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(54) SYSTEM AND METHOD FOR SIGNAL CLASSICIATION OF SIGNALS IN A FREQUENCY BAND

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(60) Provisional application No. 60/374,365, filed on Apr. 22, 2002. Provisional application No. 60/374,363, filed on Apr. 22, 2002. Provisional application No. 60/380,891, filed on May 16, 2002. Provisional application No. 60/380,890, filed on May 16, 2002. Provisional application No. 60/319,435, filed on Jul. 30, 2002. Provisional application No. 60/319,542, filed on Sep. 11, 2002.

Publication Classification

(51) **Int. Cl.**[7] **H04M 11/00**

(52) **U.S. Cl.** **455/67.11**; 455/403

(57) **ABSTRACT**

A system and method for classifying signals occurring in a frequency band. One or more characteristics of one or more signals in the frequency band are detected using any suitable technology, such as a device that can generate characteristics of signal pulses detected in the frequency band. Data pertaining to the signal pulses is accumulated over time. The accumulated signal data is compared against reference data associated with known signals to classify the one or more signals in the frequency band based on the comparison. The accumulated data may include one or more characteristics selected from the group consisting of: pulse center frequency, pulse bandwidth, pulse duration, time between pulses and number of different active pulses, and wherein the reference data associated with each of a plurality of known signals comprises one or more characteristics selected from the group consisting of: pulse center frequency, pulse bandwidth, pulse duration and time between pulses. The accumulated signal data is compared against the reference data, and depending on the degree of match with reference data, a signal can be classified. Additional levels of signal classification processing may be performed.

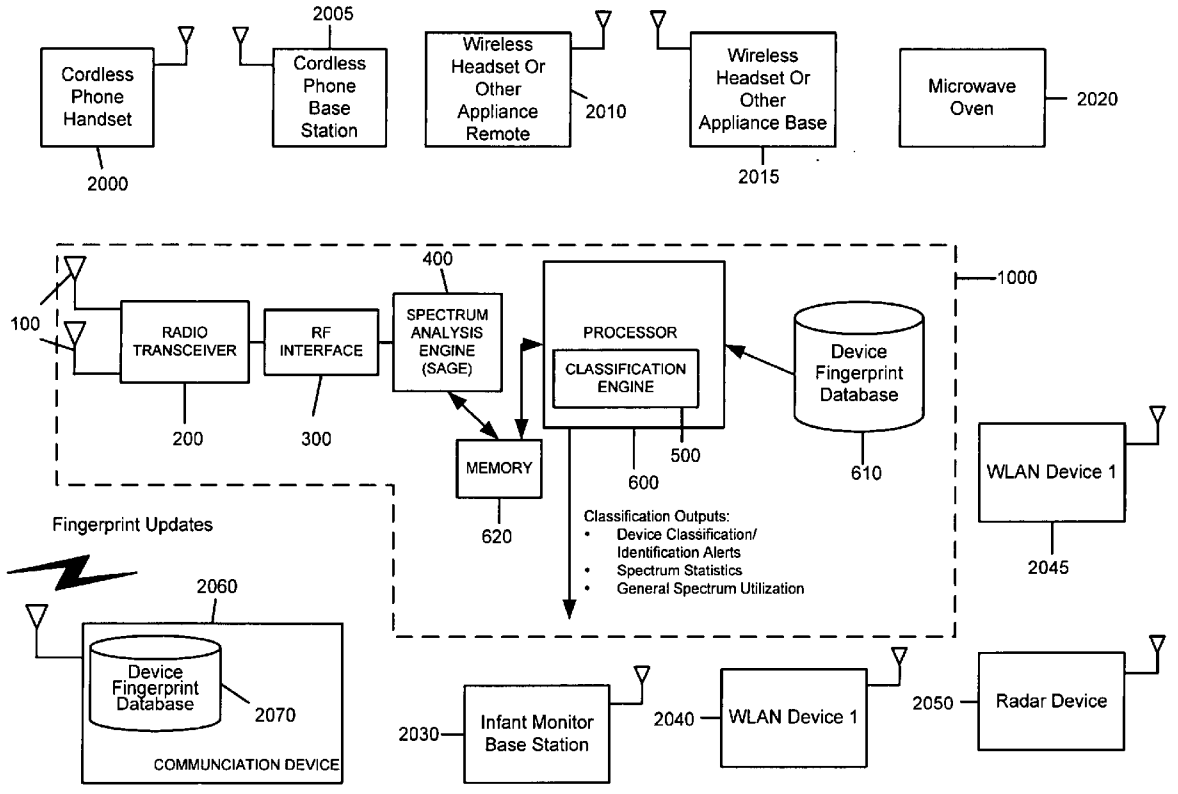
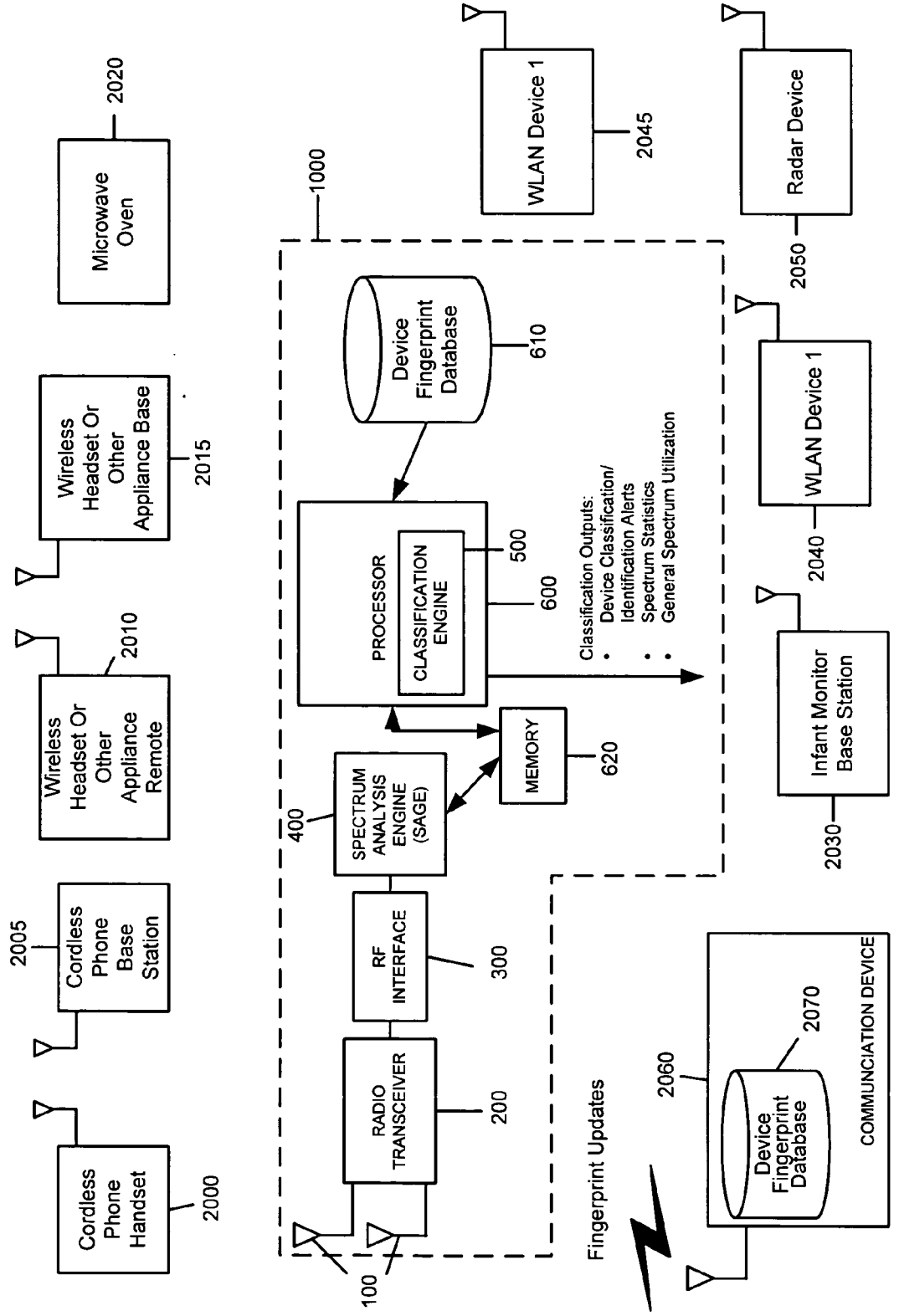


FIG. 1


Microwave Oven
2020
Wireless Headset Or Other Appliance Base
2015
Wireless Headset Or Other Appliance Remote
2010
Cordless Phone Base Station
2005
Cordless Phone Handset
2000
1000
WLAN Device 1
2045
Radar Device
2050
Device Fingerprint Database
610
PROCESSOR
CLASSIFICATION ENGINE
500
600
Classification Outputs:
• Device Classification/ Identification Alerts
• Spectrum Statistics
• General Spectrum Utilization
WLAN Device 1
2040
Infant Monitor Base Station
2030
MEMORY
620
SPECTRUM ANALYSIS ENGINE (SAGE)
400
RF INTERFACE
300
RADIO TRANSCEIVER
200
100
Fingerprint Updates
2060
Device Fingerprint Database
2070
COMMUNCIATION DEVICE

