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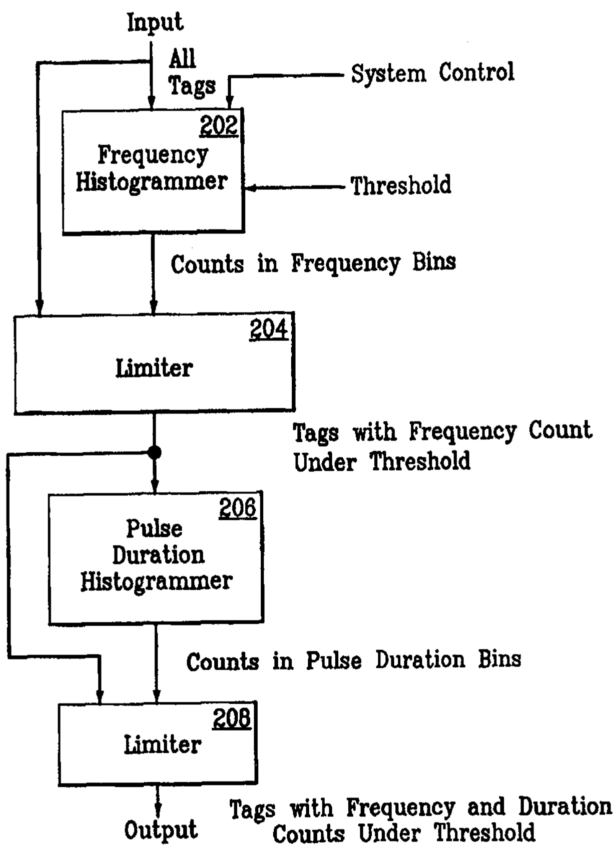
(54) Title: SYSTEM AND METHOD FOR LIMITING HISTOGRAMS

(57) Abstract

Apparatus and methods for reducing data flow through a signal processing system are disclosed. A method according to the invention includes receiving (202) a set of tags from an input system, where each tag is associated with a pulse and includes a pulse characterization parameter that characterizes the associated pulse. The pulse characterization parameter (204) can be based on, for example, pulse center frequency, duration, or angle of arrival. The method includes identifying a subset of tags from the set of tags, where each tag in the subset includes a predefined value of the pulse characterization parameter. The subset of tags can be identified by histogramming (206) the set of tags based on the pulse characterization parameter. If the number of tags in the subset exceeds a threshold number (208), then the number of tags from the subset that is forwarded through the system is limited to no more than the threshold number of tags.



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SYSTEM AND METHOD FOR LIMITING HISTOGRAMS

Field of the Invention

The present invention relates in general to signal processing systems and methods. More particularly, the present invention relates to apparatus and methods for reducing data throughput in signal processing systems by blocking redundant data while allowing relevant data to pass.

Background of the Invention

Typical signal processing systems process large amounts of data representing the signal energy that is present in an RF environment of interest. Frequently, the amount of data is so large that it exceeds the system resources available to process the data. In these circumstances, meaningful data is often lost. One approach to dealing with this problem is to add more system resources. This approach is often undesirable, however, due to cost constraints. Another approach is to reduce data throughput. Typical signal processing systems reduce data throughput by throttling the amount of data that is allowed through the system by the use of data throttling queues. Basically, data is allowed through the system until the queue fills up. Once the queue fills with data, any additional data is dropped (*i.e.*, prevented from continuing to pass through the system), thereby reducing data throughput.

An undesirable consequence of these types of throttling systems is that the data that is lost is often relevant data (*i.e.*, it includes information of interest to the signal processing system). In certain applications, however, it is known that much of the signal data that passes through the system includes redundant information. Designers of signal processing systems, therefore, would benefit from methods and apparatus that reduce data throughput by blocking redundant data while allowing relevant data to pass.

Summary of the Invention

The present invention satisfies these needs in the art by providing apparatus and methods for reducing data flow through a signal processing system. The inventive method comprises receiving a set of tags from an input system, where each tag is associated with a pulse and includes a pulse characterization parameter that characterizes the associated pulse. The pulse characterization parameter can be based on, for example, pulse center frequency, duration, or angle of arrival.

The method comprises identifying a subset of tags from the set of tags, where each tag in the subset includes a predefined value of the pulse characterization parameter. The subset of tags can be identified by histogramming the set of tags based on the pulse characterization parameter. If the number of tags in the subset exceeds a threshold number, then the number of tags from the subset that are forwarded through the system is no more than the threshold number of tags.

