

WIRELESS MESSAGING SYSTEM

FIELD OF THE INVENTION

5 The present invention relates to a wireless messaging system and more specifically, to a one way spread spectrum messaging system and a two-way messaging system that includes a communication downlink and a spread spectrum based communication uplink.

BACKGROUND OF THE INVENTION

10 Wireless communication is fast becoming one of the most rapidly growing businesses in the world today. The worldwide market for related products and services is undergoing an explosion. Within the wireless communication field, two of the fastest growing markets are those of two-way paging and telemetry, which are part of the more general market known as two-way messaging. Both the
15 two-way paging and telemetry markets are projected to grow enormously by the year 2000. Currently, the market for two-way pagers is relatively undeveloped because the technology is relatively new. The Personal Communications Industry Association (PCIA) estimates that, in the United States, there will be 48 million one-way paging customers and 8 million two-way customers by the year 2000.
20 Worldwide, it is estimated that the number of two-way pagers in use in the year 2000 is likely to exceed 24 million units. These estimates, however, are for narrowband systems only, they do not factor the use of broadband systems.

Traditional one-way paging systems may be characterized by the delivery of a message from a central point to a remote pager. Paging was originally
25 developed for numeric applications only (i.e. telephone numbers of parties wishing to contact the person holding the pager). Alphanumeric one-way paging has been developed only recently, but is however, for one-way paging only. The alphanumeric one-way pagers require approximately 10 times the amount of air time as compared to numeric one-way pagers. Alphanumeric messages are
30 generally much longer than numeric only messages and alphanumeric messaging requires a system capable of sending all the letters of the alphabet and various grammatical symbols which are not required by numeric only paging. The increase in the number of possibilities per bit of information requires coding with more bits

for each symbol than would be required by a strictly numeric only system. In addition, the enhanced complexity of the alphanumeric system requires a greater allocation of system capacity for system management functions than is required for numeric only paging.

5 In two-way paging, the remote pager receives a message, with the human operator then possibly sending a message back to the central control point. The two-way feature makes this system unique, since in traditional paging there is no data transmission to the pager and no data acquisition by the central point. Two-way paging is typically alphanumeric, so that each message in a two-way
10 system will consume an amount of airtime roughly equivalent to the amount of airtime consumed by any alphanumeric message. However, two-way alphanumeric paging as a system will consume more airtime than one-way alphanumeric paging, because in two-way paging, messages travel in both directions while in one-way alphanumeric paging messages travel only from the
15 controller to the paging unit. Thus, there is a much higher volume of message traffic in a two-way system.

The market for telemetry systems is expected to grow at substantial rates over the next five years. There are approximately 2 million radio telemetry units installed in the United States. This number is expected to rise to 15 million units in
20 the year 2000. Similar growth is expected to occur in other parts of the world. Telemetry applications include transmitting monitored information from the site of a machine or other device to some remote location. It also includes the acquisition of data from remote locations to a central point.

Telemetry by itself may not provide sufficient benefits but when coupled to a
25 supervisory control and data acquisition (SCADA) link, it becomes very beneficial. SCADA systems include both a downlink and an uplink. The downlink conveys command and control data and the uplink conveys acquired data back to the central control. The SCADA uplink can be compared to a telemetry link since most telemetry links are one way. SCADA is important because it means that both data
30 acquisition and supervisory control can occur in the same system. Supervisory control includes control of a device from a central location.

SCADA and telemetry systems usually operate from a fixed central point to fixed remote sites. However, in some systems the remote sites are mobile, such as when located in trucks or railroad engines.

Other applications for telemetry and SCADA are healthcare (i.e. monitoring patients' medical condition), manufacturing environments (i.e. monitoring machines, processes, inventories and tracking shipments), retail and financial markets (i.e. monitoring and controlling point-of-sale (POS) terminals, electronic cash registers, automated teller machines (ATMs), vending machines, lottery machines, computer and video game machines), traffic control (i.e. remote monitoring and control of traffic lights), utility meter reading (i.e. electric, gas, water), security systems, etc.

Recently, the Federal Communications Commission (FCC) in the United States allocated a portion of spectrum in the 902 to 928 MHz band to unlicensed uses, such as telemetry and two-way paging. Conventional one-way paging systems exist today that utilize narrowband channels. Currently, traditional one-way paging systems, such as POCSAG, are experiencing much congestion. This congestion is inhibiting the development of one-way alphanumeric paging as well as new two-way services such as acknowledgment paging, compressed voice, two-way paging and telemetry. In order to alleviate this congestion, the FCC recently auctioned off narrowband Personal Communications Services (PCS) radio channels in the 901-902, 930-931 and 940-941 MHz radio bands. The radio channels within these bands include channels having bandwidths of 12.5, 25 and 50 KHz.

Although current one-way paging systems operate almost exclusively on narrowband radio channels, narrowband systems provide imperfect solutions to the problem of channel congestion. Narrowband systems also do not provide a solution for the development of new two-way messaging services. The disadvantage of narrowband systems is that the data rate of the uplink or outbound link is relatively slow. The typical data rate for the downlink or inbound link on a conventional narrowband system will operate at 6.4 Kbps, while the uplink will operate at data rates between 800 bps and 9.6 Kbps depending on the channel bandwidth and infrastructure density.

Infrastructure density is related to the amount of infrastructure per unit area of territory, such as square kilometers or square miles. Infrastructure includes the three basic elements that make up a radio system, the customer end units (i.e. pagers), the base stations and the controllers. The capacity of a system is a function of the ability of the infrastructure to transmit, receive and process volumes of information traffic flow. System capacity and coverage may be enhanced by increasing the infrastructure density within the target area. Uplink speeds above

800 bps in narrowband systems will require increasingly high infrastructure densities. The maximum uplink data rate of 9.6 Kbps may require a density as high as one base station for every square mile of coverage area. Thus, rapid uplink data rates can be attained on narrowband channels but only with very heavy infrastructure costs. In addition, operators of narrowband systems face the dilemma of accepting very slow uplink speeds or increasing the uplink speed but at the cost of very high infrastructure investments coupled with high annual operating costs.

One attempt to overcome the disadvantages of the prior art utilizes the technique of spread spectrum communication techniques. Spread spectrum communications is a type of broadband radio frequency (RF) communication technique that takes a relatively narrowband message and spreads it out over a relatively much broader bandwidth. The spread spectrum approach has advantages over the narrowband approach in terms of reducing power requirements for the infrastructure and for the remote units (i.e. pagers or telemetry units), increasing cell reuse, resistance to interference and resistance to eavesdropping. These advantages translate into much lower infrastructure costs, less expensive remote units and a generally more secure system than can be offered by conventional narrowband systems.

Spread spectrum techniques include two different methods: direct sequence and frequency hopping. Direct sequence spread spectrum combines the data stream with a pseudo random spreading code running at a much higher bit rate. Each bit in the original message is represented by the much longer pseudo random code. The effect is to smear the bandwidth of the original data stream into a much longer bandwidth, providing much improved resistance to interference and noise. Frequency hopping also achieves an improvement under noisy conditions by hopping from frequency to frequency using a pseudo random pattern known to both transmitter and receiver.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a wireless messaging system that has rapid data transmission speeds and requires low infrastructure and operating costs.

- 5 It is a further object of the present invention to provide a two-way wireless messaging system that includes a communication downlink and a communication uplink.

It is also an object of the present invention to provide a one-way wireless messaging system that includes a high speed transmission rate.

- 10 Another object of the present invention is that the communication uplink, in the two-way messaging system and also in the transmission scheme in the one-way messaging system, be highly resistant to interference caused by noise, multipath and other nearby transmitters.

- 15 The present invention achieves these objects by utilizing direct sequence spread spectrum techniques in the communication uplink of the two-way messaging system and in the transmitter of the one-way messaging system.

- 20 Some of the advantages of using direct sequence spread spectrum in the transmitter of both messaging systems are outlined below. Direct sequence spread spectrum permits a much higher loading of messaging units on radio channels when compared to conventional broadcast schemes or even when compared to conventional cellular technology. This lowers the infrastructure cost per messaging unit. Using direct sequence spread spectrum for the uplink requires fewer infrastructure sites compared with the sites required by other technologies at similar data rates. This lowers the annual operating cost for system operators.
- 25 The faster bit rates of the present invention permits system operators to maximize the volume of data traffic on a particular radio channel. This eliminates queue times and enables high speed applications to be deployed. Direct sequence spread spectrum also permits the messaging units to operate at lower power levels than similar units using conventional narrowband transmission schemes. Thus, the
- 30 messaging units can get by with relatively inexpensive power amplifiers and less battery energy, reducing the cost of the messaging units. In addition, spread spectrum systems are highly resistant to all forms of environmental interference, including radio noise, environmental degradation, human tampering and eavesdropping.