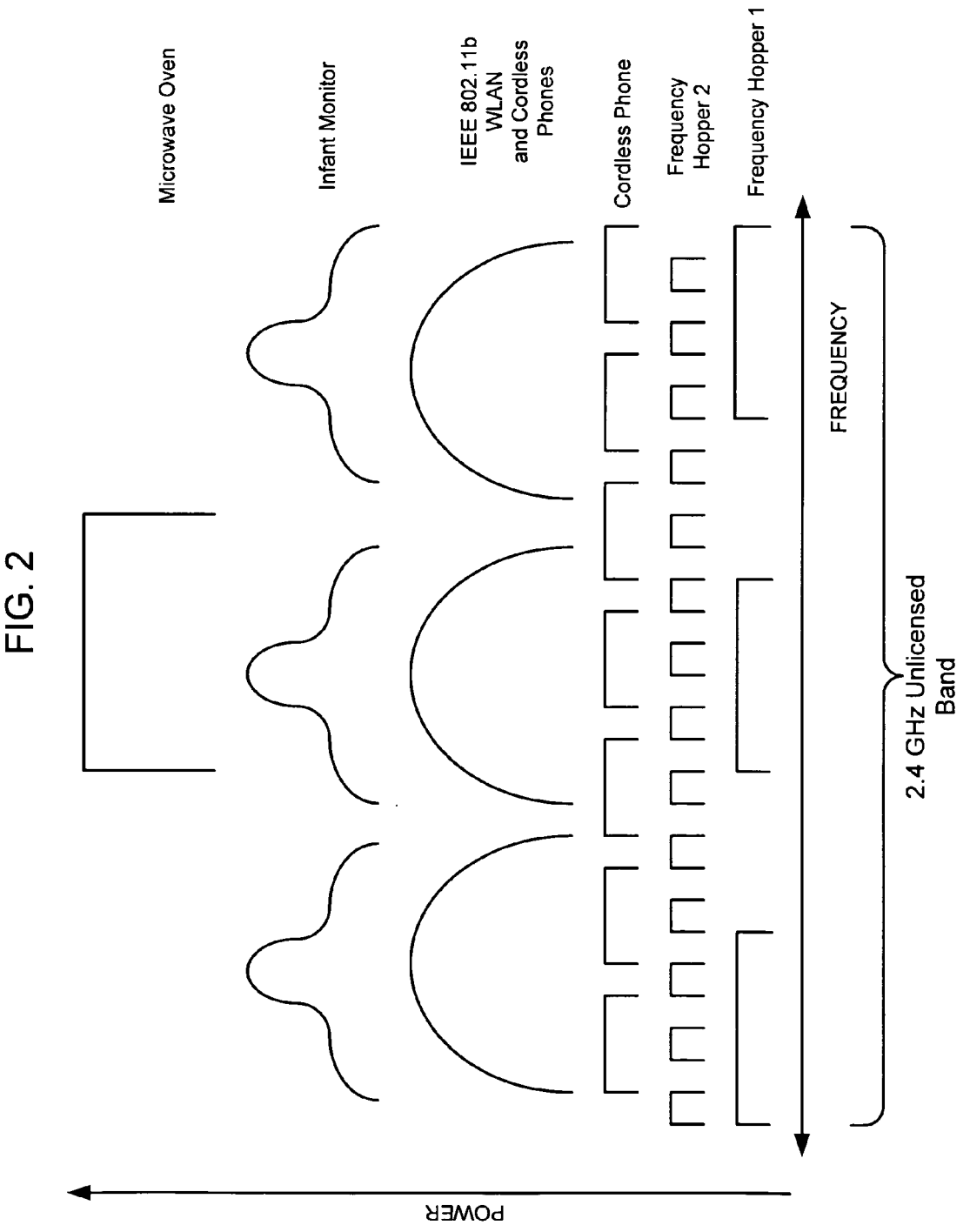
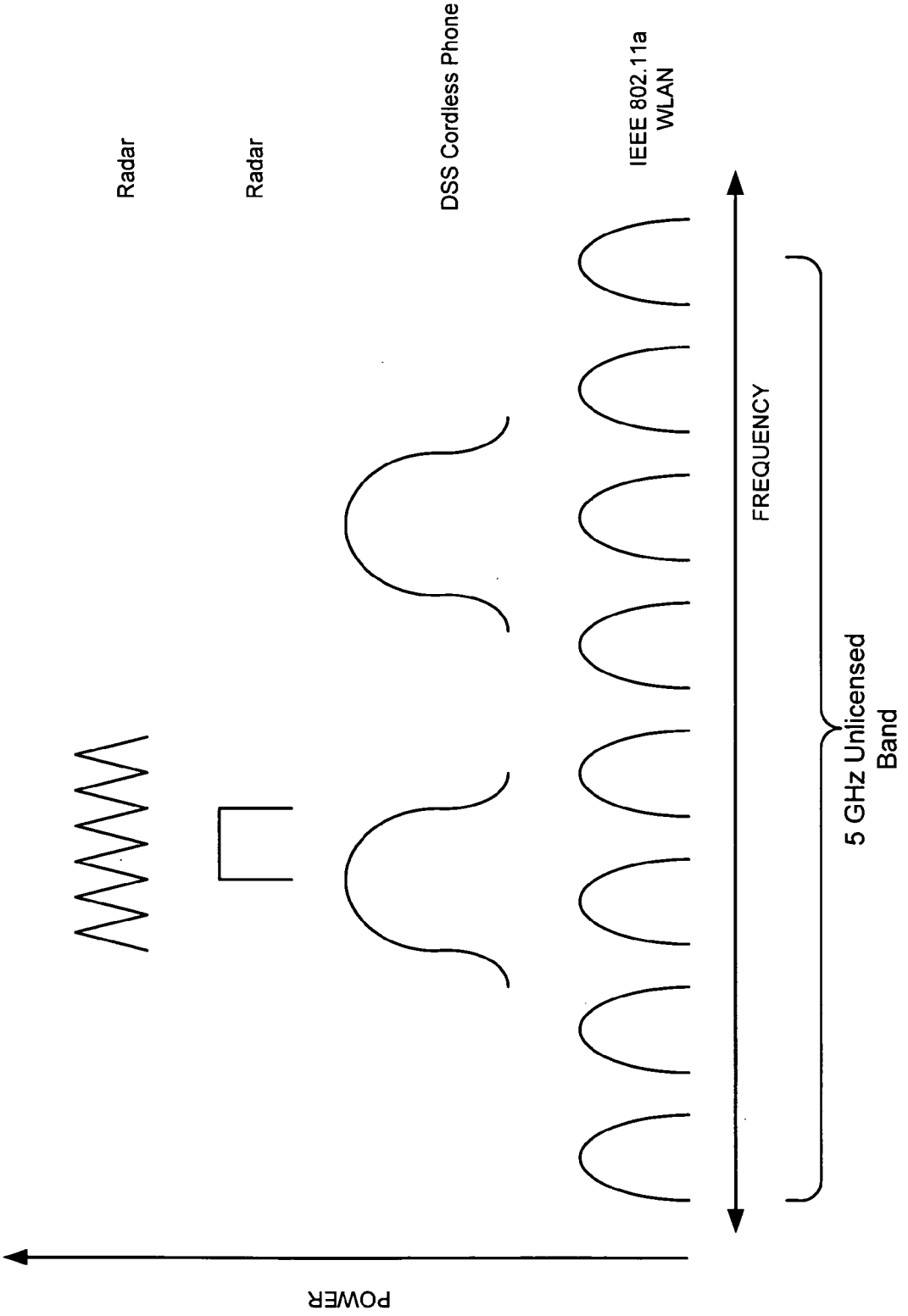

Microwave Oven
Infant Monitor
IEEE 802.11b WLAN and Cordless Phones
Cordless Phone
Frequency Hopper 2
Frequency Hopper 1
FREQUENCY
2.4 GHz Unlicensed Band
POWER

FIG. 2

FIG. 3


Radar
Radar
DSS Cordless Phone
IEEE 802.11a
WLAN
FREQUENCY
5 GHz Unlicensed
Band
POWER

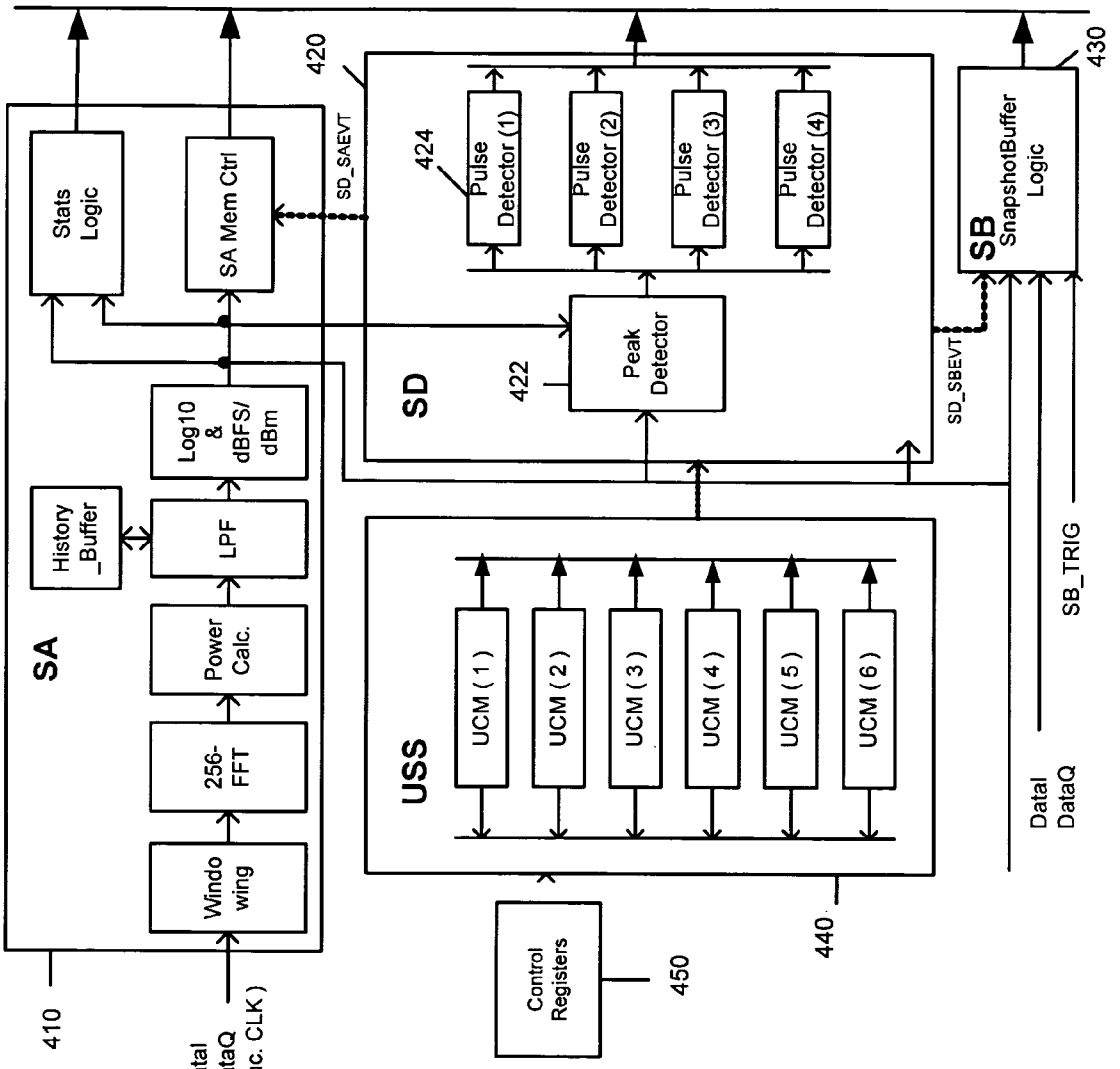

SA
Stats Logic
SA Mem Ctrl
History _Buffer
Log10 & dBFS/ dBm
LPF
Power Calc.
256-FFT
Windo wing
410
Datal DataQ (Sync. CLK)
SD_SAEVT
420
SD
424
Pulse Detector (1)
Pulse Detector (2)
Pulse Detector (3)
Pulse Detector (4)
422
Peak Detector
USS
UCM (1)
UCM (2)
UCM (3)
UCM (4)
UCM (5)
UCM (6)
Control Registers
450
440
SD_SBEVT
SB
SnapshotBuffer Logic
430
SB_TRIG
Datal DataQ