To further reduce the flow of data through the signal processing system in an application where each of the tags includes more than one pulse characterization parameter, the inventive method can further comprise identifying a second subset of tags from the first subset set of tags, where each tag in the second subset includes a predefined value of a second pulse characterization parameter. For example, the first pulse characterization parameter can be based on pulse center frequency, while the second characterization parameter is based on pulse duration. Thus, only a subset of the subset of tags is allowed to continue to pass through the system.

Apparatus for reducing data flow through a signal processing system comprises input means for receiving the set of tags from the input system, a processor coupled to the receiving means that identifies the subset of tags, and output means for forwarding tags from the first subset to an output system. As before, if the number of tags in the subset exceeds the threshold number, then no more than the threshold number of tags from the subset are forwarded to the output system. Apparatus according to the invention can include a histogramming memory that includes a counter that is incremented for each tag in the subset that includes the predefined value of the pulse characterization parameter.

Brief Description of the Drawings

The foregoing summary, as well as the following detailed description of the preferred embodiments, is better understood when read in conjunction with the appended drawings. For the purpose of illustrating the invention, there is shown in the drawings an embodiment that is presently preferred, it being understood, however, that the invention is not limited to the specific apparatus and methods disclosed.

Figure 1 is a plot of RF energy as a function of frequency and time.

Figure 2 is a block diagram of an RF energy collection and analysis system.

Figure 3 is a block diagram of an RF energy mapper according to the present invention.

Figure 4 is a block diagram of a tag generator according to the present invention.

Figure 5 is an RF energy bitmap according to the present invention.

Figure 6 is a block diagram of a tag screening process according to the present invention.

Figure 7 is a block diagram of a histogramming limiter according to the present invention.

Figure 8 provides a frequency histogram with a pulse duration histogram for one frequency bin.

Figure 9 provides a flowchart for a frequency histogramming limiter according to the present invention.

Figure 10 provides a flowchart for a duration histogramming limiter according to the present invention.

Detailed Description of Preferred Embodiments

Definitions

Figure 1 provides a general reference for definitions of certain terms that will be used throughout this disclosure. A "dwell" is a collection of radio frequency (RF) spectra within a lower frequency limit, f_l, and an upper frequency limit, f_u, with a center frequency f_0 halfway between f_l and f_u, during period t_s to t_e. An "emitter" is an RF source that contributes to the spectra. A "dwell data set" is a formatted data set representative of all the spectra contained in a dwell.

A dwell results from a receiver being tuned to f_0 and the RF energy being collected over a period between a dwell start time, t_s, and a dwell end time, t_e. For events within a dwell, time is relative, where the beginning of a spectrum observation period, *i.e.*, the dwell, is zero time and t_1 and t_2 are some number of ticks on a counter that is initialized at the beginning of the spectrum observation period.

A "pulse" is an energy burst occurring within a dwell. Typically, many pulses occur within one dwell. A pulse is characterized by an upper and lower frequency bound, f_2 and f_1, respectively, and occurring between the start of the energy burst, t_1, and the end of the energy burst, t_2. A pulse has a center frequency of f_c halfway between f_1 and f_2, and a "pulse duration" of $t_2 - t_1$. A "tag" is a characterization of a pulse and contains the value t_1, t_2, f_1, and f_2, which mark the pulse boundaries. A "tag generator" is a device that converts a pulse into a tag. A "frequency segment" consists of the frequencies spanned by a frequency bin (*i.e.*, an FFT bin).

RF Energy Mapper

Figure 2 is a block diagram of an RF energy collection and analysis system according to the present invention. A wideband receiver 10 receives analog RF signals via an antenna 12. Receiver 10 passes the analog signals through an analog-to-digital (A/D) converter 14, wherein the analog signals are converted to digital signal samples via well-known analog-to-digital conversion techniques. A/D converter 14 outputs a digitized spectrum in the time domain, that is, a stream of digital signal samples that represents the received signal energy as a function of time.

According to the present invention, the stream of time domain samples is input into an RF energy mapper 100. RF energy mapper 100, which is described in detail below, performs a spectral analysis on the input signal samples to detect the presence of signals of interest in the digitized spectrum. Energy tags are generated for the signals of interest and can be passed on to one or more follow-on systems for further analysis. Preferably, RF energy mapper 100 stores the signal samples and can forward the stored signal samples to a follow-on system on request.

Generally, RF energy mapper 100 provides apparatus and methods for detecting and capturing broadcast radar and communications signals that are present in a frequency spectrum having a spectrum bandwidth that is wide relative to the bandwidth of the signals. RF energy mapper 100 detects and captures both short and transient signals (*e.g.*, frequency hoppers), as well as conventional continuous (*i.e.*, CW) signals (*e.g.*, air guidance signals) and continuous modulated signals (*e.g.*, commercial broadcast).