The present invention is a wireless messaging system which includes both a one-way messaging system and a two-way messaging system. The two-way messaging system utilizes conventional protocols for the communication downlink and a direct sequence spread spectrum transmission scheme for the communication uplink. Included are transmitters for transmitting the downlink signal using a conventional downlink protocol, two-way messaging units for receiving the downlink signal and for transmitting a signal on the uplink using direct sequence spread spectrum techniques and receive base stations for receiving the uplink signal from the two-way messaging units. The one-way messaging system includes one-way messaging units for transmitting a signal using direct sequence spread spectrum techniques and receive base stations for receiving the transmitted signal from one-way messaging units. In both systems, receive base stations send received messages to a network center for processing and forwarding to an e-mail gateway, fax gateway, voice mail gateway or client applications. For paging applications, a messaging terminal sends messages to be transmitted to the transmitters. Also disclosed are the transmitter and spread spectrum receiver in the receive base stations. The power supply and spread spectrum transmitter in both messaging units are disclosed, including the receiver in the two-way messaging unit. A transmit frequency feedback scheme between the receive base station and messaging units provides frequency agility to the system. A scanning algorithm allows the receiver in the receive base stations to compensate for transmit frequency inaccuracies in the messaging units. In addition, mechanisms for reducing the effects of interference and noise in the receive base station are disclosed.

In accordance with a preferred embodiment of the present invention there is provided a two-way wireless messaging system having a communication downlink and a communication uplink, comprising at least one transmitter for generating and transmitting a downlink message on a downlink signal over said communication downlink, at least one two-way messaging unit for receiving the downlink signal on the communication downlink and extracting the downlink message therefrom. The two-way messaging unit generates and transmits an uplink message on an uplink signal over the communication uplink. The two-way messaging unit uses direct sequence spread spectrum to encode and generate the uplink signal. The system also comprising at least one receive base station for receiving and decoding the direct sequence spread spectrum uplink signal on the communication uplink from the two-way messaging unit and for extracting the uplink message therefrom.

The system also provides a network center coupled to at least one receive base station. The network center receives messages received and decoded by at least one receive base station. The system also provides an electronic mail gateway coupled to the network center, the electronic mail gateway for providing the network center access to electronic mail systems. Also provided by the system is a facsimile gateway coupled to the network center, the facsimile gateway for providing the network center with access to facsimile services. The system also provides a voice mail gateway coupled to the network center, the voice mail gateway providing the network center access to voice mail services.

10 In accordance with a preferred embodiment of the present invention, the system provides a transmitter/receive base station able to generate and transmit the downlink signal to the two-way messaging unit and able to receive and decode the uplink signal transmitted by the two-way messaging unit. In addition, the system includes at least one messaging terminal coupled to the transmitter and the
15 network center. The messaging terminal for constructing downlink messages and transmitting them to the transmitter. The messaging terminal for coordinating messages transmitted with messages received by the network center.

Also provided in accordance with a preferred embodiment of the present invention is a two-way messaging unit which includes a receive antenna for
20 receiving a downlink signal transmitted over a communication downlink, a receiver coupled to the receive antenna, the receiver for receiving the downlink signal from the receive antenna and for decoding and extracting a downlink message from the downlink signal. Also included is a spread spectrum transmitter for encoding an uplink message using spread spectrum encoding techniques and for generating an
25 uplink signal therefrom. In addition, a transmit antenna coupled to the spread spectrum transmitter is included, the transmit antenna for transmitting the uplink signal. Also, a controller is included coupled to the receiver and the spread spectrum transmitter. The controller receives the downlink message from the receiver and generates the uplink message. In addition, a power supply is
30 included for converting energy in an external energy source, coupled to the unit, into supply voltages for the unit.

In accordance with a preferred embodiment of the present invention the system further includes an audio indicator coupled to the controller, the audio indicator for providing an audible alarm means to the user, a vibrator coupled to the
35 controller, the vibrator for providing a vibrating alarm means to the user, a visual

indicator coupled to the controller, the visual indicator for providing a visual alarm means to the user.

5 The system also includes a data link coupled to the controller, the data link for interfacing an external device to the controller, a display coupled to the controller, the display for presenting information to the user, at least one button
coupled to the controller, the buttons enabling a user to enter information and/or
commands into the unit.

Also in accordance with a preferred embodiment of the present invention,
there is provided a receive base station which includes a receive antenna for
10 receiving a spread spectrum uplink signal transmitted over a communication uplink,
an RF receiver coupled to the receive antenna, the RF receiver for receiving the
spread spectrum uplink signal from the receive antenna and for mixing down the
spread spectrum uplink signal to an intermediate frequency. Also included is a
spread spectrum decoder coupled to the RF receiver for decoding the spread
15 spectrum uplink signal into a baseband data message, a message processor
coupled to the spread spectrum decoder for extracting a received data message,
communication circuitry coupled to the message processor, the communication
circuitry for transmitting the received data message over a communication link and
a controller coupled to the RF receiver, the spread spectrum decoder and the
20 message processor, the controller for controlling and coordinating the operation of
the receive base station.

In addition, there is provided in accordance with a preferred embodiment of
the present invention a one-way wireless messaging system which includes at
least one one-way messaging unit for generating and transmitting a message
25 carried by a transmission signal, the one-way messaging unit using direct
sequence spread spectrum to encode the message and generate the transmission
signal. Also included is at least one receive base station for receiving and
decoding the direct sequence spread spectrum transmission signal from the
one-way messaging unit and for extracting the message therefrom.

30 There is also provided in accordance with a preferred embodiment of the
present invention a one-way messaging unit which includes a spread spectrum
transmitter for encoding a message using spread spectrum encoding techniques
and for generating a transmit signal therefrom, a transmit antenna coupled to the
spread spectrum transmitter, the transmit antenna for transmitting the transmit
35 signal, a controller coupled to the spread spectrum transmitter, the controller for

generating the message and managing the generation of the transmit signal, and a power supply for converting energy in an external energy source, coupled to the unit, into supply voltages for the unit.

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BRIEF DESCRIPTION OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

Fig. 1 is a high level block diagram illustrating a wireless two-way messaging system built in accordance with a preferred embodiment of the present invention;

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Fig. 2 is a high level block diagram illustrating the directional antennas used in the base station receiver;

Fig. 3 is a high level functional block diagram illustrating the two-way messaging unit;

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Fig. 4 is a high level block diagram of the receiver portion of the two-way messaging unit;

Fig. 5 is a high level schematic diagram illustrating the RF receiver portion of the receiver in the two-way messaging unit;

Fig. 6 is a high level block diagram illustrating the spread spectrum transmitter portion of the two-way messaging unit;

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Fig. 7 is a high level functional block diagram illustrating the modulator and RF transmitter portions of the spread spectrum transmitter in the two-way messaging unit;

Fig. 8 is a high level functional block diagram illustrating the power supply portion of the two-way messaging unit;

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Fig. 9 is a high level schematic diagram illustrating the step-up converter portion of the power supply in the two-way messaging unit;

Fig. 10 is a high level schematic diagram illustrating the step-down converter portion of the power supply in the two-way messaging unit;

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Fig. 11 is a high level block diagram illustrating the receive base station portion of the two-way messaging system;

Fig. 12 is a high level functional block diagram illustrating the RF receiver portion of the receive base station;

Fig. 13 is a high level functional block diagram illustrating the IF circuitry portion of the RF receiver section of the receiver base station;

5 Fig. 14 is a high level functional block diagram illustrating the spread spectrum decoder portion of the receive base station;

Fig. 15 is a high level schematic diagram illustrating the downconverter portion of the spread spectrum decoder in the receive base station;

10 Fig. 16 is a high level schematic diagram illustrating the matched filter/correlator portion of the spread spectrum receiver;

Fig. 17 is a high level flow diagram illustrating the process of generating and encoding a data array for transmission by the two-way messaging unit;

Fig. 18 is a high level flow diagram illustrating the process of receiving and decoding the data message in the base station receiver;

15 Fig. 19 illustrates the bit format for the data message transmitted from the two-way messaging unit to the receive base station;

Fig. 20 illustrates the frequency spectrum of a sample signal received by the receiver portion of the receive base station;

20 Fig. 21 illustrates the method of tuning the receiver portion of the receive base station to the center frequency of the signal transmitted by the two-way messaging unit;

Fig. 22 illustrates the method of adjusting the center frequency of the signal transmitted by the two-way messaging unit;

25 Fig. 23 is a high level block diagram illustrating the center frequency fine tuning circuitry portion of the clock circuitry in the two-way messaging unit;

Fig. 24 illustrates the detection window generated by the flywheel mechanism;

30 Fig. 25 is a high level block diagram illustrating a wireless one-way messaging system built in accordance with a preferred embodiment of the present invention; and

Fig. 26 is a high level functional block diagram illustrating the one-way messaging unit.

DETAILED DESCRIPTION OF THE INVENTION

A high level block diagram of a two-way messaging system, generally referenced **10**, built in accordance with a preferred embodiment of the present invention is illustrated in Figure 1. System **10** comprises both transmitters for the communication downlink and receivers for the communication uplink. A messaging terminal **18** is coupled to one or more transmitters **20**. Messaging terminal **18** can be configured for any type of downlink protocol such as any one of the protocols in use today. Typically the protocol is transmitted over the communication downlink using conventional narrowband radio channel techniques. The protocols used can be related to paging, telemetry or SCADA, security, healthcare, utility metering or any other type of downlink protocol. Messaging terminals **18** are well known in the art for conventional one-way paging systems. These conventional systems may be employed in the present invention for the communication downlink. Transmitters **20** transmit the downlink message to a plurality of two-way messaging units **12**. Two-way messaging units **12** can be configured for two-way paging, SCADA, telemetry or any other type of application utilizing a two-way communication link. Examples of existing paging protocols that can be supported by two-way messaging unit **12** are POCSAG, ERMES, FLEX and APOC. In addition, a non-paging protocol can be implemented in two-way messaging units **12** such as a SCADA protocol for SCADA or telemetry applications.