FIG. 4

400

FIG. 5

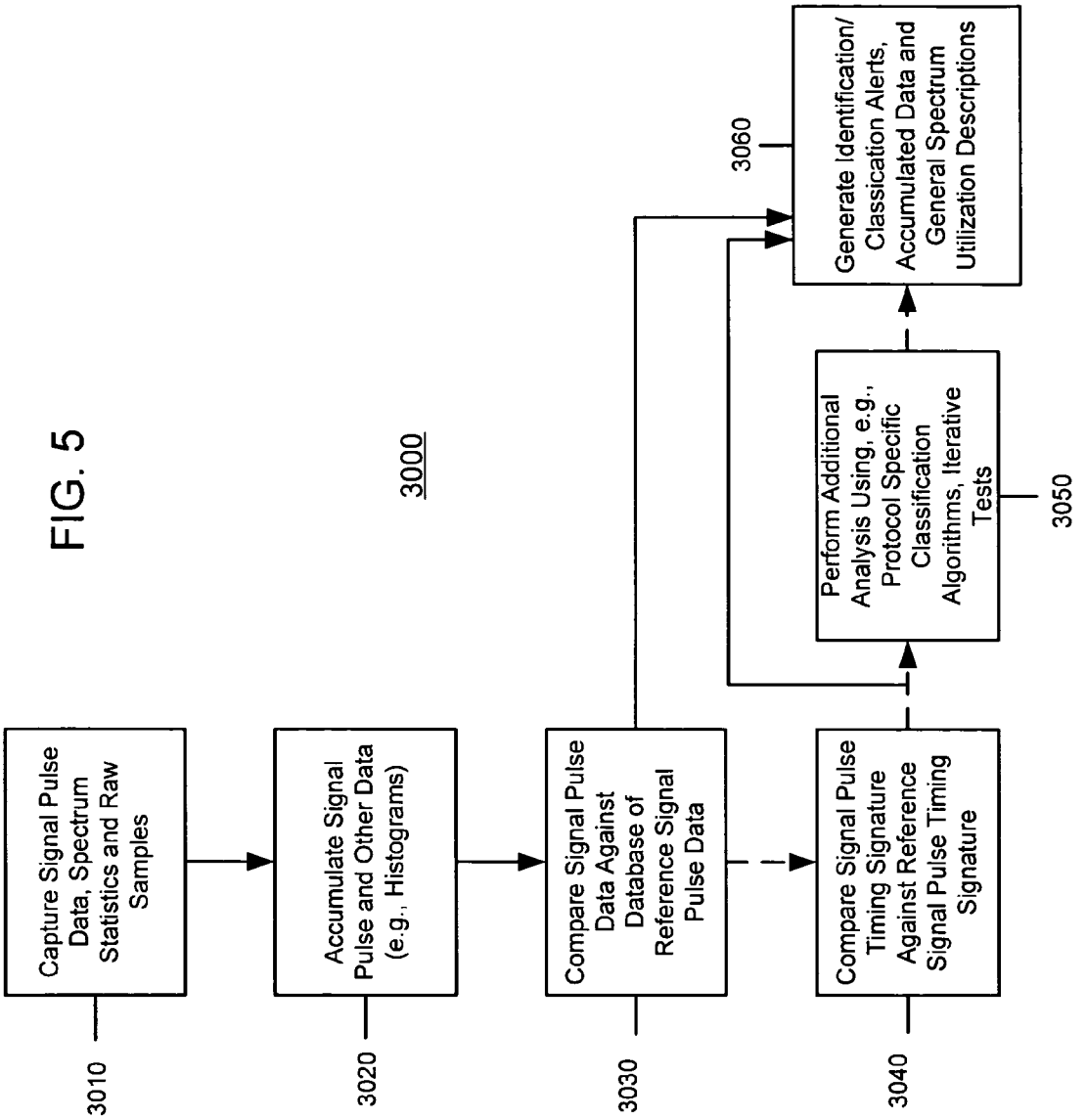

3000
Capture Signal Pulse Data, Spectrum Statistics and Raw Samples
3010
Accumulate Signal Pulse and Other Data (e.g., Histograms)
3020
Compare Signal Pulse Data Against Database of Reference Signal Pulse Data
3030
Compare Signal Pulse Timing Signature Against Reference Signal Pulse Timing Signature
3040
Perform Additional Analysis Using, e.g., Protocol Specific Classification Algorithms, Iterative Tests
3050
Generate Identification/ Classication Alerts, Accumulated Data and General Spectrum Utilization Descriptions
3060

FIG. 6

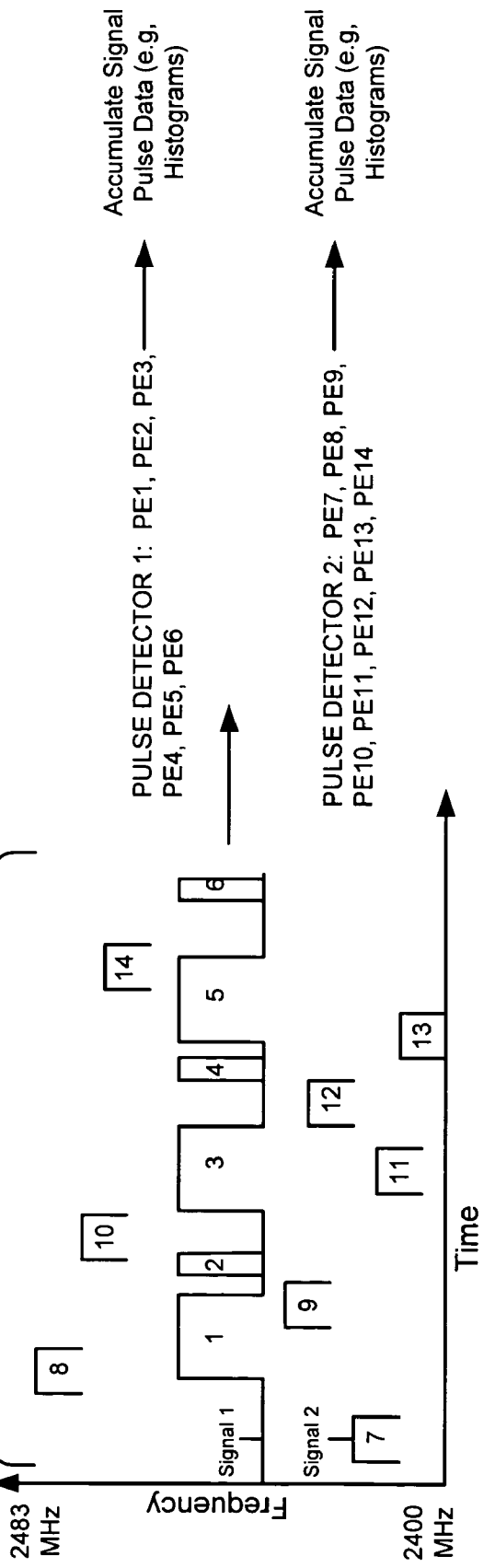

Number of Active Transmissions and Other Data
Spectrum Statistics
Accumulate Signal Pulse Data (e.g, Histograms)
PULSE DETECTOR 1: PE1, PE2, PE3, PE4, PE5, PE6
Accumulate Signal Pulse Data (e.g, Histograms)
PULSE DETECTOR 2: PE7, PE8, PE9, PE10, PE11, PE12, PE13, PE14
Signal 1
Signal 2
Frequency
Time
2483 MHz
2400 MHz
1
2
3
4
5
6
7
8
9
10
11
12
13
14

FIG. 7

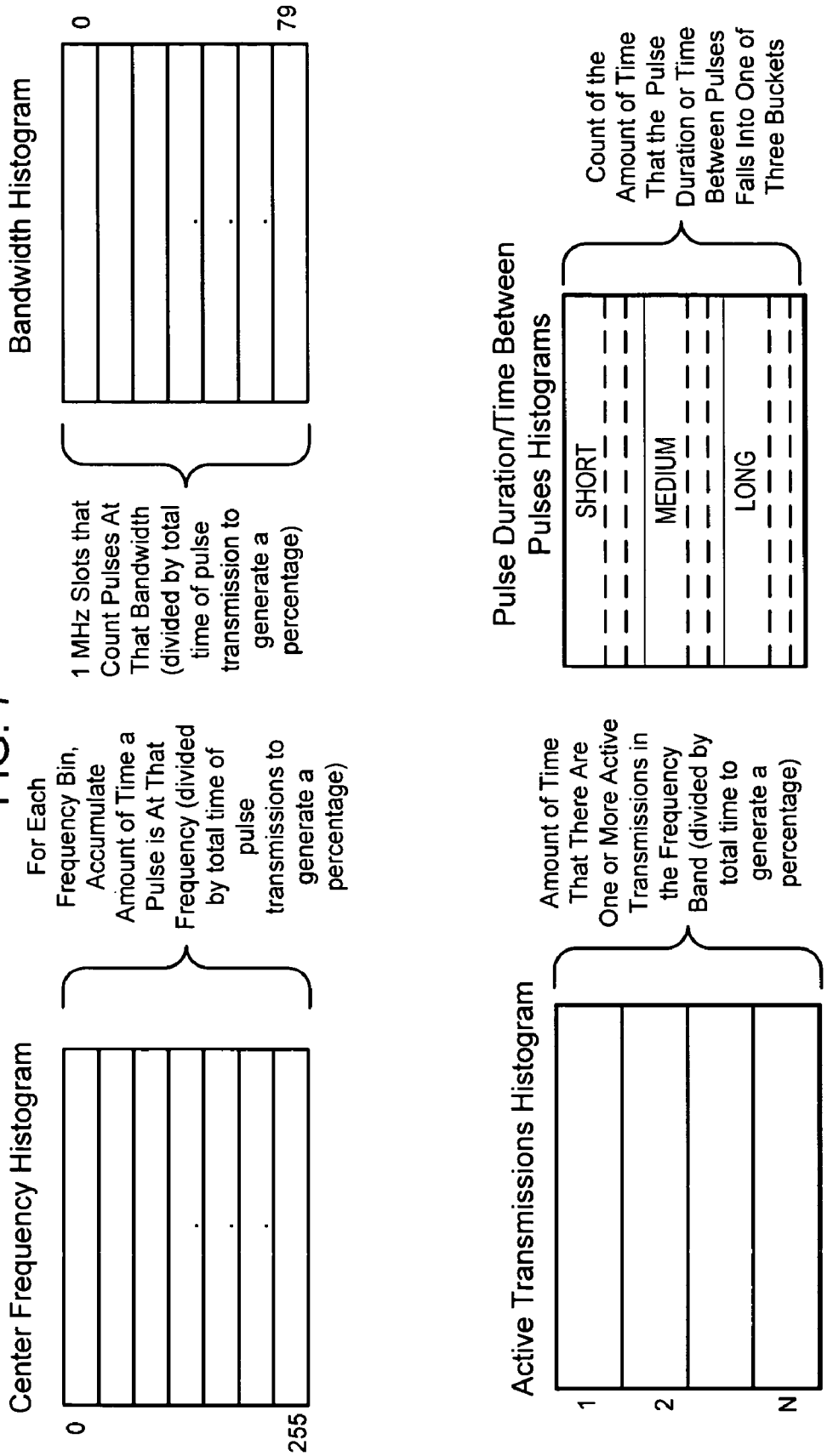
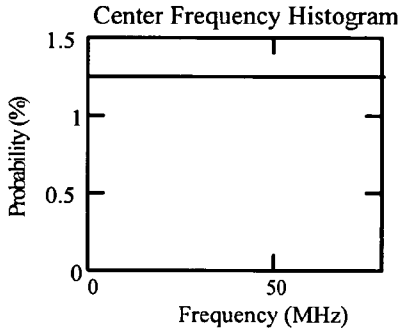
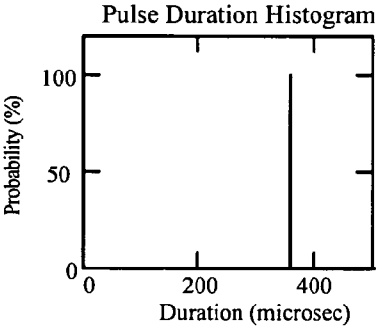

Center Frequency Histogram
0
255
For Each Frequency Bin, Accumulate Amount of Time a Pulse is At That Frequency (divided by total time of pulse transmissions to generate a percentage)
Bandwidth Histogram
0
79
1 MHz Slots that Count Pulses At That Bandwidth (divided by total time of pulse transmission to generate a percentage)
Pulse Duration/Time Between Pulses Histograms
SHORT
MEDIUM
LONG
Count of the Amount of Time That the Pulse Duration or Time Between Pulses Falls Into One of Three Buckets
Active Transmissions Histogram
1
2
N
Amount of Time That There Are One or More Active Transmissions in the Frequency Band (divided by total time to generate a percentage)