The input into RF energy mapper 100 is a stream of digitally encoded signal samples sourced by a wideband receiver. The bandwidth of the wideband receiver typically encompasses many hundreds or thousands of simultaneously transmitted signals. The system outputs tags for those collected signals. The tags describe the start and stop time and the lower and upper frequency bound of all of the signals meeting preset criteria for tagging. Where a signal is continuous rather than transient, such signal will be noted in the output tag as having a time period longer than the criteria for transient signals. A second product of the system is a randomly accessible delay line that stores all FFT representations of the incoming spectrum so that the signal associated with the tags is also outputted. The follow-on system uses the tags to request the signal samples associated with the tag.

An advantage of the system is that any and all signals within the spectrum being intercepted by the wideband receiver can be captured and described for downstream (*i.e.*, follow on) systems that will further process the signals. Thus, RF energy mapper 100 provides a very efficient method for providing the comparatively narrowband signals along with their descriptors (*i.e.*, the so-called tags). Preferably, RF energy mapper 100 tags and stores both communications signals and radar signals.

As shown in Figure 3, RF energy mapper 100 receives digital receiver samples in the time domain from one or more digital receivers, and generates selected energy tags for a follow-on subsystem. Preferably, RF energy mapper 100 performs this function in a two-step process. First, a tag generation process 102 identifies those spectral energy segments in the RF search band that are above a minimum amplitude and are not noise related. Tag generation process 102 is illustrated in Figure 4. Next, a tag screening process 104 is employed to limit the number of tags that are output to the follow-on system. Tag screening process 104 is illustrated in Figure 6.

As shown in Figure 4, a tag generator 102 according to the present can include an FFT and windowing function 106, a thresholding function 108, a pattern recognition and noise filter function 110, a line of bearing (LOB) filter 112, a signal of interest (SOI) energy definition function 114, and a signal storage function 116.

FFT and windowing function 106 serves to convert the time domain representation of the spectrum into its equivalent in the frequency domain. FFTs are performed on the signal samples at rates that accommodate the signal set intended to be captured. Thus, FFT/windowing function 106 is typically constructed to provide for variable frequency binning and variable FFT rates. For communication systems intercept, for example, narrow frequency bins can be used as part of the FFT, while for radar intercept, wide frequency bins with FFTs executed at a much more rapid rate is required. FFT bin size selection will determine the detectability of the signal, as well as the system's ability to measure the arrival and departure time of the signals to be intercepted.

The output of the FFTs, which is a set of frequency domain power samples, is stored in signal storage 116. Each of the frequency domain power samples has a value based on the RF energy that is present in the dwell bandwidth (f_u - f_l)

during the corresponding FFT window. The frequency domain samples are stored until a decision is made as to whether a pulse of interest is present in the RF spectrum. As will be described in detail below, if a pulse is detected in the RF spectrum, the tags that correspond to that pulse are forwarded to a follow-on system for further processing. Since the frequency domain samples are stored in signal storage 116, the frequency domain samples can be forwarded to the follow on system on request. The follow on system can then perform an inverse FFT on the requested frequency domain samples, which will be, in general, a subset of the set of frequency domain samples stored in signal storage 116, to reconstitute the signal of interest in the time domain.

It is important to note that this approach (*i.e.*, storing and forwarding frequency domain samples) is much more efficient than storing and forwarding the corresponding time domain samples. According to the invention, only those bins that are required to reconstitute a relatively narrow band signal detected in a relatively wide band spectrum need to be forwarded to the follow on system. At the same time, no information is lost because the set of frequency domain samples includes all the signal information that the time domain samples include.

Thus, as a practical consideration, storing the frequency domain samples in signal storage 116 (which is basically a delay line) provides for an efficiency of processing of the selected signals. A broadband receiver that captures all the signals within its bandwidth makes it more difficult to process the multiplicity of individual narrowband signals. Preferably, the receiver is matched to the bandwidth of the signal desired to be processed. In such an implementation, with the signals being stored as their frequency domain representation, the follow on systems need only process a very small part of the entire intercepted spectrum related to the (comparatively) narrow band. This can result in an order of magnitude decrease in the follow-on processing of the signal, the order of magnitude being determined by the ratio of the full spectrum to the signal bandwidth.

The output of the FFTs is also inputted to threshold detector 108, which basically converts the 3-dimensional output of the FFT function into a 2-

dimensional representation. More specifically, the signal as presented at the output of the FFT function is a series of FFT bins. Thus, there is a first dimension, *i.e.*, a representation of the spectrum in frequency. Second, the FFTs are performed periodically (*i.e.*, once each FFT window period), thus there is a time dimension. Third, the value the FFT assigns to each frequency bin is a power level that represents the signal energy in that frequency bin during that window period. Thus, the third dimension is signal power.