In accordance with a preferred embodiment of the present invention, one or more receive base stations **14** receive messages from two-way messaging units **12** on the communication uplink. In a preferred embodiment, receive base stations **14** receive direct sequence spread spectrum encoded radio signals from two-way messaging units **12**. In turn, receive base stations **14** relay received messages to a network center **28**. Network center **28** is coupled to receive base stations **14** and to messaging terminal **18** through communication links. The communication links from receive base stations **14** to network center **28** may comprise a modem on each end connected through an ordinary telephone line. Other communication links would work as well such as, RF modem, packet switched X.25, frame relay, asynchronous transfer mode (ATM), etc. Network center **28** is also coupled to an electronic mail (e-mail) gateway **22**, facsimile gateway **24** and a voice mail gateway **26**. Depending on the message and the service subscribed to by the customer, the received messages from receive base stations **14** may be forwarded to one or more of the coupled gateways. For example, if system **10** is implemented as a two-way paging system, two-way messaging unit **12** can respond to a received

page transmitted on the communication downlink. In a preferred embodiment, the response would be transmitted, using direct sequence spread spectrum techniques, from the two-way messaging unit to one or more receive base stations 14. Depending on the proximity of the two-way messaging unit, more than one
5 receive base station 14 will be able to receive the transmitted message.

In addition to sending information through a gateway, receive base stations 14 transmit received messages to one or more client applications 27. Service subscribers or other end users of the system receive the data messages from the receive base stations and process these messages using one or more custom
10 applications 27. For example, custom applications 27 may be used in systems such as SCADA, telemetry, vending machines, financial, etc.

Information is exchanged between network center 28 and messaging terminal 18 in order to correlate messages received from two-way messaging units 12 with the original message sent by messaging terminal 18 via transmitters 20. In
15 an alternative embodiment, the downlink transmitters are combined with the uplink receivers in a transmitter/receiver base station 16. In this embodiment, transmitter/receive base stations 16 maintain communication links with both messaging terminal 18 and network center 28. Both embodiments are not limited to one network center and one messaging terminal. A two-messaging system may
20 comprise more than one network center and more than one messaging terminal.

For paging applications, two-way messaging units 12 can support different types of messages on the communication uplink. For example, messages may be programmed beforehand by the user into two-way messaging units 12. In this case, the service operator at the network center must also have knowledge of the
25 user's messages programmed into the two-way messaging units. Thus, only a short code needs to be transmitted in place of the actual message. This saves airtime and reduces the operating costs of the system. In addition, the two-way messaging unit can be preprogrammed with frequently used responses such as "yes," "no" or "I'll call you later." These messages would also be represented by
30 much shorter codes when actually being transmitted on the uplink. Additionally, a user can form a random alphanumeric message not represented by any preprogrammed codes. These types of messages utilize the most air time and would be the most costly for a two-way paging system operator. An additional type of message supported by two-way messaging units 12 is compressed voice. A
35 user can generate a voice message to be sent on the communication uplink.

Two-way messaging unit 12 records the voice message, formats and compresses it for transmission to the receive base stations where it is processed further.

A high level block diagram of receive base station 14 is illustrated in Figure 2. In a preferred embodiment, a receive base station comprises one or more directional antennas 30 forming an antenna array 32. Each directional antenna 30 is coupled to a separate receiver 34. Each receiver 34 is able to receive and decode direct sequence spread spectrum encoded signals. Both directional antennas 30 and receivers 34 can be optimized to receive signals in any radio frequency range between 800 MHz to 1 GHz, including the 902-928 MHz industrial, scientific and medical (ISM) band allocated by the FCC for unlicensed use. Many broadband personal communication services (PCS) applications currently use this unlicensed band. In addition, antennas 30 and RF receivers 34 can be optimized to receive at other frequencies such as 1.9 GHz and 2.4 GHz ISM bands. If used for a paging application, for example, a processor 38 receives the data decoded by receivers 34 and formats a message containing the data for transmission to network center 28. Processor 38 is coupled to a telephone communication link through a modem 40. A watchdog 36 provides a margin of safety if one or more receivers 34 or processor 38 lose control or stop operating properly. Watchdog circuits are well known in the art and can be adapted to receive base station 14.

In two-way messaging system 10, more than one receive base station 14 may be required in order to cover the geographic area dictated by the particular application. In addition, not every receive base station 14 needs to deploy four directional antennas 30 as illustrated in Figure 2. The actual number of directional antennas 30 will depend on the needs of the particular site. The radio frequency band of the receive base station also will depend on the application. For example, the radio frequency band will likely vary according to the country in the world the system is deployed in and the type of two-way messaging system used (i.e. paging, telemetry, SCADA, security, healthcare systems, vending machines, etc.).

A high level block diagram of two-way messaging unit 12 is illustrated in Figure 3. Two-way messaging unit 12 comprises, at the core, a controller 54 for supervising and coordinating the activities and functions of the unit. For the communication downlink, signals transmitted from transmitters 20 (Figure 1) are received by receive antenna 48. Receiver antenna 48 is coupled to a receiver 52, which in turn is coupled to controller 54. For the communication uplink, controller 54 sends outgoing messages to a spread spectrum transmitter 58 which is coupled to a transmit antenna 60. A clock circuit 56 provides clock and timing signals to

controller 54, receiver 52, spread spectrum transmitter 58 and to other parts of two-way messaging unit 12. Controller 54 is also coupled to a data link circuit 62 which in turn communicates with an external device 44. Controller 54 also is coupled to various user interface devices such as a button/keypad 50, display 64,
5 audio indicator 66, a vibrator 68 and a visual indicator 70. A power supply 46 provides the needed voltages to various parts of two-way messaging unit 12 and receives its source of power from an energy source 42.

Receive antenna 48 is adapted to receive signals in the particular radio frequency band chosen for the application. Receiver 52 is a conventional RF
10 narrowband receiver constructed using techniques well known in the art. For paging applications, antenna 48 and receiver 52 receives, demodulates and decodes conventional one-way downlink paging protocols, such as POCSAG, ERMES, FLEX or APOC. Based on the received message or on command from the user, a message may be transmitted on the communication uplink from
15 two-way messaging unit 12 to receive base stations 14. As previously described, messages can be preprogrammed or randomly entered. In either case, the message is formatted by controller 54 and passed to spread spectrum transmitter 58. Spread spectrum transmitter utilizes direct sequence spread spectrum techniques to encode and modulate the message. The message is subsequently
20 modulated up to the carrier frequency of the uplink, typically in the range of 800 MHz to 1 GHz but may also be in the 1.9 GHz or 2.4 GHz ISM bands. The message is then transmitted via transmit antenna 60. Both receiver 52 and spread spectrum transmitter 58 are described in more detail below.

Two-way messaging unit 12 can be adapted for various applications such as
25 two-way paging, SCADA, telemetry, security, vending machine data acquisition, traffic control, healthcare, etc. In applications where portability and small size are desired, an advantage of two-way messaging unit 12 is that it is able to operate from a relatively small source of energy such as a conventional AA or AAA alkaline battery. Power supply 46 uses the energy from energy source 42 to generate the
30 various voltages needed by different components of two-way messaging unit 12. Power supply 46 is described in more detail below.

Clock circuitry 56 generates the various clocks used throughout the two-way messaging unit. Included are clocks and other timing signals for receiver 52, controller 54 and spread spectrum transmitter 58. Clock circuitry 56 generates a
35 regular operating set of clock signals and in addition, also generates clock signals at a much reduced frequency for low power operation of the two-way messaging

unit circuitry. A control signal from controller 54 determines whether clock circuitry 56 generates clock signals at the normal nominal rate or at the lower frequency for power down mode of operation. In addition, clock circuitry 56 has frequency adjusting circuitry, described in more detail below, to allow fine tuning of the center
5 frequency used to modulate the transmit signal in spread spectrum transmitter 58. In a preferred embodiment of the present invention, clock circuitry 56 generates a 2 MHz clock for regular operation and a 32 KHz clock for reduced power mode (i.e. sleep mode) of operation.

Data link circuitry 62 provides the means for an external device 44 to
10 communicate with the two-way messaging unit. In a preferred embodiment data link circuitry 62 provides a standard RS-232 interface to the outside world. External device 44 can be any device able to communicate via RS-232. Such devices include a personal computer (PC), handheld computers, specialized programming devices, etc. Data link circuitry is provided to enable service
15 operators to program the units, facilitate troubleshooting and maintenance, to allow a user to program messages into the unit, download messages received from the downlink or for other related purposes.

As embodied as a two-way pager, two-way messaging unit also comprises a set of buttons and/or a keypad 50 for a user to enter messages and commands as
20 part of the user interface of the unit. In addition, the user interface includes a display 64 such as a liquid crystal display (LCD) type, well known in the art. Display 64 is used to convey alphanumeric and other data to the user. An audible indicator 66, such as a buzzer or other type of alarm device, provides an audible alarm to signify certain events such as when messages are received or low battery
25 indication. A vibrator 68 provides indication to a user that messages or pages have been received. Vibrator 68 is useful when it is desirable that the user receive messages or pages without an audible alarm going off that might be disturbing to others. Unit 12 also comprises one or more visual indicators 70 to alert the user to various events such as when messages have been received. Visual indicator 70
30 serves as another indicating means for use by the user.

