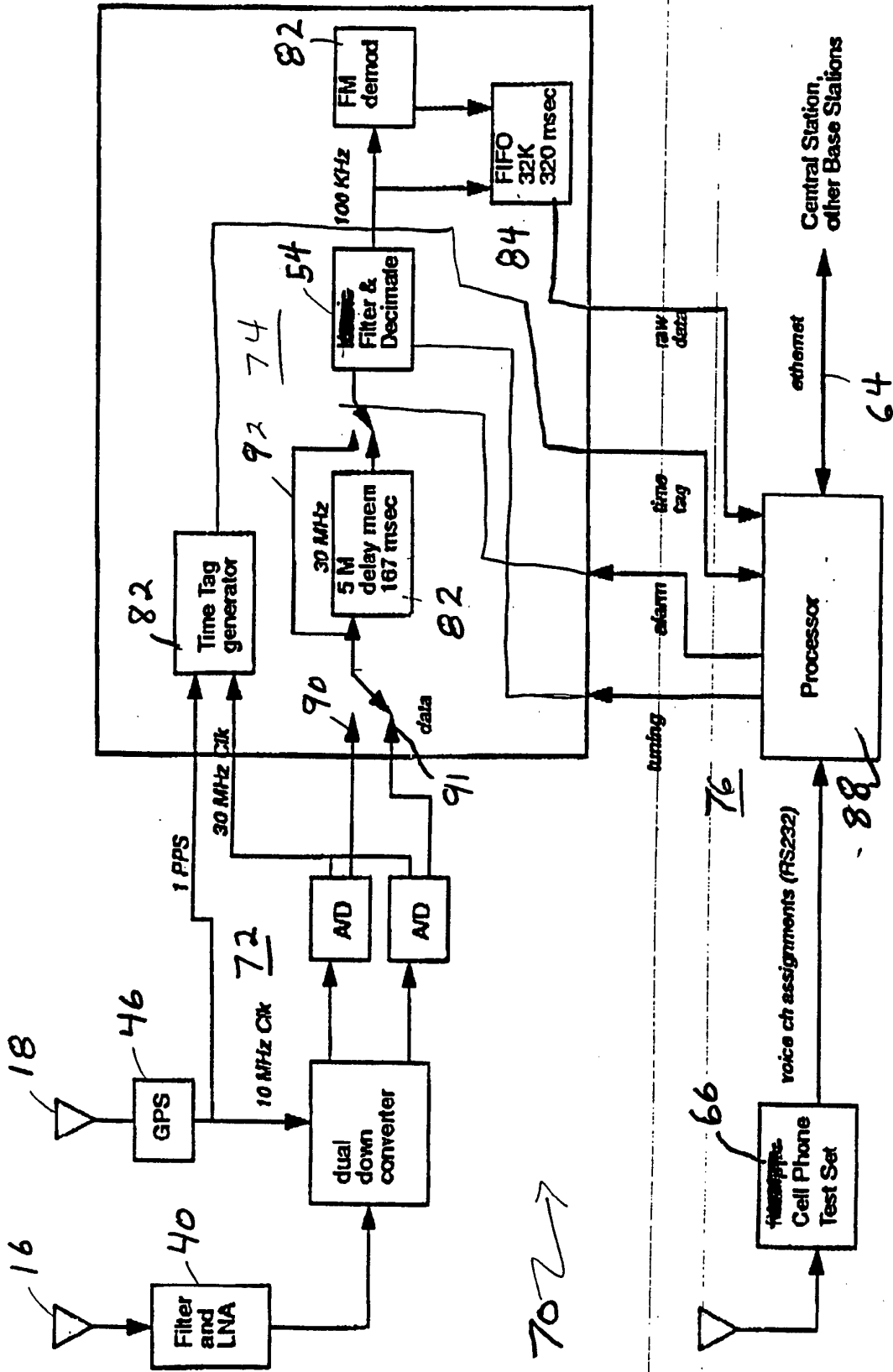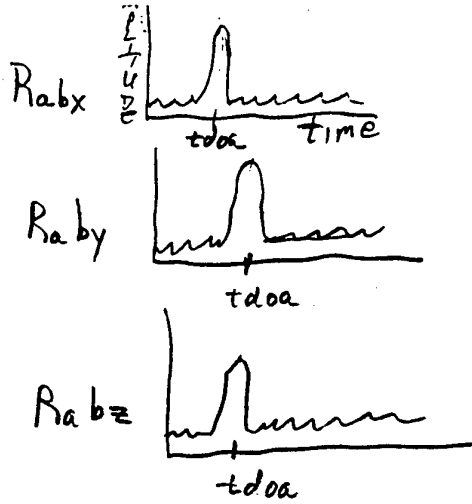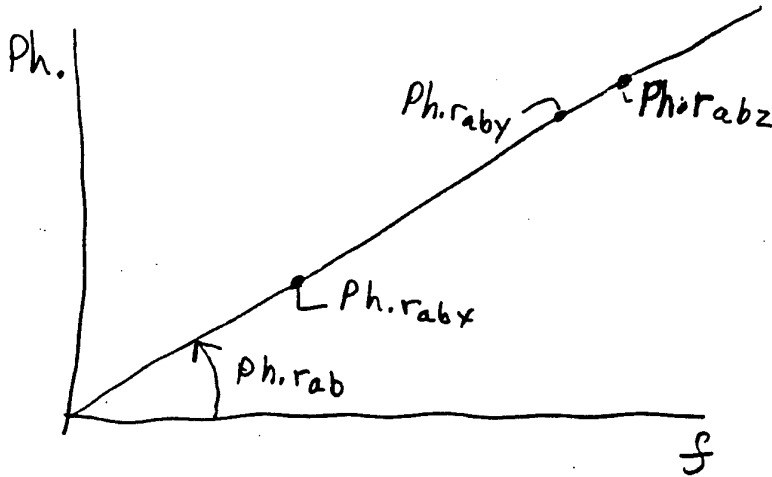
Fig. 1