For each frequency cell for each FFT window period, a binary decision is made to indicate the presence or absence of energy relative to a noise floor computation that, preferably, is continually adjusted for the RF intercept environment. The frequency-time-power vectors that are inputted to thresholding function 108 is reduced to a frequency-time grid, whose entries have a binary value (*i.e.*, either a 1 or a 0) that depends on the power within each cell. The thresholding is a decision that can be made using varying degrees of complexity. The simplest form is a fixed level entered into the thresholder and any bin having a power level that exceeds the threshold results in the power level being converted to a one; wherever it is below the threshold, the power level is replaced by a zero. Thus, the output of threshold detector 108 is a grid in frequency and time that depicts significant power exceedances in each of the bins.

An exemplary frequency-time grid is shown in Figure 5 (where Xs are used to represent bins having a value of one, and blanks are used to represent bins having a value of zero). As shown in Figure 5, a preferred frequency-time grid includes 1024 frequency cells for each 2.56 microsecond window period. It should be understood that the number of frequency cells (*i.e.*, FFT bins) can be selected based on the requirements of the specific application. For example, some radar signals are known to have pulse widths as low as 50 nanoseconds with a duty cycle on the order of 1%, while other radar signals can have pulse widths up to 1.5 microseconds at nearly 50% duty cycle. The proliferation of radar signals is typically in the 2-18 GHz band, but can occur in the range of 500 MHz to 40 GHz. Communications signals, on the other hand, can be much more narrow band than radar signals, and typically have nearly 100% duty cycle. It is known, however, that for signal systems such as frequency hoppers, the 100% duty cycle is relative to a hop frequency. Most communications signals are under 2GHz, but can extend above 2 GHz in microwave and millimeter wave communications.

One advantage of the present invention is that the RF energy mapper provides apparatus and methods for detecting the presence of radar signals as well as communications signals in the same dwell data set. A system according to the present invention can utilize the RF energy mapper for both radar and communications intercept, although, in a preferred embodiment, it does not perform them simultaneously, but rather sequentially.

Threshold detector 108 can also be built to include more complex criteria for inclusion of a 1 or a 0 in each cell. That criteria analyzes the degree to which the power exceeds the threshold and for the duration that the power is there. Thus, short signals that barely make thresholds are more likely to be noise than signal, while strong signals of short duration are more likely to be signals than noise. Signals of low power with extended duration are also more likely to be signals than noise. Thus, a set of rules are formulated and implemented in a combination of hardware, firmware and software to execute this more elaborate threshold making function.

At this point, there is an N-to-1 data reduction in the amount of data passing through the system, where N is determined by the dynamic range of the digital samples representing the spectrum. For example, an 8-bit code would result in an 8-bit bin size, while a 16-bit code would result in a 16-bit bin size. In the first example, there would be an 8-to-1 data reduction, while in the second example there would be a 16-to-1 data reduction. The data reduction is a function of the requirements of the system that includes the RF Energy Mapper as a subsystem.

The frequency-time grid output from threshold detector 108 is then submitted to a noise filter 110, wherein the grid is processed to eliminate noise. Noise, as that term is used herein, means anything other than a pattern indicative of a signal of interest (SOI), and that will be most of the energy in the frequency-time grid. Thus, a system according to the present invention is very much a noise processor. The noise filter is used principally to separate pulsed from continuous signals and to eliminate obvious noise patterns. “Continuous” includes modulated continuous waveform (CW) which, on a map, will appear as a continuous ragged signal relative to the frequency cells occupied. Lightning strokes, ignition noise, and other spiking, broadband noise produces clear patterns that can be deleted.

Once the noise is eliminated from the signals in the frequency-time bit map, the bit map is passed to a line of bearing (LOB) filter 112. Line of bearing is also commonly referred to as “angle of arrival” or “azimuth.” The next level of processing uses angle of arrival to pass only those signals that are radiating from a sector or sectors that could contain signals of interest. The angle of arrival data reduction in a uniformly distributed environment will be the ratio of the sector size to 360 degrees.