Receiver 52 is shown in more detail in Figure 4. Illustrated is receive antenna 48 coupled to receiver 52 which comprises an RF receiver 92 coupled to a decoder 94. Communication downlink signals transmitted from transmitters 20 (Figure 1) are received by two-way messaging unit 12 via receive antenna 48. The
35 signal from receive antenna 48 enters RF receiver 92 which mixes down and demodulates the received signal and outputs a digital data stream representing the

received message. Decoder 94 receives data bits from RF receiver 92 and decodes them in accordance with the particular protocol in use in that particular system. The output of decoder 94 is the message received such as a numeric or alphanumeric message, in the case of a two-way paging unit. In paging applications, for example, the protocol decoded may be POCSAG, ERMES, FLEX, etc. As mentioned previously, RF receiver 92 and decoder 94 can both be adapted to handle any transmitted signal suitable for a particular application, such as paging, SCADA, telemetry, security, etc. In a preferred embodiment, decoder 94 can readily be adapted to decode the POCSAG protocol using the PCO5003 or the PCF5001T integrated circuits manufactured by Philips Semiconductors, Sunnyvale, California.

The output of decoder 94 is then passed to controller 54 (Figure 3), which then alerts the user via audio indicator 66, vibrator 68 and/or visual indicator 70. Controller 54 also displays the message on display 64. The user then is able to respond to the received message by using buttons/keypad 50 to key in a response.

RF receiver 92, shown in Figure 5, will now be described in more detail. RF receiver comprises a differential band pass filter 72, low noise amplifier 74, phase shifters 76 and 78, mixers 80 and 82, local oscillator 90, low pass filters 84 and 86 and demodulator 88. Receive antenna 48 can be adapted to receive signals at VHF, UHF and 900 MHz frequencies and is preferably a loop antenna. Band pass filter 72 receives a differential signal from receive antenna 48 and is constructed to pass only frequencies in the band containing the message signal. The output of band pass filter 72 is also a differential signal and is input to low noise amplifier 74 which amplifies the input signal to a higher level. The differential output of low noise amplifier 74 is simultaneously input to 45 degree phase shifters 76, 78. Phase shifter 76 shifts its input signal +45 degrees and phase shifter 78 shifts its input signal by -45 degrees. Shifters 76, 78 are LC networks, well known in the art, constructed to apply quadrature phase shifted RF signals, I and Q, to mixer inputs 80, 82. Local oscillator 90 is input to both mixers 80, 82. The I and Q output signals of both mixers 80, 82 feed identical signal channels in phase quadrature. Low pass filters 84, 86 remove the unwanted upper frequency spectrum. The I and Q outputs of both low pass filters are input to demodulator 88. Demodulator 88 detects the relative phase of both input channel signals at each zero crossing point in either channel. In a preferred embodiment, demodulator 88 receives a signal originally modulated using frequency shift keying (FSK). If the I channel signal leads the Q channel, the FSK tone frequency lies above the local oscillator

frequency (i.e. using the POCSAG protocol, the data is a '0'). If the I channel signal lags the Q channel, the FSK tone lies below the local oscillator frequency (i.e. POCSAG data '1'). The data bits output by demodulator are input to decoder 94 (Figure 4). RF receiver can be constructed using the UAA2080 paging receiver
5 integrated circuit chip manufactured by Philips Semiconductor, Sunnyvale, California. As discussed previously, decoder 94, receives the data bits output by RF receiver 92 and, in accordance with the particular protocol, decodes them, outputting the numeric or alphanumeric message, in the case of a paging protocol. In an alternative embodiment, RF receiver 92 performs conventional heterodyning,
10 well known in the art, rather than the direct conversion technique illustrated in Figure 5.

Illustrated in Figure 6 is a detailed block diagram of spread spectrum transmitter 58, used to transmit data destined for the communication uplink. Comprising a spread spectrum encoder 96, modulator 98 and RF transmitter,
15 spread spectrum transmitter 58 receives a block of data comprising the data message from controller 54, encodes the data message using direct sequence spread spectrum techniques and subsequently transmits the encoded message via transmit antenna 60. As discussed previously, controller 54 receives a block of data either from external device 44 through data link circuitry or from the
20 buttons/keypad 50 (Figure 3). In a preferred embodiment, controller 54 adds an error correcting code (ECC), cyclic redundancy check (CRC) checksum and synchronizing (sync) words to the data message. In addition, controller 54 performs bit interleaving on the data block, preferably to a depth of eight, creating a new interleaved bitstream. In the beginning of the message, controller 54 inserts a
25 preamble of all 0's or all 1's as a training sequence, to assist receive base stations 14 in locking onto the received signal. Spread spectrum encoder 96 receives the formatted block of data from controller 54 and performs direct sequence spreading and differential encoding functions to output baseband I and Q symbols, using techniques well known in the art.

30 Direct sequence spread spectrum communications takes an input data stream having a particular bit rate and spreads the bandwidth of that data stream over a bandwidth many times the original bandwidth. This is achieved by multiplying pseudo random codes or pseudo noise (PN) codes having finite bit lengths with the input bit stream. In a preferred embodiment, a pseudo random
35 code sequence with a length of 255 is used for the spreading function. The pseudo random length code used in a preferred embodiment is a maximal length

code (i.e. length of $2^N - 1$). Other code lengths could also be used with varying performance results. A 4 Kbps input data bit stream achieves a final output data rate, after spreading, of 1 Mbps, generally referred to as chips per second or cps.

5 In a preferred embodiment, spread spectrum encoder 96 supports code division multiple access (CDMA) and time division multiple access (TDMA). These schemes allow the spread spectrum based system to support multiple simultaneous users on the same wideband channel (i.e. the 902 to 928 MHz ISM band). In a CDMA system, each CDMA receiver recovers only the end user information it is looking for (i.e. information related to the particular pseudo random
10 code assigned to the receiver). The other direct sequence spread spectrum signals continue to look like white noise. Thus, an advantage to CDMA is that no there is no need to segregate users into distinct channels or time slots.

In a preferred embodiment, the chip rate used by spread spectrum encoder is 1 Mcps. The pseudo random code length used in a preferred embodiment is
15 255 bits long. A longer code is used to achieve better immunity against interference and multipath for bit rates, shorter length PN codes can be used. Depending on the modulation scheme used by modulator 98, the input data stream is either kept as a single bit stream (i.e. I channel) or split into two alternating bit streams (i.e. I and Q channels) representing the data message to be transmitted
20 on the uplink. In a preferred embodiment, the data message remains one data stream. In this case, the data bits of the formatted messages are multiplied or XORed by the PN code sequence. From this bit stream, a differential bit stream is created representing the difference from one output bit to the next. In an alternative embodiment of two bit streams, each stream is multiplied or XORed by
25 the PN sequence and the output passed through a differential encoder, forming I and Q baseband channels.

Modulator 98 and RF transmitter 100 are illustrated in more detail in Figure 7. Baseband I and Q channels are input to low pass filters 102, 104 respectively. Low pass filters 102, 104 have a cutoff frequency of approximately 1.33 MHz. The
30 filtered output signals are input to phase shift key (PSK) modulator 106. In a preferred embodiment, only the I channel is used, therefore PSK modulator 106 generates a binary phase shift keyed (BPSK) output signal. In an alternative embodiment, both I and Q channels are used and PSK modulator 106 generates a quadrature phase shift keyed (QPSK) output signal. The local oscillator signal
35 used by PSK modulator 106 is derived from frequency source 108, synthesizer 110 and voltage controlled oscillator (VCO) 112. Preferably a temperature

compensated (TC) crystal oscillator is used for frequency source 108. The output of frequency source 108 is coupled to synthesizer 110, which in a preferred embodiment, is a UMA1018M manufactured by Philips Semiconductor. The output of synthesizer 110 is fed into VCO 112. The output of VCO 112 provides the local oscillator signal for PSK modulator 106.

The signal output from PSK modulator 106 is first amplified by RF preamplifier 114 which boosts the output of PSK modulator to approximately 7 dBm (i.e. 7 mW). The signal is then input to RF power amplifier 116, which preferably is a PM2103A class A/B amplifier manufactured by Pacific Monolithics. RF power amplifier 116 amplifies the output of RF preamplifier 114 to a level of approximately 30 dBm, the equivalent of 1 W of RF power. The signal is then filtered to conform to FCC Part 15 regulations and matched to 50 ohm transmit antenna 60 which transmits the output signal over the air.