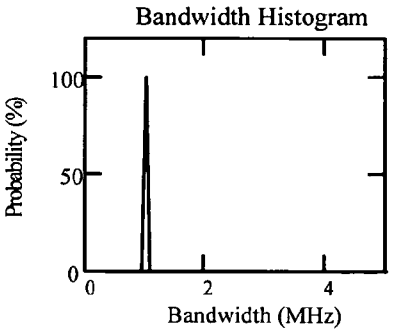
FIG. 8



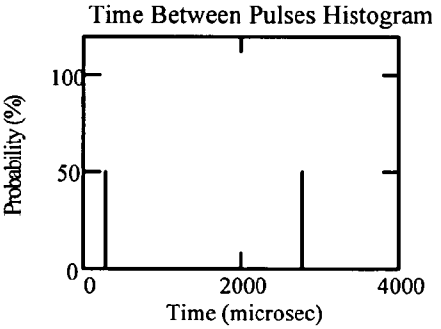
BLUETOOTH SCO



BLUETOOTH SCO

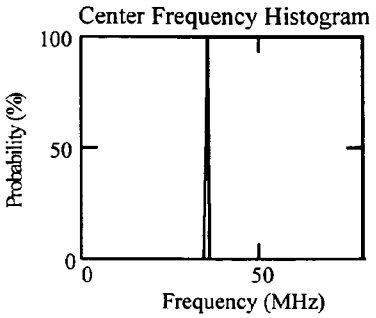


BLUETOOTH SCO

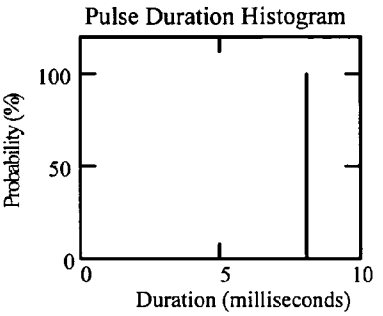


BLUETOOTH SCO

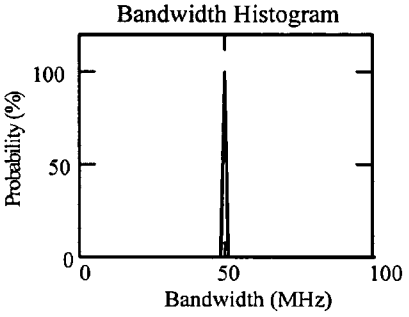
FIG. 9



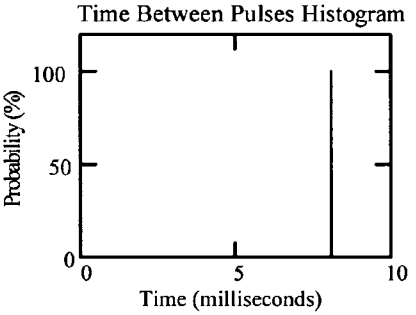
MICROWAVE OVEN



MICROWAVE OVEN

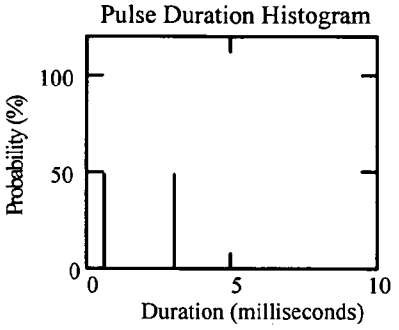


MICROWAVE OVEN

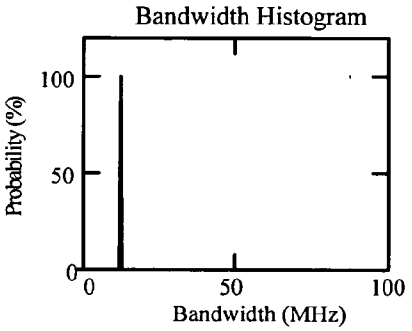


MICROWAVE OVEN

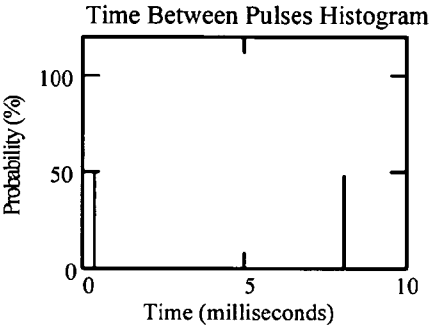
FIG. 10



802.11b SIGNAL

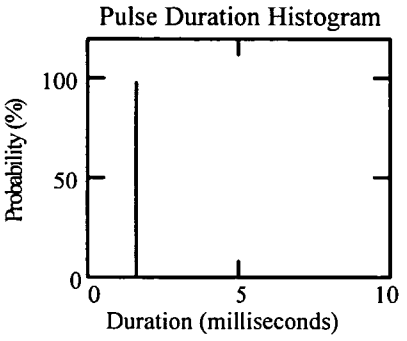


802.11b SIGNAL



802.11b SIGNAL

FIG. 11


Pulse Duration Histogram
Probability (%)
100
50
0
0
5
10
Duration (milliseconds)

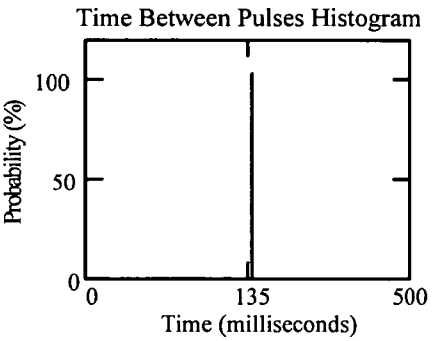

Time Between Pulses Histogram
Probability (%)
100
50
0
0
135
500
Time (milliseconds)

FIG. 12

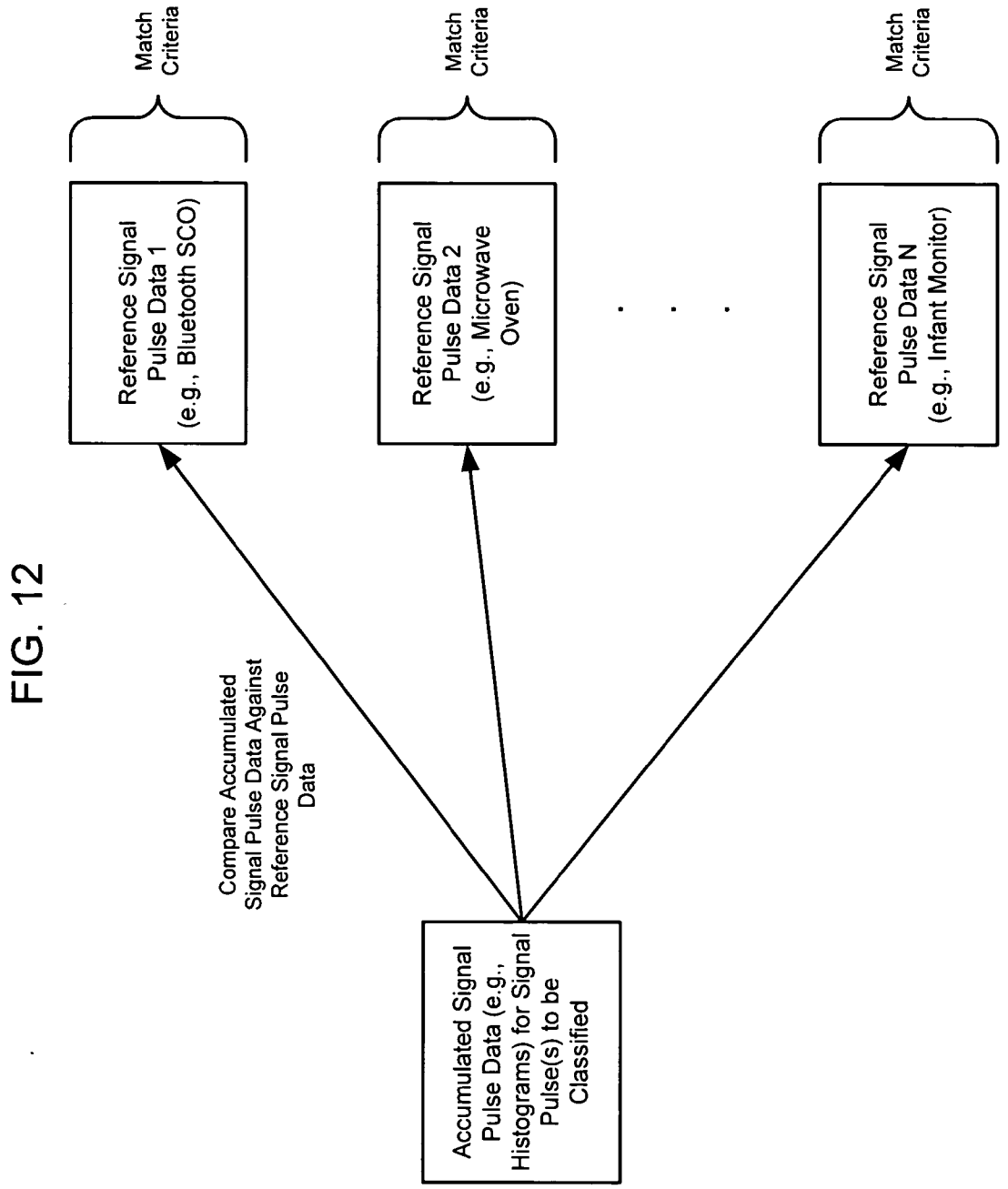

Match Criteria
Match Criteria
Match Criteria
Reference Signal Pulse Data 1 (e.g., Bluetooth SCO)
Reference Signal Pulse Data 2 (e.g., Microwave Oven)
Reference Signal Pulse Data N (e.g., Infant Monitor)
Compare Accumulated Signal Pulse Data Against Reference Signal Pulse Data
Accumulated Signal Pulse Data (e.g., Histograms) for Signal Pulse(s) to be Classified

FIG. 13

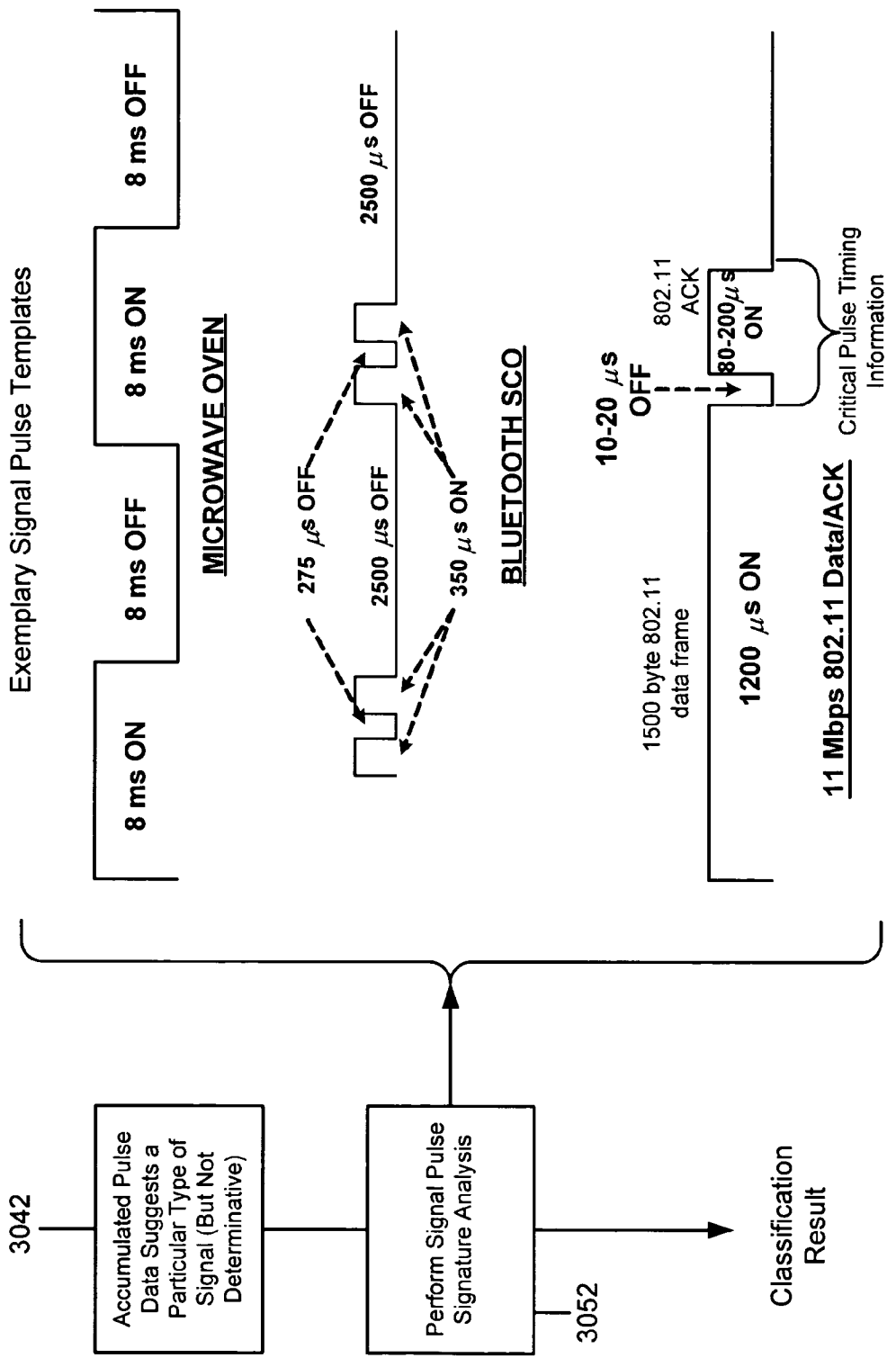

Exemplary Signal Pulse Templates
8 ms ON
8 ms OFF
8 ms ON
8 ms OFF
MICROWAVE OVEN
275 μs OFF
2500 μs OFF
350 μs ON
2500 μs OFF
BLUETOOTH SCO
10-20 μs OFF
802.11 ACK
80-200μs ON
1500 byte 802.11 data frame
1200 μs ON
11 Mbps 802.11 Data/ACK
Critical Pulse Timing Information
3042
Accumulated Pulse Data Suggests a Particular Type of Signal (But Not Determinative)
Perform Signal Pulse Signature Analysis
3052
Classification Result