Those spectral energy segments that have not been eliminated as noise are then subjected to pattern recognition and SOI energy definition process 114 to formally define the energy time and frequency extent. Process 114 follows a set of rules (which can be implemented in hardware, firmware, or software) for drawing rectangles in time and frequency around the patterns in the frequency-time grid. The length and width of those rectangles are measured in frequency and time, with specific starting and stopping positions, such as a lower frequency extent, f_L, an upper frequency extent, f_U, a start time of the rectangle, t_1, and an end time of the rectangle, t_2. The rules are set to encompass the whole frequency-time pattern of a given transient pulse when characterizing transient pulses. Thus, maximum variations in frequency determine the frequency extents and maximum extents in time determine the time extents. Any signal having a duration (t_2-t_1) that exceeds a preset time duration, T_{max}, is considered to be a continuous signal.

Process 114 also includes rejecting corrupted pulses and connecting fractured pulses in order to define a rectangular area to completely encompass each valid pulse. Energy may appear disassociated in a frequency-time grid when, in fact, the energy should be treated as a unified transmission. For example, in communications, voice signals have numerous breaks. Discrete frequency shifts and data communications will result in disconnections within the bit map when, in fact, it is a single, unified transmission.

Breaks in a pulse, if less than a preset percentage, can be ignored. In a preferred embodiment, this so-called "signal drop time percentage" is set at 1/3 of t_2 minus t_1. It should be noted that this percentage is not critical to the pattern recognition function. It is merely a judgmental factor that can be considered a design variable. This sub-function within pattern recognition function 110, which is sometimes referred to as "pulse healing," can be implemented in hardware, firmware or software.

Then, as a function of the SOI, rules are applied for examination of not only each region where there is energy evident, but also in the surrounding region and an estimate is made of the frequency and time extents and a rectangle in frequency and time is drawn around energy containing regions. A tag is generated for each rectangle defining its bandwidth, center frequency, duration, and time of arrival. These tags are then subjected to a tag screening process as shown in Figure 6. This screening begins by subjecting the tags to a bandwidth filter 120 and a duration filter 122. Signals that are too short or too long to fit the SOI characteristic will be filtered out. Signals with bandwidths not matching the SOI will also be filtered out. At this point, a refined examination of the RF energy map has been made.

For high rate signals, histogramming limiters 130, which are described in greater detail below, can be used to limit pulses entering the narrowband processing section, which can be as high as 300,000/pps for a pulse doppler emitter. The azimuth and frequency histogrammers 124, 126 serve to limit the maximum number of pulses accepted from a single emitter. In the case of a pulse doppler where a 100 ms dwell is employed during the intercept, as many as 30,000 pulses could be submitted to the system, it is unnecessary and undesirable to collect and process all of these pulses. The azimuth and frequency histogrammers will limit pulses to a programmable maximum, usually 128 pulses in any azimuth frequency range (nominally 1.25 MHz by 3 degrees). Typically, 128 pulses will be more than sufficient to characterize an emitter and track it accurately. In the example provided, a 300:1 reduction with no loss of performance is realized. For pulse rates under 1 kilopulse/sec with system setup described, no pulses would be lost due to thresholding.

Histogramming Limiters

A histogramming limiter according to the present invention is a system that uses histograms to limit data flow through a signal processing system so that the system is not overloaded. In a preferred embodiment, the histogramming limiter selectively limits data flow based on density of signal frequency and signal duration.

As described above in connection with Figure 2, data flows through the system in dwell data sets. Typically, the dwell data set has redundant information in the case of high rate emitters when the purpose of the system is to detect and locate an emitter. To reduce data flow, a histogramming limiter allows only essential data to pass through the system while blocking redundant data.

Figure 7 provides a flowchart of a histogramming limiter according to the present invention. A set of tags is produced, for example, by a tag generator such as described above. Each tag represents a pulse defined by a start time, end time, upper frequency, and lower frequency. From these values, pulse center frequency and pulse duration can be determined. The set of tags is provided as input to the histogramming limiter.

At step 202, a frequency histogrammer generates a frequency histogram that represents the number of pulses that fall into each of a plurality of frequency bins. The frequency histogram is generated based on the center frequencies that are included in the tags. At step 204, a frequency limiter determines, for each frequency bin, whether the number of pulses that fall into that bin exceed a predefined threshold. If so, only the threshold number of tags is passed on further into the signal processing system. Thus, the frequency histogrammer limits the number of tags that are allowed through the system based on frequency.

At step 206, a pulse duration histogrammer generates a pulse duration histogram that represents the number of pulses that fall into each of a plurality of pulse duration bins. The pulse duration histogram is generated based on the pulse durations that are included in the tags. At step 208, a pulse duration limiter determines, for each pulse duration bin, whether the number of pulses that fall into that bin exceed a predefined threshold. If so, only the threshold number of tags is passed on further into the signal processing system. Thus, the pulse duration histogrammer limits the number of tags that are allowed through the system based on pulse duration.