Power supply 46 is illustrated in more detail in Figure 8. Two-way messaging unit 12 operates from a portable energy source when embodied as a two-way paging unit or a remote SCADA or telemetry unit without a source of utility power or other constant energy source. Thus, the power requirements on power supply 46 are severe. Receiver 52 (Figure 3) draws relatively little power from energy source 42. Spread spectrum transmitter 58, however, draws a significantly larger amount of power. The power consumption of spread spectrum transmitter 58 is of a bursty nature, occurring only during actual transmission. During transmission, RF power amplifier 116 (Figure 7) must be supplied with sufficient power to transmit the signal at 1 W. The transmit message make take up to approximately 100 ms to transmit and RF power amplifier requires approximately 600 ma of current at 5 V. Standard alkaline or NiCad AA or AAA batteries cannot supply sufficient power to fulfill this requirement. To overcome this problem, power supply 46 utilizes a step-up converter 120 coupled to an energy storage device 122. Energy storage device 122 is coupled to step-down converter 124. When a message is ready to be transmitted onto the communication uplink, step-up converter 120 boosts the voltage of energy source 42, which is typically a standard AA or AAA battery cell, from a nominal 1.5 V to approximately 25 V. The energy is stored as electrical charge on energy storage device 122. Preferably, energy storage device 122 is a capacitor of sufficient capacity to hold the necessary charge to power RF power amplifier 116 (Figure 7). To provide sufficient charge capacity, it is readily shown that a capacitor of at least 1000 uF is required. Soft start circuitry 126, coupled to step-up converter 120 provides a controlled smooth

ramping up of the current applied to energy storage device 122. Soft start circuitry 126 prevents huge current from flowing through energy storage device 122 initially when step-up converter 120 is first turned on.

At the time of transmission, step-down converter 124 provides sufficient
5 current flow at the proper voltage level to power RF power amplifier 116. The energy previously stored in energy storage device 122 is released in a controlled fashion by step-down converter 124. Soft start circuitry 132 controls the rate of discharge of energy storage device 122 so as to prevent potentially damaging large initial currents and/or voltages. Step-down converter 124 and step-up
10 converter are described in more detail below.

Low voltage, low current power is provided by DC/DC converter 128. Battery voltage is stepped up to a nominal 5 V by DC/DC converter 128. In addition, upon control of controller 54 (Figure 3), the low voltage output can be switched between 5 V nominal and 3.0 V for low power operation of the circuit.
15 Preferably, DC/DC converter 128 is constructed around a MAX856 adjustable output step-up converter manufactured by Maxim Integrated Products, Sunnyvale, California. In addition to providing a low voltage supply, power supply 46 also supplies an intermediate voltage via intermediate DC/DC converter 130. The input to intermediate DC/DC converter 130 is the low voltage output of low voltage
20 DC/DC converter 128. Intermediate voltage DC/DC converter steps the input voltage from a typical 5 V to 10 V. The MAX 680 manufactured by Maxim Integrated Products can be used to construct intermediate voltage DC/DC converter 130.

Step-up converter circuit 120 is illustrated in more detail in Figure 9. Energy
25 source 42, typically a AA or AAA battery 146 is coupled to switch 134. Switch 134 provides on/off control for two-way messaging unit 12. Switch 134 turns power on and off to not only step-up converter 120 but also to low voltage DC/DC converter 128 (Figure 8). Step-up converter 120 comprises inductor 136, semiconductor switch 140, switch control circuitry 138 and diode 142. Controller 54 (Figure 3)
30 individually controls the on/off operation of converters 120, 124, 128 and 130. Thus, each element is turned on only when required in order to reduce unnecessary power consumption.

Assuming switch 134 is closed, and controller 54 has enabled step-up
converter 120, battery voltage is applied to inductor 136. Switch control circuitry
35 138 operates to open and close semiconductor switch 140, which may be any

suitable semiconductor switch, preferably an n-channel enhancement mode metal oxide semiconductor field effect transistor (MOSFET). Other types of semiconductor switches known in the art would work as well. Switch control circuitry 138 operates, preferably, at approximately 100 KHz opening and closing switch 140. When switch 140 is closed, current flows from the battery through inductor 136 and forward biased diode 142 to charge energy storage device 122, a large capacitor 144. When switch 140 is opened, the back EMF generated across inductor 136 causes a voltage larger than the battery voltage to appear across capacitor 144. Diode 142 prevents capacitor 144 from discharging through inductor 136 or switch 140. To achieve the proper voltage/current capabilities for RF power amplifier 116 (Figure 7), capacitor 144 is charged to a voltage of approximately 25 V. As discussed previously, soft start circuitry 126 is coupled to switch control circuitry 138 and functions to prevent large initial currents through capacitor 144.

Illustrated in Figure 10 is a more detailed schematic diagram of step-down converter 124. Energy storage device 122, comprising capacitor 144, is coupled to step-down converter 124, which comprises semiconductor switch 150, capacitor 152, diode 154, inductor 158 and capacitor 156. Step-down converter 124 operates as a conventional step-down converter, well known in the art. Switch 150 is switched on and off at a rate of approximately 100 KHz by switch control circuitry 148, when enabled by controller 54 (Figure 3) at the moment of transmission. Inductor 158 and capacitor 156 function to reduce the nominal 25 V on capacitor 144 to approximately 5 V supplied to RF power amplifier 116. Diode 154 prevents the back EMF of inductor 158 from discharging capacitor 156 during the time switch 150 is closed. Soft start circuitry 132 provides a smooth ramping-up of the output voltage and prevents large initial currents through the components.

Capacitor 152 functions to provide a ground reference to enable switch 150, preferably a MOSFET device, to turn on. Initially, the source terminal of MOSFET 150 has no reference to ground. Thus, V_{GS} is zero and cannot be increased to turn the switch on. In order to create a positive V_{GS} and turn switch 150 on, capacitor 152 is used to generate a lower voltage at the source terminal. It does this by causing inductor 158 to generate a back EMF voltage lowering the source terminal voltage relative to the gate, thus turning switch 150 on.

Thus, power supply 46 provides sufficient power to RF power amplifier 116 by slowly charging an energy storage device to a higher voltage and later stepping

this higher voltage down to the appropriate lower voltage and discharging the energy storage device over a relatively short time interval.

A detailed high level block diagram of receiver base station 14 is illustrated in Figure 11. Receive base station 14 comprises antenna 160, RF receiver 162, spread spectrum decoder 164, message processor 166, communication circuitry 168, controller 172 and watchdog 170. In operation, one or more receive base stations 14 would be deployed to cover a geographic area. The number of receive base stations 14 needed depends on the size and type of the terrain within the geographic area, among other things, for example. In operation, uplink signals transmitted from two-way messaging unit 12 are received by receiver antenna 160. The received signal is input to an RF receiver 162 which mixes the signal down to an intermediate frequency. The signal is then decoded by spread spectrum decoder 164 which passes the spread spectrum signal through a matched filter and a correlator which function to extract the raw data bits of the transmitted message. A message processor 166 receives these raw data bits and de-interleaves the data stream, performs ECC and CRC computations. The original transmitted data message is output by message processor 166 to communication circuitry 168 which, in a preferred embodiment transmits the message over a communication link to network center 28 (Figure 1). A controller 172 directs the various components of receive base station 14 and a watchdog timer 170 assures that controller 172 continues to operate properly.

A detailed high level block diagram of RF receiver 162 is illustrated in Figure 12. The signal is received by antenna 160 and input to a band pass filter 174 having a bandwidth large enough to pass the frequency band of interest. Band pass filter 174 can be any suitably constructed passive filter but preferably is a cavity filter having a suitably large pass band. The output of band pass filter 174 is input to a low noise amplifier 176. Amplifier 176 should preferably be located as close as possible to antenna 160 so as to minimize relatively large losses in the cable runs. The gain of amplifier 176 is set by an automatic gain control (AGC) control circuitry 196 which is configured so that the IF output of RF receiver 162 is negatively feedback to AGC control circuitry 196. The output of low noise amplifier 176 is input to a band pass filter 178 having a suitably set pass band. The output of band pass filter 178 is input to mixer 180 which mixes the input signal with a local oscillator signal derived from a synthesizer 182. In a preferred embodiment, the output frequency output of synthesizer is configured so that the mixer output is centered around 70 MHz. For receiving signals in the 902 to 928 MHz ISM band,

the frequency of the output of synthesizer 182 is able to be varied from 972 to 998 MHz. Synthesizer 182 is preferably tunable in 400 KHz steps upon command from controller 172 (Figure 11). In a preferred embodiment, synthesizer 182 can also function to provide a spectrum analysis function. The signal received by RF receiver 162 can be scanned to determine the relative signal strength at each frequency step. This feature can optionally be used to sense the level of interference within the band of interest or to search for the uplink transmitted signal if the system is configured to allow multiple uplink transmit frequencies. Typically, synthesizer 182 is configured to output a particular frequency upon initialization and is not modified thereafter.

An IF low noise amplifier 184 amplifies the output of mixer 180 and outputs the amplified signal to band pass filter 186 which has a center frequency of 70 MHz and a pass band of suitable size. Preferably, band pass filter 186 is a surface acoustic wave (SAW) device such as the BP1042 70 MHz SAW filter manufactured by RF Monolithics, Inc. The output of band pass filter 186 is amplified by a low noise amplifier 188. The output of low noise amplifier 188 is input to a mixer 190. The signal from a local oscillator 191 is mixed with the output of low noise amplifier 188. The frequency of local oscillator 191 is preferably fixed at 64.667 MHz and is derived from a stable crystal oscillator as known in the art. Mixer 190 downconverts the 70 MHz signal to approximately 5.33 MHz and outputs the signal to IF circuitry 192, which is described in more detail below. The output of IF circuitry is input to a low pass filter 194 which has a suitable cutoff frequency.