FIG. 14

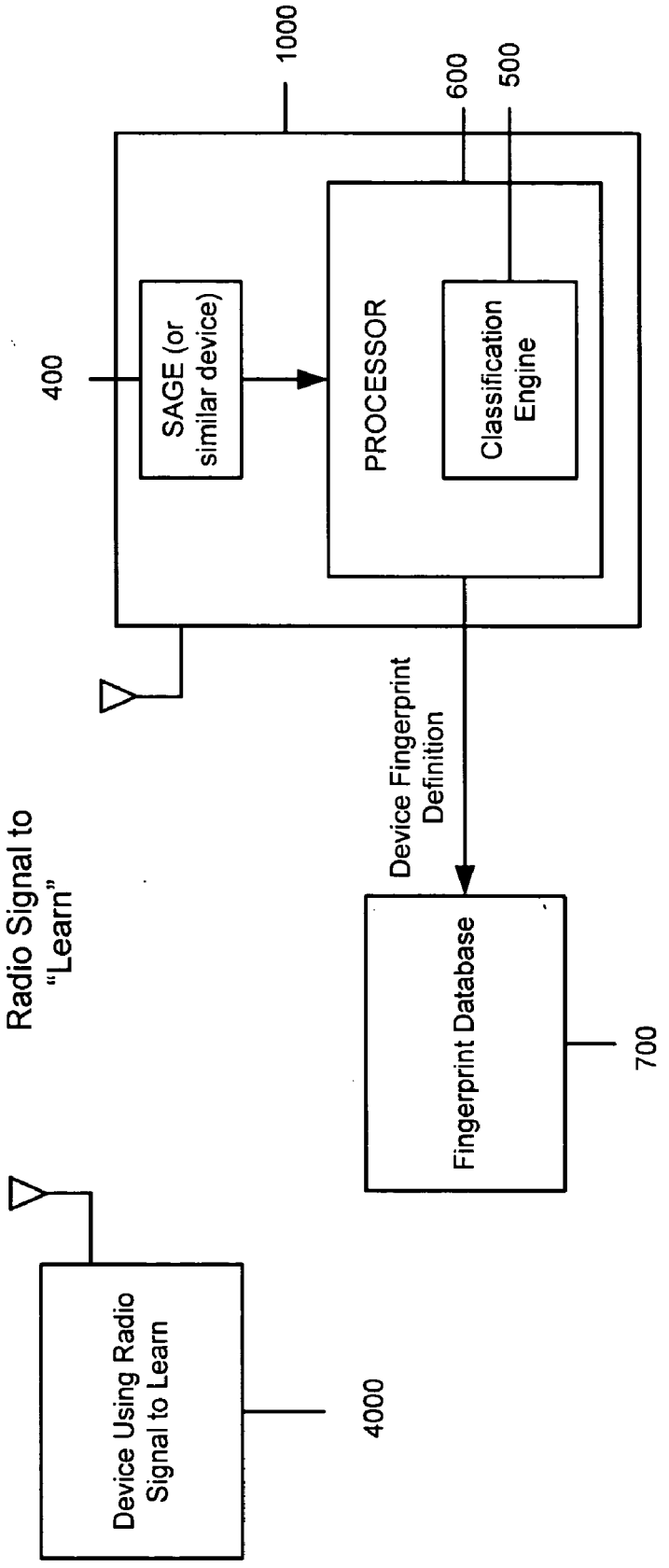

1000
600
500
400
SAGE (or similar device)
PROCESSOR
Classification Engine
Device Fingerprint Definition
Radio Signal to "Learn"
Fingerprint Database
700
Device Using Radio Signal to Learn
4000

FIG. 15

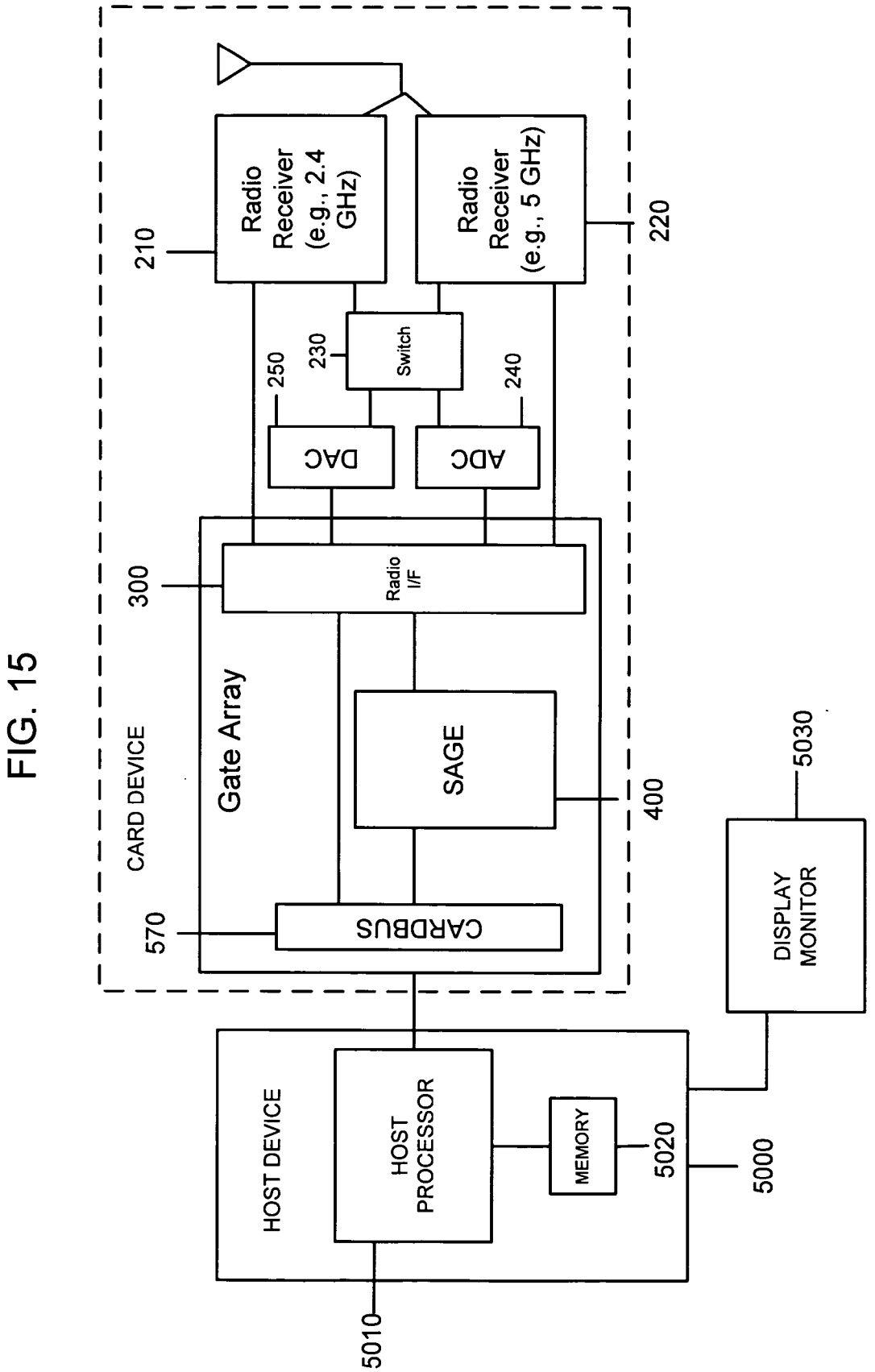
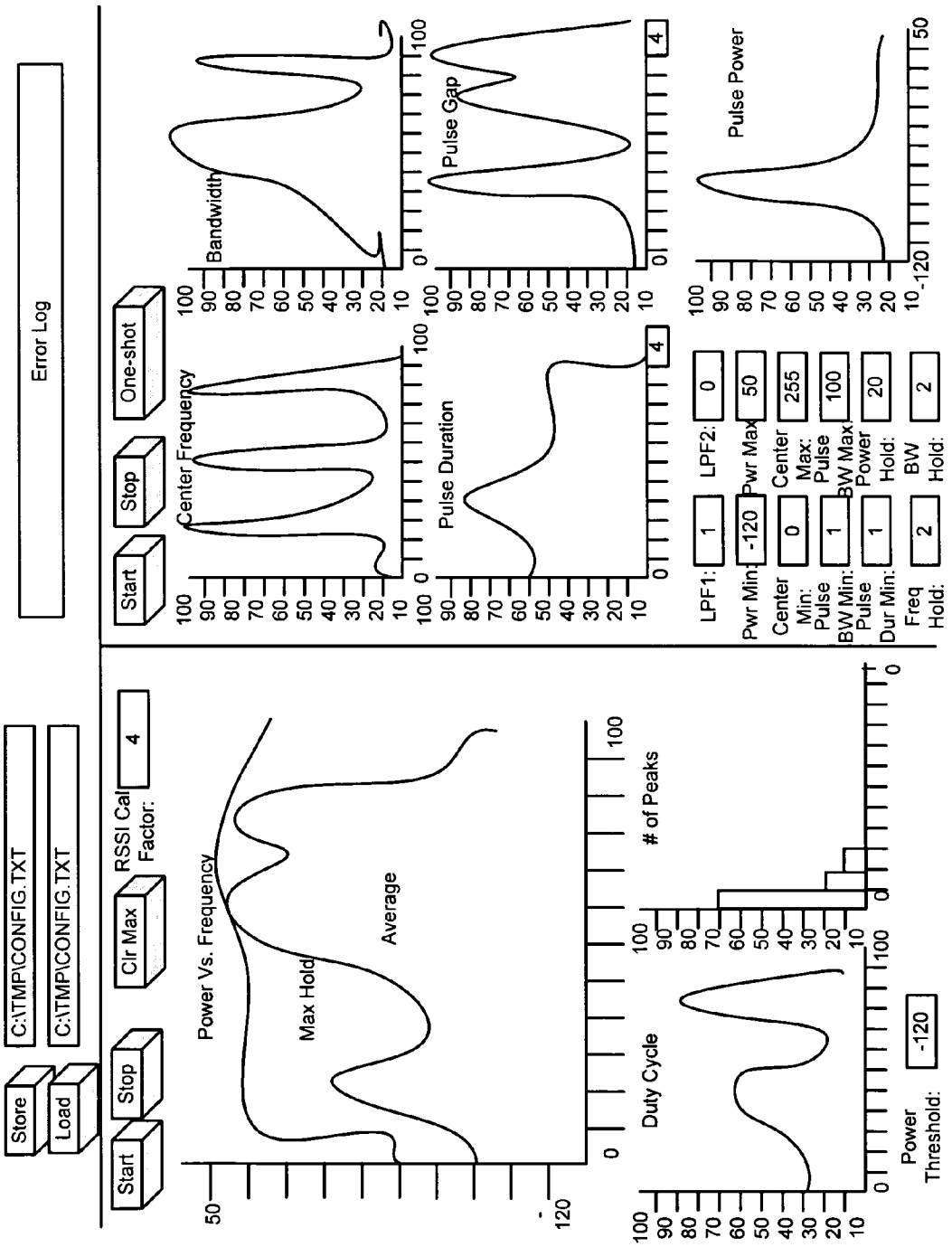