Figure 8 provides a frequency histogram example with a pulse duration histogram for one frequency bin.

Figure 9 provides a detailed description of a frequency histogrammer according to the present invention. As described above, the frequency histogrammer receives as input all the tags for a given dwell. In a preferred embodiment, the histogram is empty at the start of each dwell because the histogram counts pulses within each dwell period. At step 212, the center frequency, f_c, of each tag is computed by taking an average of the sum of f_1 and f_2, the lower and upper frequencies of the tags. At step 214, a histogram bin address is determined for each pulse. The frequency bin within which the pulse falls is determined by f_c and its relation to f_l, the lower frequency limit of the dwell. Thus, each frequency bin covers a range of frequencies.

Preferably, the pulse center frequency, f_c, is rounded to the numeric precision of bin size at step 216. For rapid computation and ease of construction, binary integer bin sizes can be used. At step 218, the resulting binary integer is used as a relative address into the histogram, which, in a preferred embodiment, is a set of counters in memory. The content of a counter is advanced by one each time a pulse falls within its range. When a counter is advanced, the count is compared to a threshold value, at step 220, and if the count exceeds the threshold, the limiter stops the tag from proceeding further through the system. Otherwise, the tag is passed through the system. The threshold is a value typically established when the system is initialized.

A similar process occurs for the pulse duration histogramming limiter, as shown in Figure 10. The input to this part of the histogrammer limiter is the subset of tags output from the frequency histogrammer limiter, and comprises the tag and the frequency bin number associated with each tag. The first operation is the computation of the pulse duration, t_2 - t_1, at step 232. The bin associated with the duration is determined, at step 234, by rounding to a binary integer of length $\log_2(M)$, where M is the total number of duration bins. Preferably, the pulse duration histogrammer limiter uses a set of histograms, one histogram for each frequency bin. At step 234, the frequency bin number in the input then is used to select the corresponding duration histogram and, at step 236, the pulse duration counter corresponding to the pulse duration bin is advanced within the selected histogram. The bin count in the selected bin is then output at step 238. The output bin count is compared to a threshold at step 240 and, if the count does not exceed threshold, the tag is outputted for additional system processing. Otherwise, the tag is suppressed. Again, this threshold is normally set at system initialization.

Thus there have been described systems and methods for limiting data throughput using histogramming limiters. Those skilled in the art will appreciate that numerous changes and modifications can be made to the preferred embodiments of the invention and that such changes and modifications can be made without departing from the spirit of the invention. It is therefore intended that the appended claims cover all such equivalent variations as fall within the true spirit and scope of the invention.

I CLAIM:

1. A method for reducing data flow through a signal processing system comprising:

receiving from an input system a set of tags, wherein each said tag is associated with a pulse and includes a first pulse characterization parameter that characterizes the associated pulse;

identifying a first subset of tags from the set of tags, wherein each said tag in the first subset includes a predefined value of the pulse characterization parameter; and

if the number of tags in the first subset exceeds a threshold number, forwarding to an output system no more than the threshold number of tags from the first subset.

2. The method of claim 1, wherein identifying the first subset of tags includes histogramming the set of tags based on the pulse characterization parameter.

3. The method of claim 1, wherein the pulse characterization parameter is based on pulse center frequency.

4. The method of claim 1, wherein the pulse characterization parameter is based on pulse duration.

5. The method of claim 1, wherein the pulse characterization parameter is based on pulse angle of arrival.

6. The method of claim 1, wherein each said tag includes a second pulse characterization parameter that characterizes the associated pulse, the method further comprising:

identifying a second subset of tags from the first subset set of tags, wherein each said tag in the second subset includes a predefined value of the second pulse characterization parameter; and

if the number of tags in the second subset exceeds a second threshold number, forwarding to the output system no more than the second threshold number of tags from the second subset.

7. The method of claim 6, wherein the first pulse characterization parameter is based on pulse center frequency and the second characterization parameter is based on pulse duration.

8. Apparatus for reducing data flow through a signal processing system comprising:

input means for receiving from an input system a set of tags, wherein each said tag is associated with a pulse and includes a first pulse characterization parameter that characterizes the associated pulse;

a processor coupled to the receiving means that identifies a first subset of tags from the set of tags, wherein each said tag in the first subset includes a predefined value of the pulse characterization parameter, and determines whether the number of tags in the first subset exceeds a threshold number; and

output means coupled to the processor for forwarding tags from the first subset to an output system,

wherein, if the number of tags in the first subset exceeds the threshold number, then the processor forwards to the output system via the output means, no more than the threshold number of tags from the first subset.