A detailed high level block diagram of IF circuitry 192 is illustrated in Figure 13. The function of IF circuitry 192 is to output a relatively constant amplitude signal regardless of the input signal amplitude. IF circuitry 192 applies AGC to the signal so that the output of IF circuitry 192 has a constant amplitude in order that the signal have the maximum dynamic range upon input to the analog to digital (A/D) converters in spread spectrum decoder 164. AGC is accomplished using three variable gain low noise amplifiers 176 (Figure 12), 200 and 204. Each low noise amplifier acts an AGC stage with all three stages applying a unified effect to bring the output signal up to a level of 0 dBm. AGC control circuitry 196 receives a feedback signal from the IF output of IF circuitry 192. A level detector 198 provides a control signal to AGC control circuitry 196 which generates suitable gain control signals for low noise amplifiers 176 (Figure 12), 200 and 204.

The output of mixer 190 is input to low noise amplifier 200. The gain of low noise amplifier 200 is set by AGC control circuitry 196. The output of amplifier 200

is input to a band pass filter 202 which, preferably, has a center frequency of 5.33 MHz. The output band pass filter 202 is input to low noise amplifier 204 whose gain control signal is provided by AGC control circuitry 196. The amplitude of the signal output by amplifier 204 is at a constant level of -30 dBm. This signal is then
5 amplified by fixed gain low noise amplifiers 206 and 208 which have a combined gain of 30 dB to bring the output signal level up to 0 dBm. The output of amplifier 208 is low pass filtered by filter 194 which is set to a suitable cutoff frequency.

The IF output signal is output from low pass filter 194 and input to spread spectrum decoder 164 which is illustrated in more detail in Figure 14. The
10 bandwidth of the IF input signal is approximately 1.33 MHz, as discussed in the section on spread spectrum transmitter 58 (Figure 6), with a center frequency of 5.33 MHz. The IF input signal is first converted to digital format by A/D converter circuitry 210. In a preferred embodiment, the A/D converter within A/D converter circuitry 210 is clocked asynchronously at a frequency of 16 MHz. The operation
15 of A/D converter circuitry is not phase locked to the received signal, thus the RF receiver implements incoherent detection. As discussed previously, the modulation scheme used in modulator 98 (Figure 6) may be BPSK or QPSK. Regardless of the modulation scheme, in a preferred embodiment, one A/D converter is required for the I channel. In this embodiment, the digital output of A/D
20 converter 210 is input to a downconverter 212 which mixes the input I channel data with the signal generated by local oscillator 218. Local oscillator generates both cosine and sine clock signals permitting a complex multiplier within downconverter 212 to generate complex summed products. Local oscillator 218 is preferably a digital numerically controlled oscillator which can be constructed using a sine wave
25 look up table coupled to a digital to analog converter. The look up table can be configured to achieve any desired precision by varying the depth and resolution of the table. The digital downconverter/carrier tracker STEL-2130A from Stanford Telecom, Santa Clara, California can be utilized to perform the downconverter and local oscillator functions.

30 In an alternative embodiment, two A/D converters are utilized rather than one to digitize the IF in from the RF receiver. Two A/D converters can be used to digitize bit streams at higher rates. If two A/D converters are used, both I and Q channels would be input to downconverter 212 and a complex multiply would be performed on both, as described in more detail below. Alternatively, to digitize bit
35 streams at higher rates, one A/D converter can still be used but it is clocked at a faster clock speed.

A detailed high level block diagram of the complex multiplier portion of downconverter 212 is illustrated in Figure 15. In the embodiment of one A/D converter, only the I channel is input to multipliers 224 and 226, the Q channel input is tied to ground, presenting a zero at the Q input and reducing the unit's power consumption. The Q input is coupled to multipliers 228 and 230. The cosine signal from local oscillator 218 is coupled to multiplier 224 and 230. The sine signal from local oscillator 218 is coupled to multipliers 226 and 228. The I channel output signal is generated from the output of multiplier 228 subtracted from the output of multiplier 224. The Q channel output signal is generated from the output of multiplier 226 added to the output of multiplier 230.

Referring again to Figure 14, the I and Q signals output from downconverter 212 are input to a matched filter/correlator 214. Matched filter/correlator 214 comprises a 256 bit shift register for the I channel bit stream, Q channel bit stream and for the PN code sequence. The PN code sequence must be identical with the PN code sequence used in spread spectrum encoder 96 (Figure 6). Matched filter/correlator 214, described in more detail below, looks for a correlation between the PN code sequence and the input signal data. When a match is found, the corresponding I and Q bits are output to a demodulator 216.

A detailed high level block diagram of matched filter/correlator 214 is illustrated in Figure 16. Matched filter/correlator 214 comprises a 256 bit shift register for the I data channel 236, Q data channel 240 and the coefficient data 238 (i.e. PN code sequence). Coefficient data register 238 is coupled to multipliers 332 associated with both I and Q registers 236, 240, respectively. During each clock cycle, each bit of the PN code sequence is separately multiplied with the corresponding bit from the I and Q channel data via multipliers 332. The 256 I channel products are summed in summer 242. The 256 Q channel products are summed in summer 244. The outputs of summers 242, 244 are output as I sum and Q sum to demodulator 216 (Figure 14). A magnitude generator 246 generates the square root of the sum of the squares of the outputs from summers 242, 244. The generated magnitude is input to a comparator 248 along with a threshold value stored in a threshold register 250. Comparator 248 compares the magnitude to the threshold and outputs a detect signal when the magnitude is greater than the threshold. Preferably matched filter/correlator 214 utilizes the STEL-3310 integrated circuit manufactured by Stanford Telecom, Santa Clara, California. In a preferred embodiment, four STEL-3310 devices are cascaded together, each implementing a 64 bit coefficient register, for a total of 256 bits.

Referring again to Figure 14, the I and Q sum outputs from matched filter/correlator 214 are input to demodulator 216. Demodulator 216 performs BPSK or QPSK demodulation depending on the modulation scheme used in the transmitter. In a preferred embodiment, demodulator 216 performs differential BPSK demodulation. Differential demodulator 216 can be constructed using the STEL-2120 bit synchronizer/differential PSK demodulator from Stanford Telecom, Santa Clara, California. To help differential demodulator 216 lock onto the received signal, a preamble of either all 1's or all 0's is sent by the transmitter. In addition, due to inaccuracies in the frequency sources used in the transmitter, a controller 220 performs a scanning algorithm, described in more detail below. For proper reception of a 4 Kbps data stream, the output frequency of local oscillator 218 must be within 1 KHz of the center frequency of the received signal. A phase or frequency error signal is generated by demodulator 216 and fed back to controller 220 which then calculates a correction for local oscillator 218. Controller 220 acts to close a feedback loop between demodulator 216 and downconverter 212/local oscillator 218 combination. Controller 220 also receives the magnitude generated by magnitude generator 246 (Figure 16). Once receive lock is achieved, it is possible that a bursty noise source or strong interference can cause matched filter/correlator 214 to lose signal detection. Consequently, the inputs to demodulator 216 are also effected by the interference, corrupting the outputs. To prevent spread spectrum decoder 164 from going out of lock and losing its detect signal, flywheel circuitry 222 functions to insert an artificially created detect signal at the proper time. Flywheel circuitry 222 is explained in greater detail below.

The process of forming a message by controller 54 (Figure 3) in two-way messaging unit 12 and the complementary process of de-formatting the message by message processor 166 will now be described in more detail. The primary function of this process is to combat interference from surrounding noise sources. Illustrated in Figure 17 is the process of formatting a message in two-way messaging unit 12. Initially, controller 54 (Figure 3) forms the raw data block or array to be sent to receive base station 14 (Figure 1) (step 260). A CRC checksum is generated on the data array using, preferably, the standard CCITT-16 CRC check as is well known in the art (step 262). The checksum is then appended to the data block. An ECC code is then generated on the entire data block, including the CRC checksum (step 264). Preferably, the data is passed through either a Hamming coder or a convolution coder. In a preferred embodiment, a Hamming coder is used. The Hamming code process results in a bit overhead of

approximately three code bits for every four data bits. Thus, in a preferred embodiment, for every seven bits, a one bit error can be corrected. The bits are then interleaved to a depth of eight (step 266). The process of interleaving prevents a burst of noise from destroying the ability of the receiver to decode the transmitted message. Using interleaving, noise or interference spanning adjacent bits result in a lost bit only every 8 bits, as opposed to consecutive bits which would destroy reception of the message. One bit error every 7 bits can be corrected by the ECC data transmitted along with the data message. To facilitate finding the beginning and end of a message, three sync words are inserted into the message (step 268). One at the beginning, one in the middle and one at the end of the data message. These sync words are unique bit patterns that allow the receiver to identify the start and end of a message. After the sync words are inserted, the preamble is inserted at the beginning of the data message (step 270). As discussed previously, the preamble may be either all 0's or all 1's. The preamble is used by the receiver to lock onto and begin decoding the received spread spectrum signal. After the preamble is added to the data message, it is passed to spread spectrum transmitter 58 (Figure 3) by controller 54 for transmission (step 272).