CARD DEVICE
Gate Array
Radio Receiver (e.g., 2.4 GHz)
Radio Receiver (e.g., 5 GHz)
210
220
Switch
230
250
240
DAC
ADC
Radio I/F
300
SAGE
400
CARDBUS
570
DISPLAY MONITOR
5030
HOST DEVICE
HOST PROCESSOR
MEMORY
5020
5000
5010

FIG. 16


Error Log
C:\TMP\CONFIG.TXT
C:\TMP\CONFIG.TXT
Store
Load
Start
Stop
Clr Max
RSSI Cal Factor:
4
Power Vs. Frequency
Max Hold
Average
50
-120
Duty Cycle
# of Peaks
Power Threshold:
-120
Start
Stop
One-shot
Center Frequency
Bandwidth
Pulse Duration
Pulse Gap
Pulse Power
LPF1:
1
LPF2:
0
Pwr Min:
-120
Pwr Max
50
Center Min:
0
Center Max:
255
Pulse BW Min:
1
Pulse BW Max
100
Pulse Dur Min:
1
Power Hold:
20
Freq Hold:
2
BW Hold:
2

SYSTEM AND METHOD FOR SIGNAL CLASSICIATION OF SIGNALS IN A FREQUENCY BAND

RELATED APPLICATIONS

[0001] This application is a continuation of U.S. application Ser. No. 10/246,364, filed Sep. 18, 2002, which in turn claims priority to each of the following U.S. Provisional Applications, all of which are incorporated herein by reference:

[0002] Application No. 60/374,365, filed Apr. 22, 2002.

[0003] Application No. 60/374,363, filed Apr. 22, 2002.

[0004] Application No. 60/380,891, filed May 16, 2002.

[0005] Application No. 60/380,890, filed May 16, 2002.

[0006] Application No. 60/319,435, filed Jul. 30, 2002.

[0007] Application No. 60/319,542, filed Sep. 11, 2002.

[0008] This application is related to each of the following commonly assigned U.S. patent and Non-Provisional application, filed on even date (the entirety of both of which is incorporated herein by reference):

[0009] U.S. Pat. No. 6,714,605, entitled "System and Method for Real-Time Spectrum Analysis in a Communication Device," issued Mar. 30, 2004.

[0010] U.S. application Ser. No. 10/246,363, entitled "System and Method for Spectrum Management of a Shared Frequency Band."

BACKGROUND OF THE INVENTION

[0011] The present invention is directed to radio communication devices, and more particularly to technology used in a radio communication device to classify or identify signals in a radio frequency band.

[0012] In certain radio communication systems, it would be desirable to know whether and what types of other signals or devices are active. For example, an unlicensed radio frequency band is, by its nature, free to be used by any device that emits within certain power levels in that part of the allocated spectrum. It is possible that many devices would share the unlicensed frequency band at the same time, potentially causing interference with each other. Under these circumstances, it would be useful to identify or classify signals detected in the frequency band in order to know whether a device should take certain actions to avoid interfering with other devices operating in the frequency band.

SUMMARY OF THE INVENTION

[0013] Briefly, a system and method are provided for classifying signals occurring in a frequency band. One or more characteristics of one or more signals in the frequency band are detected using any suitable technology, such as a device that can generate characteristics of signal pulses detected in the frequency band. Data pertaining to the signal pulses is accumulated over time. The accumulated signal data is compared against reference data associated with known signals to classify the one or more signals in the frequency band based on the comparison. The accumulated data may include one or more characteristics selected from the group consisting of: pulse center frequency, pulse bandwidth, pulse duration, time between pulses and number of different active pulses, and wherein the reference data associated with each of a plurality of known signals comprises one or more characteristics selected from the group consisting of: pulse center frequency, pulse bandwidth, pulse duration and time between pulses. The accumulated signal data is compared against the reference data, and depending on the degree of match with reference data, a signal can be classified. Additional levels of signal classification may include generating a pulse timing signature for each signal pulse and comparing that pulse timing signature with reference pulse timing signatures associated with known signals. Further, samples of the signals themselves can be taken and examined to classify the signal. Further still, classification may involve iterating through a plurality of different signal characteristics to detect signals that meet one or more of the plurality of different signal characteristics.

[0014] The above and other objects and advantages will become readily apparent when reference is made to the following description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] **FIG. 1** is a block diagram showing a general environment for a signal classification system and method.

[0016] **FIGS. 2 and 3** illustrate examples of the types of signals that may be simultaneously present in two exemplary radio frequency bands.

[0017] **FIG. 4** is a block diagram of an exemplary spectrum analysis device that generates data useful as input to a signal classification process.

[0018] **FIG. 5** is a flow chart depicting the various steps of the signal classification process.

[0019] **FIG. 6** is a graphical diagram illustrating exemplary signals that may occur in a frequency band and how data related to those signals is accumulated for input into the signal classification process.

[0020] **FIG. 7** illustrates examples of accumulated signal pulse data used by the signal classification process.

[0021] **FIGS. 8-11** illustrate histograms of signal pulse characteristics of several exemplary signals that may occur in an unlicensed radio frequency band.

[0022] **FIG. 12** is a diagram depicting how accumulated signal pulse data is compared with reference signal pulse data of known signals.

[0023] **FIG. 13** is a diagram depicting how signal pulse timing signatures of unknown signals are compared against signal pulse timing signature templates of known signals for purposes of signal classification.

[0024] **FIG. 14** is a block diagram showing how reference data for new signals can be generated for use in a signal classification process.

[0025] **FIG. 15** is a block diagram showing another environment in which signal classification may be deployed.

[0026] **FIG. 16** is a graphical diagram showing exemplary output that may accompany signal classification output.

DETAILED DESCRIPTION OF THE DRAWINGS

[0027] **FIG. 1** shows a general environment for a signal classification system and method. A wireless communication device **1000** operates in an environment, such as an unlicensed radio frequency band, where signals from other devices sharing the same frequency band may be present. Examples of other devices sharing the unlicensed frequency band with communication device **1000** are, for example, a cordless phone handset **2000** and cordless phone base station **2005**, a wireless headset or other appliance remote **2010** and its base station **2015** (such as a device using the Bluetooth™ protocol or a device using the HomeRF™ protocol), a microwave oven **2020**, an infant (video and/or audio) monitor base station **2030**, a first wireless local area network (WLAN) device **2040** (such as an access point), a second WLAN device **2045** (such as a station) and a radar device **2050**. Additional WLAN devices (e.g., stations) may be operating in the frequency band. Device **1000** may be any type of communication device, such as a WLAN device for example. Device **1000** may be in communication, or capable of communicating, with one or both WLAN devices **2040** and **2045**.

[0028] The communication device **1000** has an RF transceiver **200** coupled to one or more antennas **100**. An RF interface **300** is coupled to the radio transceiver **200**. A spectrum analysis engine (SAGE) **400** is coupled to the radio transceiver **200**. The SAGE **400** is a hardware peripheral that generates real-time spectrum activity information. The output of the SAGE **400** is the raw information used in the classification process. The SAGE **400** will be generally described hereinafter with reference to **FIG. 4**. It should be understood that any device capable of detecting signals in the frequency band and supplying raw information about those signals can be used in a classification process as described herein.

[0029] Though not specifically shown, the SAGE **400** may reside in a baseband section of a communication device in a VLSI implementation. A processor **600** executes a classification software program, called the classification engine **500**, stored in a processor readable memory **620**. Information used by the classification engine **500** to classify signals may be stored locally in a device fingerprint database **610** (also referred to as a profile or reference database). The concept of a fingerprint will be described hereinafter. In addition, new and updated device fingerprints may be downloaded to the communication device **1000** from another communication device **2060** that stores a more comprehensive and updated database **2070** of fingerprint definitions. The processor **600** executing the classification engine **500** may be an on-chip processor in the baseband section, or may be a host processor external to the baseband section, but in the communication device **1000** itself. Alternatively, the classification engine **500** may be executed on another device entirely separate from communication device **1000**, in which case communication device **1000** would transmit raw spectrum information generated by the SAGE **400** via a wireless or wired link to the other device. For example, the classification engine could be executed on a server computer that communicates by wire or wirelessly to communication device **1000**. Alternatively, if the communication device **1000** is a WLAN station, it may transmit the raw classification information to WLAN device **2045** which may be an access point with greater processing power and capable of overseeing communications in the WLAN. Data output by the SAGE **400** is stored in a memory **620** that the processor **600** accesses when performing the classification operations. The memory **620** may contain the fingerprint database **610** as well.

[0030] The communication device **1000** samples the RF spectrum in which it is operating via the radio transceiver **200**. The SAGE **400** receives and processes the RF information from the radio transceiver **200** to output first level spectrum information, described hereinafter. The classification engine **500** processes the first level spectrum information with the use of device fingerprints to output information characterizing the activity in the RF spectrum and which classifieds/identifies devices operating in the spectrum. When a signal is "classified," data that describes the spectral parameters of the signal are determined sufficient to know generally what type of signal it is. The parameters may include the bandwidth, center frequency, frequency hopping rate (if it hops), pulse duration, time between pulses, etc. A signal that is classified can also be "identified" such as by the brand of the chipset that transmits its signal, or perhaps so specific as to identify the brand and model of the device that transmits the signal.

[0031] **FIGS. 2 and 3** illustrate some examples of the spectral usage of two unlicensed frequency bands in the United States. **FIG. 2** shows the spectral profiles of exemplary devices that operate in the 2.4 GHz unlicensed frequency band such as for frequency hopper devices, cordless phones, IEEE 802.11b WLAN communication devices, infant monitor devices and microwave ovens. A frequency hopping device will occupy a predictable or random frequency sub-band at any given time, and therefore, over time, may span the entire frequency band. A cordless phone, of the non-frequency hopping variety, may occupy one of several frequency sub-bands (channels) at any given time. An IEEE 802.11b device will occupy one of several channels in the 2.4 GHz band at any given time, and an infant monitor is similar. A microwave oven will emit a burst of energy that may span a significant portion of the unlicensed band.

[0032] **FIG. 3** shows a similar set of circumstances for the 5 GHz unlicensed bands. There are actually three unlicensed frequency bands at 5 GHz in the United States. Two of these are contiguous (and are meant to be represented by the diagram in **FIG. 3**) and the third is not contiguous with the other two (which for simplicity is not considered in **FIG. 3**). In the 5 GHz unlicensed bands, currently there are IEEE 802.11a WLAN devices operating in one of 8 different frequency sub-bands (channels), direct sequence spread spectrum (DSS) cordless phones, and various radar devices. At the time of this writing, the 5 GHz unlicensed band is relatively new, and not as widely used. However, as history has proven with the 2.4 GHz unlicensed band, greater use of the 5 GHz band is fully expected.

[0033] In an unlicensed band, it is inevitable that two or more of these devices will be transmitting at the same time. There is, therefore, a high likelihood that they will interfere

with each other. When interference occurs, a signal from one device to another may not be received properly, causing the sending device to retransmit (and therefore reduce throughput), or possibly entirely destroying the communication link between two communication devices. Therefore, being able to classify or identify signals is an important prerequisite to intelligently managing the use of a shared frequency band.