9. The apparatus of claim 8, further comprising:

a histogramming memory that includes a counter that is incremented for each said tag in the first subset that includes the predefined value of the pulse characterization parameter.

10. The apparatus of claim 9, wherein each said tag includes a second pulse characterization parameter that characterizes the associated pulse,

wherein the processor identifies a second subset of tags from the first subset set of tags, wherein each said tag in the second subset includes a predefined value of the second pulse characterization parameter, and

wherein the histogramming memory includes a second counter that is incremented for each said tag in the second subset that includes the predefined value of the second pulse characterization parameter.

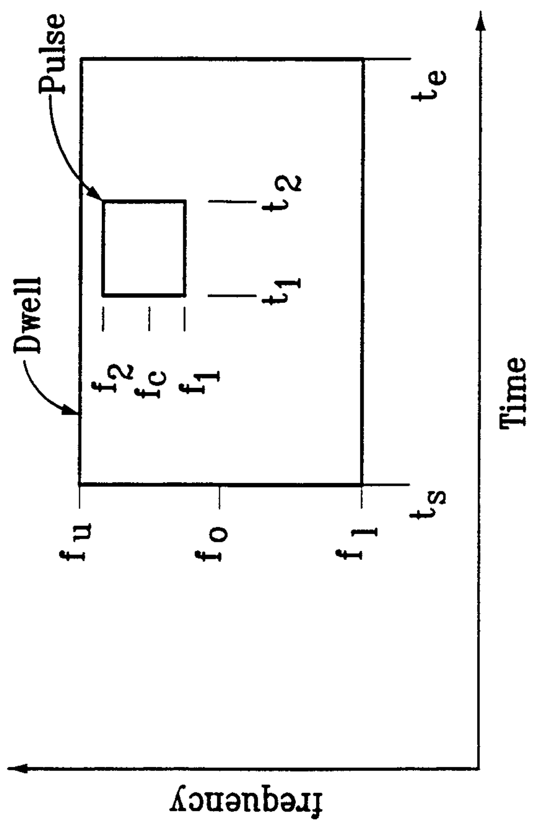

Pulse
Dwell
f2
fc
f1
t1
t2
fu
fo
fl
ts
te
Time
frequency

FIG. 1

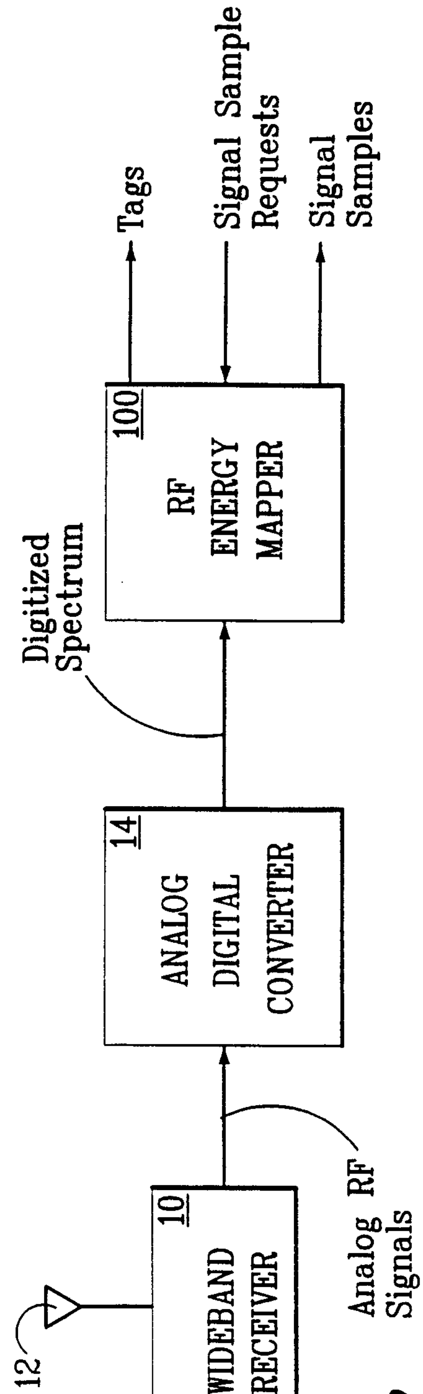

12
10
WIDEBAND
RECEIVER
Analog RF
Signals
14
ANALOG
DIGITAL
CONVERTER
Digitized
Spectrum
100
RF
ENERGY
MAPPER
Tags
Signal Sample
Requests
Signal
Samples