The process performed by message processor 166 (Figure 11) is illustrated in more detail in Figure 18. Message processor 166 receives the I and Q data bit stream from spread spectrum decoder 164. The I and Q bits output correspond to the original message input to spread spectrum encoder 96 (Figure 6) but interleaved by 2. Message processor 166 de-interleaves the I and Q channel data bit streams forming one bit stream (step 274). The preamble is first searched for (step 276) and then the sync words are located (step 278). Once the sync words are found, it is known that the message lies between the first and the second sync word and the second and the third sync word (step 280). The data message is then de-interleaved (step 282). Following de-interleaving, the data is passed through the ECC coders (step 284). Bit errors having rates of one in seven and lower can be corrected, in a preferred embodiment. After ECC processing, the CRC checksum is computed and compared with the transmitted checksum (step 286). After the CRC check, the complete data message is formed (step 288) and transmitted to network center 28 (Figure 1) through a communication link (step 290). Typically, receive base station 14 would be connected to network center 28 via modems utilizing ordinary telephone lines. The format of the data message as it is transmitted is shown in detail in Figure 19. Data sections 296 and 300 include

the original data array with the ECC, CRC and the interleaving having been already performed. Sync words 294, 298 and 302 are placed at the beginning, middle and end of the data message. Preamble 292 is added to the beginning of the message.

- 5 As discussed previously, the center frequency of the signal transmitted by the transmitter can vary due to inaccuracies in the components used. Sources of inaccuracies are the crystal oscillators, for example, that may have accuracies on the order of 5 to 10 ppm. These inaccuracies may result in the transmitted signal having a center frequency skew of ± 10 KHz. To improve reception of the
- 10 transmitted signal, controller 172 (Figure 11) in receive base station 14 performs a scanning procedure which steps through a frequency range hunting for the center frequency of the transmitted signal. A frequency spectrum plot of the received signal is illustrated in Figure 20 to aid in understanding the scanning procedure. A high level flow diagram of the scan procedure is illustrated in Figure 21. Referring
- 15 to Figure 20, the transmitted signal is modeled as a $\sin x/x$ frequency pattern. To properly receive the signal, it is desirable that the receiver local oscillator be locked onto the center frequency of the transmitted signal, represented by f_m . In general, for a range of frequencies, controller 172 steps through the range and writes a frequency value into local oscillator 191 in RF receiver 162 (Figure 12).
- 20 The magnitude generated by matched filter/correlator 214 (Figure 14) is monitored by controller 220. The process continues until f_m is located.

- Referring to Figures 20 and 21, the scan procedure begins by initializing local oscillator 218 (step 304). The frequency of local oscillator 191 is set to f_{low} , the lower limit of the range of frequencies to be scanned (step 306). Next,
- 25 controller 172 enters into a loop comprising the following steps. First, the lower frequency f_l of the main lobe of the transmitted signal is located (step 308). To scan for f_l , controller 172 increments the local oscillator frequency value until the output of matched filter/correlator 214 crosses a certain threshold T . In a preferred embodiment, T is chosen to be higher than the anticipated level of the first side
- 30 lobes of the signal but lower than the level of the main lobe. Once the frequency f_l is located, controller 172 continues scanning for f_u (step 310). To find f_u , controller 172 increments the local oscillator frequency value until the output of matched filter/correlator 214 falls below the threshold T . Once the lower and upper frequencies of the main lobe are found, the middle frequency f_m is calculated (step
- 35 312). Local oscillator 191 frequency value is set to this value f_m (step 314). If the output of matched filter/correlator 214 is above the threshold and above the values

received at frequencies f_L and f_U , then it is likely that the center frequency of the main lobe has been found (step 316). As a check, the frequencies f_{LS} and f_{US} are calculated (step 317). These are the center frequencies of the lower sidelobe and upper sidelobe, respectively. The final frequency chosen is the frequency
5 corresponding to the maximum signal magnitude among frequencies f_M , f_{LS} and f_{US} (step 319). If the frequency determined in step 312 is actually the center frequency of the main lobe than the signal magnitude at f_M will at a maximum. If f_M does have the maximum signal magnitude, the main lobe is actually to either the left or right of this lobe. Next, local oscillator 218 in spread spectrum decoder 164 is fine tuned
10 by controller 220 (Figure 14) (step 318). Based on the error signal from demodulator 216, controller 220 adjusts the frequency value used by local oscillator 218 to generates the reference signal for downconverter 212. If during the scan process, f_{HIGH} is reached while searching for f_L or f_U , then an error condition is generated and the signal cannot be received.

15 To further overcome improve reception of the uplink signal in receive base station 14, a preferred embodiment of the present invention includes a mechanism to adjust the center frequency of the transmitted signal in spread spectrum transmitter 58 of two-way messaging unit 12 (Figure 3). Generally, a feedback loop is created between receive base station 14 and two-way messaging unit 12.
20 The feedback loop is closed by controller 172 (Figure 11) transmitting a frequency correction signal or value back to the two-way messaging unit 12 on the conventional downlink. The error signal is used by controller 54 (Figure 3) in two-way messaging unit 12 to fine tune the reference clock signal input to synthesizer 110 by clock circuitry 56 in modulator 98 (Figure 7). A high level flow
25 diagram illustrating the center frequency fine tuning procedure is shown in Figure 22. The first step is to determine the center frequency of the actual received signal in the receive base station 14 (step 320). This is done using the scan procedure discussed above. The amount of deviation in center frequency remaining after the scan procedure is performed, is used by controller 172 to calculate a frequency
30 error value (step 322). A control message is generated containing the frequency error value and is transmitted to two-way messaging unit 12 (step 324) using the downlink protocol. Once received by two-way messaging unit 12, controller 54 fine tunes clock circuitry 56 using the received frequency error value (step 326). Thus, PSK modulator 106 (Figure 7) can generate a signal having much better center
35 frequency accuracy.

The ability to alter the frequency of the transmitter (i.e. change its channel) has other applications as well, not only as a fine tuning mechanism. If, for example, the receiver senses that a particular channel is becoming overloaded or approaching capacity, it can instruct the two-way messaging units to switch their transmitters to another channel. This gives the system frequency agility and enables the system to perform frequency hopping from crowded channels to lightly loaded or other more preferable channels.

A detailed high level schematic diagram of the portion of clock circuitry 56 that enables the center frequency feedback mechanism discussed above, is illustrated in Figure 23. Generally, a variable capacitance device such as a varactor is used to vary the total capacitance that forms a resonant circuit with a crystal oscillator. In operation, the control message is received over the conventional downlink by receive antenna 48 and receiver 52. The message is decoded by controller 54 and a suitable frequency error value is written to a frequency error data register 340. Digital to analog (D/A) converter 342 converts the digital error value into an analog representation and resistors 344, 346, 350 and capacitor 348 form a filter network for the analog signal output by D/A converter 342. The result of the filter network is a voltage generated across a varactor 352. The capacitance value of varactor 352 is linearly related to the voltage applied across it. Thus, the varactor capacitance combined with capacitor 356 effectively alters the capacitance across crystal 360. The capacitance coupled across crystal 360 determines the frequency at which it will resonate. Altering the capacitance across crystal 360, via varactor 352, allows the frequency of the signal input to a clock generator 364 to be varied, thus altering the frequency of the clock signals sent to spread spectrum transmitter 58. Using this mechanism, mid message fine tuning of the center frequency of the transmitted message is possible. In addition, frequency source inaccuracies in two-way messaging unit 12 can be compensated for.

Flywheel circuitry 222 in spread spectrum decoder 164 (Figure 14) will now be described in more detail. Flywheel circuitry 222, in a preferred embodiment of the present invention, is another mechanism to combat interference, noise and multipath in the received signal. Reference is made to Figure 24 which illustrates the bits of one of the registers 236, 238 or 240 in matched filter/correlator 214 (Figure 16). If the noise interference in the received signal is too large and lasts the duration of enough chip times, then reception of that bit is not possible and matched filter/correlator will not detect the bit. Consequently, demodulator 216

(Figure 14) will not be able to output the proper message bits. However, the use of ECC codes, CRC codes and interleaving in the transmitter, allow the receiver to recover from multiple bit hits. Once the receiver has locked onto the receive signal, a loss of a finite number of consecutive bits will not prevent correct reception of the message. Thus, flywheel circuitry 222 generates and inserts synthesized detect signals at the proper time to prevent demodulator 216 from losing signal lock. The incorrect bits from demodulator 216 are later corrected by processes within message processor 166 (Figure 11).

Flywheel circuitry 222 operates by first determining the chip position within the PN code sequence time that detect signal 330 would normally be generated for the particular message being received. This chip position is found after two or more consecutive bit detects have occurred. It then creates a gating window 328 around the chip time the detect signal would normally be generated. The width of the gate or window is approximately ± 2 chip times around the detect signal. Thus, if after initial lock is achieved, a detect signal is not generated by matched filter/correlator 214 within window 328 a detect signal, generated by flywheel circuitry 222, is substituted into the chip position it would normally have been generated in. Flywheel circuitry 222 reduces multipath interference by gating the false detect signals generated due to noise and multipath. Any false detect signal generated outside window 328 is gated out by flywheel circuitry 222.

A high level block diagram of a one-way wireless messaging system, generally referred as 10, built in accordance with a preferred embodiment of the present invention is illustrated in Figure 25. For a one-way system only receive base stations 14 are needed, as there is no communication downlink. A one-way messaging unit 13 transmits data to one or more receive base stations 14 which are coupled through a communication link to network center 28. Similarly as with the two-way messaging system, the one-way messaging system of Figure 25 includes gateways 22, 24, 26 coupled to network center 28. In addition, network center 28 is coupled to one or more client applications 27 that receive the messages transmitted by one-way messaging units 13 and further process in accordance with the particular requirements of the user or service subscriber. Applications of one-way messaging system include data acquisition, telemetry, vending machine, or any other one-way data gathering application.