[0034] With reference to **FIG. 4**, the SAGE **400** comprises a spectrum analyzer **410**, a signal detector **420**, a snapshot buffer **430** and a universal signal synchronizer **440**. The outputs of these components are coupled to the memory **610** (**FIG. 1**). The processor **600** accesses the output of the SAGE **400** via the memory **610** and controls the SAGE **400** by writing configuration information to the control registers **450** that configures operation of the SAGE components. More details on the SAGE **400** are disclosed in co-pending commonly assigned referred to above. As described in that application, the signal detector **420** comprises a peak detector **422** and one or more configurable pulse detectors **424** coupled to the peak detector. The processor **600** (or another processor coupled to the processor **600**, not shown) configures the one or more pulse detectors to detect signal pulses that fall within ranges of bandwidth, power, center frequency, duration, etc., to detect signal pulses of certain types of signals. If a pulse detector detects a pulse that meets the configured criteria, it outputs signal pulse data for that pulse. The spectrum analyzer **410** outputs duty cycle statistics such as the percentage of time of energy at each frequency in a frequency band and the average power and maximum power at each frequency (for example, at each of the 256 FFT frequency bins processed by the spectrum analyzer **410**). A pulse detector **424** in the signal detector **420** can also be configured by the processor **600** to trigger the snapshot buffer to store raw analog-to-digital (ADC) samples of the received signal when a pulse of a particular type is detected. Other devices or processes may be used to generate raw spectrum information useful by a signal classification process.

[0035] Consequently, the first level spectrum information may include one or more of:

[0036] 1. Signal pulse data (called pulse events): a list of pulse center frequencies, bandwidths, power, duration and time between pulses, for pulses detected by each of the pulse detectors.

[0037] 2. Duty cycle statistics.

[0038] 3. Average power and maximum power at each frequency.

[0039] 4. Raw analog-to-digital samples of the received signal.

[0040] With reference to the flow chart of **FIG. 5**, the signal classification process **3000** executed by the classification engine **500** will be generally described. In step **3010**, the classification engine captures raw spectrum information, such as signal pulse data, duty cycle and other spectrum statistics, and raw snapshot samples (if any). In step **3020**, the classification engine **500** accumulates signal pulse and other data from the raw spectrum information. The accumulated data may take the form of histograms, examples of which will be described hereinafter. In steps **3030** through **3050**, the accumulated data is compared against fingerprints (profiles or reference data) for known signals.

[0041] The classification engine **500** uses device fingerprint definitions from a fingerprint database to compare with accumulated signal pulse data. A fingerprint definition includes signal descriptive information that identifies a device or a class of devices. A fingerprint definition may include:

[0042] 1. Characteristics of a signal pulse: center frequency, pulse duration, bandwidth, time between pulses, etc.

[0043] 2. Pulse timing signature template: definition of recurring pulse patterns, commonly related to a particular communication protocol or standard.

[0044] 3. Iterative test definitions: iteratively search for specific signal characteristics.

[0045] 4. Custom algorithms: specific algorithms which examine statistics and pulses looking for a specific device. These are usually communication protocol-specific programs.

[0046] 5. "Expert" system analysis: more "intelligent" program to process historical statistics and pulse events over longer periods of time.

[0047] 6. Techniques for analyzing snapshot samples for a specific preamble/codeword pattern.

[0048] In step **3030**, the classification engine **500** compares the accumulated signal pulse data with reference data of known signals in the fingerprint database **610** and tries to classify the pulse(s). If the pulses can be classified by this comparison step, the process may jump to step **3060** and generate a signal identification alert. If the pulses cannot be classified based on the accumulated data alone, or if additional confirmation is desired, the process continues to step **3040**, where pulse timing signatures derived from the pulse events are compared with pulse timing signature templates in the fingerprint database **610**. If a match can be determined in step **3040**, then the process jumps to step **3060**, otherwise, the process continues to step **3050**. In step **3050**, additional algorithms or iterative tests can be performed that are designed to classify otherwise hard to match pulse types. For example, in some cases, fingerprinting may be enhanced by detecting the leading sync-word of a pulse. Raw ADC samples of the frequency spectrum are analyzed for matches with sync-word formats or patterns in the fingerprint database. An algorithm running on a standard microprocessor can classify most sync-words expected to be detected in the unlicensed frequency band. In step **3060**, an identification/classification alert is generated for each signal that either classifies the signal or specifically identifies it. In addition, the power, duty cycle and center frequency (channel) information for each detected and/or identified pulse (referred to as general spectrum utilization descriptions) is output, as well as information generated by the spectrum analyzer (SA statistics) and the signal detector in the SAGE **400**. An identification/classification alert may contain center frequency information (when relevant), a signal identification/classification (described above), a probability indicator, as a well as power and duty cycle information for the signal. The signal identification/classification information may indicate whether the signal is a microwave oven, frequency hopping signal (Bluetooth™ SCO or Bluetooth™ ACL, for example), cordless telephone, IEEE 802.11 signal, IEEE 802.15.3 device, or one of various radar types.

[0049] The order of the steps for the flowchart in **FIG. 5** is not meant to be restrictive. For example, in some cases, it may be desirable to execute specific classification algorithms on signal pulse data first or early in the sequence of signal classification events.

[0050] Information used to build or compile a fingerprint definition is obtained from one or more of the following sources:

[0051] 1. Industry standards or protocols, such as IEEE 802.11, Bluetooth™, IEEE 802.15.3, HomeRF™, etc.

[0052] 2. Public filings with the U.S. Federal Communications Commission (FCC).

[0053] 3. Public information from research publications.

[0054] 4. Lab tests using a spectrum analyzer, duty cycle analyzer and/or vector analyzer.

[0055] 5. Operations of spectrum analysis engine (e.g., SAGE **400** in **FIG. 4**) to obtain pulse event duty cycle and spectrum analyzer output information representative of various signals. See **FIG. 14** and the accompanying description hereinafter.

[0056] **FIG. 6** illustrates exemplary signal pulses of signals that may be present in the frequency band. There is IEEE 802.11b signal activity that consists of pulses **1-6**. Pulses **1**, **3** and **5** are the forward channel 802.11b transmissions and pulses **2**, **4** and **6** are acknowledgement signals. There is also a frequency hopping signal, such as a Bluetooth™ SCO signal comprising pulses **7-14**. The timing, strength and duration of the signals are not shown at precise scale. Pulse event information (pulse data) is generated for signal pulses **1-6**, for example, by a pulse detector configured appropriately. Pulse event information is generated for signal pulses **7-14** by another pulse detector configured appropriately. The signal pulse data is accumulated over time for the two types of signals. The signal pulse data may be accumulated into various histograms to be described in conjunction with **FIG. 7**. In addition, spectrum analysis information may be derived from the signal activity in the frequency band, and this information can be used to generate, for example, the number of different transmissions that appear to be present in the frequency band at a given time period by counting the number of power values (above a threshold) at different frequencies in the band during the same time interval.

[0057] Examples of the pulse event data that is generated for exemplary pulses shown in **FIG. 6** are provided below.

Pulse 1	
SDID:	1 (identifying pulse detector 1)
Pulse Bandwidth:	11 MHz
Center Frequency:	37 MHz
Pulse Duration:	1.1 msec
Power:	−75 dBm
Pulse 2	
SDID:	1
Pulse Bandwidth:	11 MHz
Center Frequency:	37 MHz
Pulse Duration:	200 microsec
Power:	−60 dBm

[0058] Though not listed above, also included in the information for each pulse is the start time of a pulse, thereby enabling computation of the time between consecutive pulses detected by a pulse detector.

[0059] The pulse event data for pulses **7-14** are very similar, with the exception of the center frequency. For example, pulses **7-14** may have a pulse bandwidth of 1 MHz, a pulse duration of 350 microsec, whereas the center frequency will vary across nearly all of the 2400 MHz to 2483 MHz frequency band. The SDID for pulses **7-14** is 2, since pulse detector **2** is configured to detect these types of pulses, for example.

[0060] Turning to **FIG. 7**, examples of the types of accumulated signal pulse data will be described. These examples of accumulated signal pulse data are histograms of pulse characteristics, but it should be understood that other ways to accumulate different types of signal pulse data may also be suitable. There is a center frequency histogram that tracks the percentage of time a given center frequency is observed for a signal pulse. For example, for a 256 FFT, there are 256 frequency bins that accumulate the amount of time (or number of events) that pulses occur at a particular frequency/frequencies. After a certain amount of time, each accumulated time in a frequency bin is divided by a total amount of time that the pulses were being transmitted, to generate a percentage at each frequency bin or frequency bins. Each frequency bin may be represented by a byte that ranges from 0 to 100 and represents the percent of time at that center frequency.

[0061] Similarly, there is a bandwidth histogram that tracks a given bandwidth observed for signal pulses. For example, if the entire bandwidth of the frequency band is 80 MHz, then there may be 80 1 MHz slots that are used to count the amount of time a pulse is at a particular bandwidth. Again, after a certain amount of time, each bandwidth count is divided by a total amount of time that the pulses were being transmitted in order generate a percentage value. For example, each byte bwPercent[N] represents the percentage of pulses having a bandwidth of N.

[0062] The pulse duration and time between pulses (also called pulse gap) observed for a signal pulse may be tracked with separate histograms that have generally the same form as shown in **FIG. 7**. There may be three categories of pulse duration and time between pulses: short, medium and long, partitioned by appropriate thresholds. The categories can be broken down as follows:

Bin Size Type	Bin Start Range (microsec)	Individual Bin Size (microsec)	Number of Bins in Range	First Bin in Range (microsec)	Last Bin in Range (microsec)
Short	0 to 190	10	20	0 to 9	190 to 199
Medium	200 to 1499	50	26	200 to 249	1450 to 1499

-continued

Bin Size Type	Bin Start Range (microsec)	Individual Bin Size (microsec)	Number of Bins in Range	First Bin in Range (microsec)	Last Bin in Range (microsec)
Long	1500 to 14500	500	27	1500 to 1999	All times greater than 14500

[0063] Each of the bins represents the percentage of occurrences of gaps or durations within the range of that bin. The percentage values range from 0 to 100, with accuracy with ½ percentage point. For example, an 8-bit unsigned value from 0 to 200 can be used to represent the 0 to 100 percentage value.

[0064] Another data that can be generated and used for signal classification and other purposes is data that tracks the number of different simultaneous transmissions in the frequency band during a period of time. The active transmission histogram is an example of such data. It shows the percentage or time that one to 4 or more different signal transmissions were in progress during a sampling interval, based on the number of different pulses tracked by the 4 pulse detectors. It should be understood that 4 is only an example of the number of different pulses that could be simultaneously tracked. This type of data is very useful in determining when two or more signals of the same or different type are simultaneously active in the frequency band.

[0065] The reference signal pulse data against which the accumulated signal pulse data is compared, is similar in structure to the accumulated signal pulse data. The active transmission data is useful to classify signals that are simultaneously occurring in the frequency band; it is not generally part of the reference data for a particular signal type, but is useful intelligence to process the signal data.

[0066] **FIGS. 8-11** are pictorial diagrams that represent accumulated signal pulse data in the form of histograms of individual pulse characteristics of known signals. These diagrams are merely representative of the underlying reference histogram data, and are not meant to represent how the data is stored and processed. **FIG. 8** shows histograms for a frequency hopping signal device, such as a Bluetooth™ synchronous (SCO) packet. The center frequency histogram for this type of signal indicates that the center frequency may be anywhere in the frequency band with equal likelihood. The pulse duration histogram indicates that this signal is consistently approximately 400 microsec long. (This may fall into a short bin of pulse duration as explained above in conjunction with **FIG. 7**, if the pulse duration is represented that way.) The bandwidth histogram for this signal indicates that it is always approximately 1 MHz wide. Finally, the time between pulses histogram indicates that half the time, the pulse gap is very short, and the other half of the time, the pulse gap is approximately 3000 microsec. In order to match accumulated signal pulse data to a signal of this type, the match criteria (referred to hereinafter in conjunction with **FIG. 12**) may be quite rigid with respect to the pulse duration, bandwidth and time between pulses histograms.