Fig. 2

Fig. 3

Fig. 4.

Fig. 5

Reconstructed Wideband Time Domain Plot of Multiple Arrivals
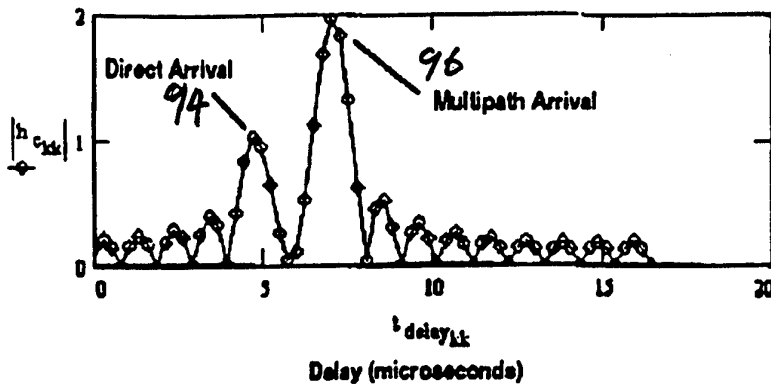16 Frequencies uniformly spaced over a 1 MHz Band

FIG. 6

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6)   :G01S 1/24; H04M 11/00
US CL   : 342/387, 451; 379/59
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. :   342/387, 451; 379/59

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 4,433,335 (WIND) 21 February 1984, col. 1, line 56-col. 3, line 4.	1-8
A	US, A, 5,327,144 (STILP ET AL) 05 July 1994, entire document	1-17
A	US, A, 5,317,323 (KENNEDY ET AL) 31 May 1994, entire document	1-17

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance		
"E"	earlier document published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 OCTOBER 1995	24 NOV 1995

Name and mailing address of the ISA/US	Authorized officer
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