A high level block diagram of one-way messaging unit 13 is illustrated in Figure 26. One-way messaging unit 13 is similar to messaging unit 12 illustrated in Figure 3. However, one-way messaging unit 13 does not need a receiver because

it operates in a one-way only system. One-way messaging unit 13 is thus only required to transmit. Buttons 50, display 64, audio indicator 66, vibrator 68 and visual indicator 70 are optionally included depending on the application. Used in connection with one-way messaging unit 13, the purpose of these indicators might
5 be different than that in two-way messaging unit 12.

While the invention has been described with respect to a limited number of embodiments, it will be appreciated that many variations, modifications and other applications of the invention may be made.

CLAIMS

1. A two-way wireless messaging system having a communication downlink and a communication uplink, comprising:
 - a. at least one transmitter for generating and transmitting a downlink message on a downlink signal over said communication downlink;
 - b. at least one two-way messaging unit for receiving said downlink signal on said communication downlink and extracting said downlink message therefrom, said two-way messaging unit for generating and transmitting an uplink message on an uplink signal over said communication uplink, said two-way messaging unit using direct sequence spread spectrum to encode and generate said uplink signal; and
 - c. at least one receive base station for receiving and decoding said direct sequence spread spectrum uplink signal on said communication uplink from said two-way messaging unit and for extracting said uplink message therefrom.
2. The system according to claim 1, further comprising a network center coupled to said at least one receive base station, said network center for receiving messages received and decoded by said at least one receive base station.
3. The system according to claim 2, further comprising an electronic mail gateway coupled to said network center, said electronic mail gateway for providing said network center access to electronic mail systems.
4. The system according to any of claims 2 - 3, further comprising a facsimile gateway coupled to said network center, said facsimile gateway for providing said network center with access to facsimile services.
5. The system according to any of claims 2 - 4, further comprising a voice mail gateway coupled to said network center, said voice mail gateway for providing said network center access to voice mail services.
6. The system according to any of claims 1 - 5, further comprising a transmitter/receive base station able to generate and transmit said downlink signal to said two-way messaging unit and able to receive



and decode said uplink signal transmitted by said two-way messaging unit.

- 5 7. The system according to any of claims 2 - 6, further comprising at least one messaging terminal coupled to said at least one transmitter and said network center, said messaging terminal for constructing said downlink messages and transmitting them to said at least one transmitter, said messaging terminal for coordinating messages transmitted with messages received by said network center.
- 10 8. A two-way wireless paging system having a communication downlink and a communication uplink, comprising:
- a. at least one transmitter for generating and transmitting a downlink message on a downlink signal over said communication downlink;
- 15 b. at least one two-way paging unit for receiving said downlink signal on said communication downlink and extracting said downlink message therefrom, said two-way paging unit for generating and transmitting an uplink message on an uplink signal over said communication uplink, said two-way paging unit using direct sequence spread spectrum to encode and generate said uplink signal; and
- 20 c. at least one receive base station for receiving and decoding said direct sequence spread spectrum uplink signal on said communication uplink from said two-way paging unit and for extracting said uplink message therefrom.
- 25 9. The system according to claim 8, further comprising a network center coupled to said at least one receive base station, said network center for receiving messages received and decoded by said at least one receive base station.
- 30 10. The system according to claim 9, further comprising an electronic mail gateway coupled to said network center, said electronic mail gateway for providing said network center access to electronic mail systems.
11. The system according to any of claims 9 - 10, further comprising a facsimile gateway coupled to said network center, said facsimile gateway for providing said network center with access to facsimile services.
- 35 12. The system according to any of claims 9 - 11, further comprising a voice mail gateway coupled to said network center, said voice mail



gateway for providing said network center access to voice mail services.

13. The system according to claim 8 - 12, further comprising a transmitter/receive base station able to generate and transmit said downlink signal to said two-way paging unit and able to receive and decode said uplink signal transmitted by said two-way paging unit.
14. The system according to claim 9 - 13, further comprising at least one messaging terminal coupled to said at least one transmitter and said network center, said messaging terminal for constructing said downlink messages and transmitting them to said at least one transmitter, said messaging terminal for coordinating messages transmitted with messages received by said network center.
15. A two-way wireless supervisory control/telemetry system having a communication downlink and a communication uplink, comprising:
- at least one transmitter for generating and transmitting a downlink message on a downlink signal over said communication downlink;
 - at least one two-way supervisory control/telemetry unit for receiving said downlink signal on said communication downlink and extracting said downlink message therefrom, said two-way supervisory control/telemetry unit for generating and transmitting an uplink message on an uplink signal over said communication uplink, said two-way supervisory control/telemetry unit using direct sequence spread spectrum to encode and generate said uplink signal; and
 - at least one receive base station for receiving and decoding said direct sequence spread spectrum uplink signal on said communication uplink from said two-way supervisory control/telemetry unit and for extracting said uplink message therefrom.
16. The system according to claim 15, further comprising a network center coupled to said at least one receive base station, said network center for receiving messages received and decoded by said at least one receive base station.
17. The system according to claim 16, further comprising an electronic mail gateway coupled to said network center, said electronic mail



gateway for providing said network center access to electronic mail systems.

18. The system according to any of claims 16 - 17, further comprising a facsimile gateway coupled to said network center, said facsimile gateway for providing said network center with access to facsimile services.

19. The system according to any of claims 16 - 18, further comprising a voice mail gateway coupled to said network center, said voice mail gateway for providing said network center access to voice mail services.

20. The system according to any of claims 15 - 19, further comprising a transmitter/receive base station able to generate and transmit said downlink signal to said two-way supervisory control/telemetry unit and able to receive and decode said uplink signal transmitted by said two-way supervisory control/telemetry unit.

21. The system according to any of claims 16 - 20, further comprising at least one supervisory control terminal coupled to said at least one transmitter and said network center, said supervisory control terminal for constructing said downlink messages and transmitting them to said at least one transmitter, said supervisory control terminal for coordinating messages transmitted with messages received by said network center.

22. A two-way messaging unit comprising:

a. a receive antenna for receiving a downlink signal transmitted over a communication downlink;

b. a receiver coupled to said receive antenna, said receiver for receiving said downlink signal from said receive antenna and for decoding and extracting a downlink message from said downlink signal;

c. a spread spectrum transmitter for encoding an uplink message using spread spectrum encoding techniques and for generating an uplink signal therefrom;

d. a transmit antenna coupled to said spread spectrum transmitter, said transmit antenna for transmitting said uplink signal;



- e. a controller coupled to said receiver and said spread spectrum transmitter, said controller for receiving said downlink message from said receiver and for generating said uplink message; and
- f. a power supply for converting energy in an external energy source, coupled to said unit, into supply voltages for said unit.
23. The unit according to claim 22, further comprising an audio indicator coupled to said controller, said audio indicator for providing an audible alarm means to said user.
24. The unit according to any of claims 22 - 23, further comprising a vibrator coupled to said controller, said vibrator for providing a vibrating alarm means to said user.
25. The unit according to any of claims 22 - 24, further comprising a visual indicator coupled to said controller, said visual indicator for providing a visual alarm means to said user.
26. The unit according to any of claims 22 - 25, further comprising a data link coupled to said controller, said data link for interfacing an external device to said controller.
27. The unit according to claim 26, wherein said data link is an RS-232 data link.
28. The unit according to any of claims 22 - 27, further comprising a display coupled to said controller, said display for presenting information to a user.
29. The unit according to any of claims 22 - 28, further comprising at least one button coupled to said controller, said at least one button enabling a user to enter information and/or commands into said unit.
30. A receive base station comprising:
- a. a receive antenna for receiving a spread spectrum uplink signal transmitted over a communication uplink;
- b. an RF receiver coupled to said receive antenna, said RF receiver for receiving said spread spectrum uplink signal from said receive antenna and for mixing down said spread spectrum uplink signal to an intermediate frequency;
- c. a spread spectrum decoder coupled to said RF receiver for decoding said spread spectrum uplink signal into a baseband data message;
- d. a message processor coupled to said spread spectrum decoder for extracting a received data message;



- e. communication circuitry coupled to said message processor, said communication circuitry for transmitting said received data message over a communication link; and
- f. a controller coupled to said RF receiver, said spread spectrum decoder and said message processor, said controller for controlling and coordinating the operation of said receive base station.
31. The receive base station according to claim 30, wherein spread spectrum decoder decodes a direct sequence spread spectrum uplink signal.
32. A one-way wireless messaging system comprising:
- a. at least one one-way messaging unit for generating and transmitting a message carried by a transmission signal, said one-way messaging unit using direct sequence spread spectrum to encode said message and generate said transmission signal; and
- b. at least one receive base station for receiving and decoding said direct sequence spread spectrum transmission signal from said one-way messaging unit and for extracting said message therefrom.
33. A one-way messaging unit comprising:
- a. a spread spectrum transmitter for encoding a message using spread spectrum encoding techniques and for generating a transmit signal therefrom;
- b. a transmit antenna coupled to said spread spectrum transmitter, said transmit antenna for transmitting said transmit signal;
- c. a controller coupled to said spread spectrum transmitter, said controller for generating said message and managing the generation of said transmit signal; and
- d. a power supply for converting energy in an external energy source, coupled to said unit, into supply voltages for said unit.



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