[0067] **FIG. 9** shows histogram data for a microwave oven. The center frequency histogram for this type of signal indicates that it is always at approximately one frequency, such as 40 MHz (in the 80 MHz wide 2.4 GHz unlicensed band). The pulse duration histogram indicates that it is always approximately 8 msec long. The bandwidth histogram indicates that the microwave oven pulse is always approximately 50 MHz wide. Finally, the time between pulses histogram indicates that it is always approximately 8 msec.

[0068] **FIG. 10** shows histogram data for an IEEE 802.11b signal. Because an IEEE 802.11b signal could occur at any of several frequency channels in the frequency band, the center frequency histogram is not by itself very useful (unless prior knowledge is gained from general spectrum activity information that suggests there is 802.11 activity at a particular frequency channel). However, the bandwidth, pulse duration and time between pulses are useful, if not for classifying an 802.11 signal, then at least for a guide to suggest application of other signal classification techniques, such as a classification program or algorithm, described hereinafter.

[0069] **FIG. 11** shows histogram data for one type of a radar signal. This type of signal may have a pulse duration of approximately 2 msec and a time between pulses of 135 msec. For example, most radar devices emit a pulse for a single pulse duration and repeat at the same time duration between pulses. Thus, the pulse duration histogram and the time between pulses histogram are very useful in identifying a signal as radar.

[0070] **FIG. 12** depicts what is occurring during the comparison step **3030** in the flowchart of **FIG. 5**. The accumulated signal pulse data (e.g., histograms) for the signals to be classified are compared against reference or profile signal pulse data for known signals. Each histogram of the accumulated signal pulse data is compared against a like-kind histogram of the reference signal pulse data. The degree of match between the accumulated signal pulse data and the reference signal pulse data may be adjustable and for certain reference signal pulses, a very close match on certain pulse data must be found, as compared to other signal pulse data. To this end, each reference data set may have its own match criteria that must be satisfied in order to ultimately declare a match. For example, when comparing accumulated signal pulse data with reference data for a Bluetooth™ SCO signal, there must be very precise matches between the pulse duration, bandwidth and time between pulses histograms in order to declare a match. A scoring system may be used, where a numeric value is assigned to the comparison results between each signal characteristic. For certain signal types, if the total numeric value (e.g., total score) is at least as great as a certain value, then a match may be declared. An additional constraint may also require that certain signal characteristics must have a minimum degree of match.

[0071] Pulse time signatures can provide a distinctive representation of a device or class of devices. In some cases, they can be used to confirm a suspected match with a particular signal type. **FIG. 13** shows a process whereby in step **3042**, the accumulated pulse data for a particular pulse suggests that it is of a particular type, but it is not determinative. For example, suggestive characteristics of an 802.11 signal is the presence of a signal pulse with a very short duration, no more than 200 microsec and a time between pulses of no more than 20 microsec. However, the additional

data (center frequency and bandwidth) is not sufficient to confirm that it is an 802.11 signal. Therefore, in step **3052**, pulse timing signature analysis (i.e., pattern) is performed on the pulse data. For example, the pulse timing analysis for an 802.11 signal is focused on identifying two signal pulses on the same center frequency separated from each other by no more than 20 microsec, and where the second signal pulse (an 802.11 ACK pulse) is no more than 200 microsec. The duration of the first pulse for an 802.11 signal is not particularly relevant to this analysis. A similar analysis may be performed on the pulse data against pulse signature information for a Bluetooth™ SCO signal. Classifying a pulse using timing signature templates is particularly useful when more than one device is transmitting in the frequency band. Pulse timing signature information for a signal can be represented by data describing the characteristic of a pulse, such as pulse duration, time between pulses, etc. This information can then compared against similar pulse timing signature information to determine whether there is a match.

[**0072**] Another way to iteratively search for different signal characteristics is to iteratively operate the pulse detectors in the SAGE with different parameters, with the goal of eventually detecting signal pulses that match the configured parameters of a pulse detector. The matching signal pulse characteristics are accumulated over time, and then run through the signal classification processes.

[**0073**] **FIG. 14** illustrates an environment that is useful to learn the distinctive profile of a device and create a fingerprint definition. A device **4000** that transmits a radio signal to learn is turned on in an environment where a communication device **1000** having the SAGE **400** (or other device capable of providing similar output as the SAGE **400**) resides. The communication device **1000** operates the SAGE **400** to generate signal pulse data, spectrum analysis statistics, etc., from the signal that it receives from the device **4000**. This SAGE output may be processed by processor **600** executing the classification engine **500**. The processor **600** may be part of the communication device **1000** using the SAGE **400**, or may be located in another device remote from communication device **1000**, such as in a server computer, for example. If located remotely, the SAGE outputs are transmitted wirelessly or by wire to processor **600**. The classification engine **500** processes the SAGE outputs generated based on the transmission in the frequency band by the device **4000**, accumulates signal pulse data (e.g., builds histograms) similar to the ones described above and uses those histograms as the appropriate set of fingerprint definitions to classify/identify the device **4000**. Alternatively, the accumulated data can be used to design specific classification algorithms, pulse timing signature templates, etc., to classify/identify signals of the device **4000**.

[**0074**] **FIG. 15** illustrates another example of an application of the signal classification schemes. In this example, the SAGE **400** or other device capable of generating signal pulse data is deployed together with the radio I/F **300** and an interface, such as a cardbus interface **570**. These components may be implemented in a field programmable gate array together with the cardbus interface **570**. The cardbus interface **570** may interface with various card-slot types, such as Type II PC-Card slot. The SAGE **400** is used by a host device **5000** that has a host processor **5010** as well as other components. A display monitor **5030** may be coupled to the host device **5000**. The host device **1000** may be, for example, an access point for a wireless local area network, in which case it would have the requisite radio transceiver and baseband signal processing components. Alternatively, the host device **5000** may be a desktop or notebook personal computer or personal digital assistant. A memory **5020** in the host device may store a software programs for controlling the use of the SAGE **400** as well as the classification engine program. In addition, the memory **5020** may store driver software for the host device, such as drivers for operating systems such as Windows operating systems (Windows® XP, Windows® CE, etc.).

[**0075**] One or more radio receivers may be coupled to the radio I/F **300**. For example, one radio receiver **210** may be dedicated to one frequency band (such as the 2.4 GHz unlicensed band) and another radio receiver **220** may be dedicated to another frequency band (such as the 5 GHz unlicensed bands). A switch **230** selects the baseband analog output from one of the radio receivers, and couples it to an ADC **240**, which is in turn coupled to the radio I/F **300**. The DAC **250** is used to couple control signals to the radio receivers to, for example, control the bandwidth of operation of the radio receiver for wideband or narrowband operation. The larger dotted block around the elements in **FIG. 15** is meant to indicate that these components may reside in a card device, such as a PC-card device, that interfaces with the host device **5000**. Thus, the card device essentially is a spectrum analyzer device and much more for a radio frequency band, that interfaces to a host device **5000**.

[**0076**] The host processor **5010** performs the functions to control, and interface with, the SAGE **400**, as well as other functions, such as executing the classification engine based on the output of the SAGE **400**. In addition, another application program residing in the memory **5020** of the host device **5000** may generate a graphic user interface display of the SAGE and/or classification engine output, as shown in **FIG. 16**. In addition, there may controls to trigger display of newly captured data as shown by the buttons at the top of **FIG. 16**.

[**0077**] Moreover, the radio I/F **300** and SAGE **400** are shown in phantom to indicate that all of the functions of these components may be performed by a software program stored in the memory **910** and executed by the host processor **900**. In this configuration, the output of the ADC **240** is coupled through an interface, such as the cardbus interface **570** to the host processor **5010**, which executes processes that would otherwise be performed in hardware by the SAGE **400**, as well as the classification engine and other processes referred to above.

[**0078**] In sum, a method is provided for classifying signals occurring in a frequency band, comprising detecting one or more characteristics of one or more signals in the frequency band; accumulating signal data pertaining to the signals over time; comparing the signal data against reference data associated with known signals; and classifying the one or more signals in the frequency band based on the comparison. Similarly, a system is provided for classifying signals occurring in a frequency band, comprising: a memory that stores accumulated signal data pertaining to signals occurring in the frequency band over time; and a processor coupled to the memory that compares the accumulated signal data against reference data to classify the one or more signals in the frequency band.

[0079] Moreover, a method is provided for generating data indicative of a signal of a device operating in a frequency band, comprising steps of detecting a signal transmitted by the device operating in the frequency band; accumulating signal data pertaining the signal over time; and generating characteristics of the signal data useful to classify or identify the device when it operates in the frequency band.

[0080] Further still, a processor readable medium is provided that is encoded with instructions that, when executed by a processor, cause the processor to perform the steps of comparing signal data against reference data associated with known signals; and classifying the one or more signals in the frequency band based on the comparison.

[0081] The above description is intended by way of example only.

What is claimed is:

1. A method for classifying signals occurring in a frequency band, comprising:

a. detecting one or more characteristics of pulses of radio frequency energy occurring in the frequency band;

b. accumulating data pertaining to the characteristics over time; and

c. analyzing the data to classify one or more signals in the frequency band.

2. The method of claim 1, wherein the step of accumulating data comprises accumulating data pertaining to characteristics including: pulse center frequency, pulse bandwidth, pulse duration, time between pulses and number of different active pulses.

3. The method of claim 1, wherein the step of analyzing comprises comparing the accumulated data against a timing template defining a time period between pulses associated with known signals.

4. The method of claim 1, and further comprising the step of obtaining a sample of a radio frequency energy detected for a time interval, wherein the step of analyzing further comprises examining the sample of the radio frequency energy.

5. The method of claim 4, wherein the step of analyzing further comprises the step of correlating the sample against a sync-word associated with a known signal based on preliminary indications of a match to a corresponding known signal from analysis of the data.

6. The method of claim 1, and further comprising the step of outputting, for a signal that can be classified, information that describes the type of signal, as well as one or more of: a center frequency of the signal, if relevant, a measure of probability that there is a match, power of the signal and duty cycle of the signal.

7. A system for classifying signals occurring in a frequency band, comprising:

a. a memory that stores accumulated data pertaining characteristics of pulses of radio frequency energy occurring in the frequency band over time; and

b. a processor coupled to the memory that analyzes the data to classify one or more signals in the frequency band.

8. The system of claim 7, wherein the memory stores accumulated data comprises accumulating pulse data pertaining to characteristics including: pulse center frequency, pulse bandwidth, pulse duration, time between pulses and number of different active pulses.

9. The system of claim 7, wherein the processor analyzes the accumulated data against a timing template defining a time period between pulses associated with known signals.

10. The system of claim 7, wherein the memory stores accumulated data pertaining to characteristics including: pulse center frequency, pulse bandwidth, pulse duration histogram and time between pulses.

11. The system of claim 7, wherein the processor further correlates data describing a sample of radio frequency energy detected for a time interval against a sync-word associated with a known signal based on preliminary indications of a match to a corresponding known signal from analysis of the data.

12. The system of claim 7, wherein the processor outputs, for a signal that can be classified, information that describes the type of signal, as well as one or more of: a center frequency of the signal, if relevant, a measure of probability that there is a match, power of the signal and duty cycle of the signal.

13. A processor readable medium encoded with instructions that, when executed by a processor, cause the processor to perform the steps of:

a. accumulating data pertaining characteristics of pulses of radio frequency energy occurring in the frequency band over time; and

b. analyzing the data to classify one or more signals in the frequency band.

14. The medium of claim 13, wherein the instructions encoded on the medium for performing the step of accumulating comprise instructions for accumulating data pertaining to characteristics including: pulse center frequency, pulse bandwidth, pulse duration, time between pulses and number of different active pulses.

15. The medium of claim 13, wherein the instructions encoded on the medium for performing the step of analyzing comprises instructions for comparing the accumulated data against a timing template defining a time period between pulses associated with known signals.

16. The medium of claim 13, wherein the instructions encoded on the medium for performing the step of analyzing comprises instructions for correlating data describing a sample of radio frequency energy detected for a time interval against a sync-word associated with a known signal based on preliminary indications of a match to a corresponding known signal from analysis of the data.

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