FIG. 2

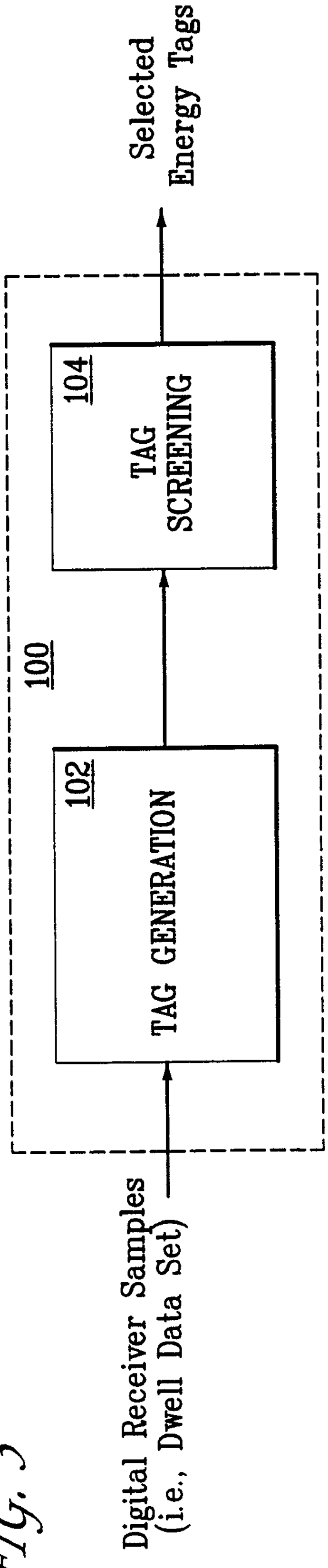

Digital Receiver Samples
(i.e., Dwell Data Set)
100
102
TAG GENERATION
104
TAG
SCREENING
Selected
Energy Tags

FIG. 3

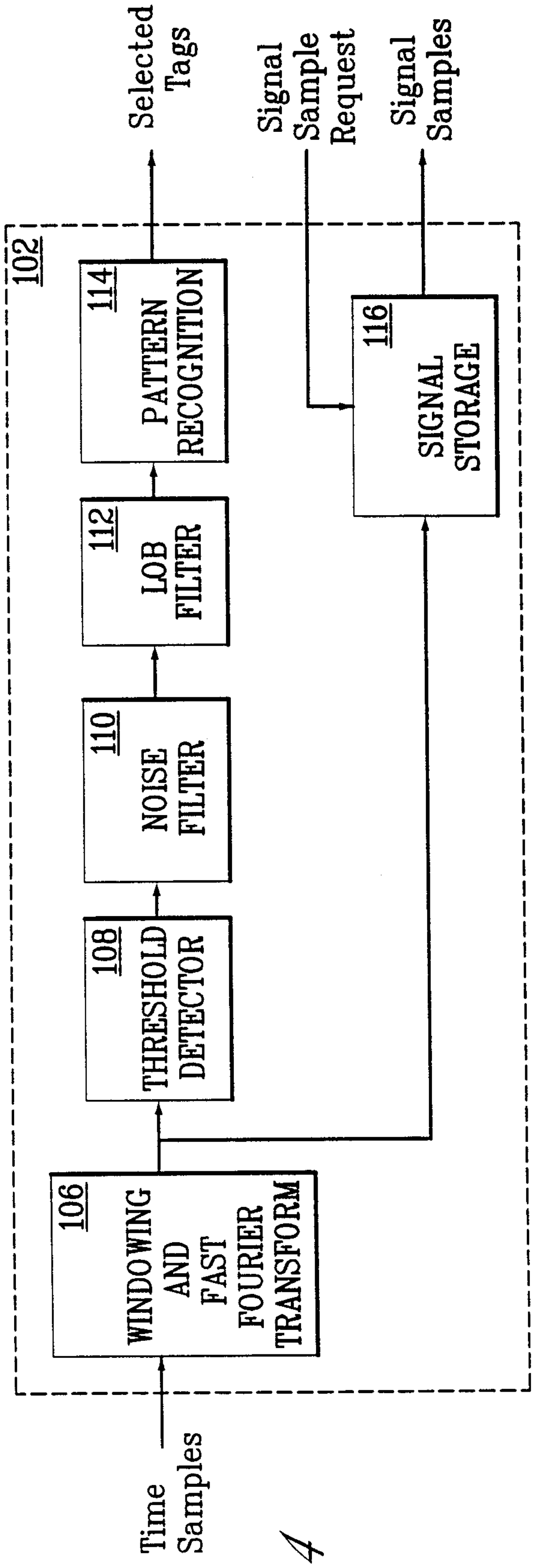
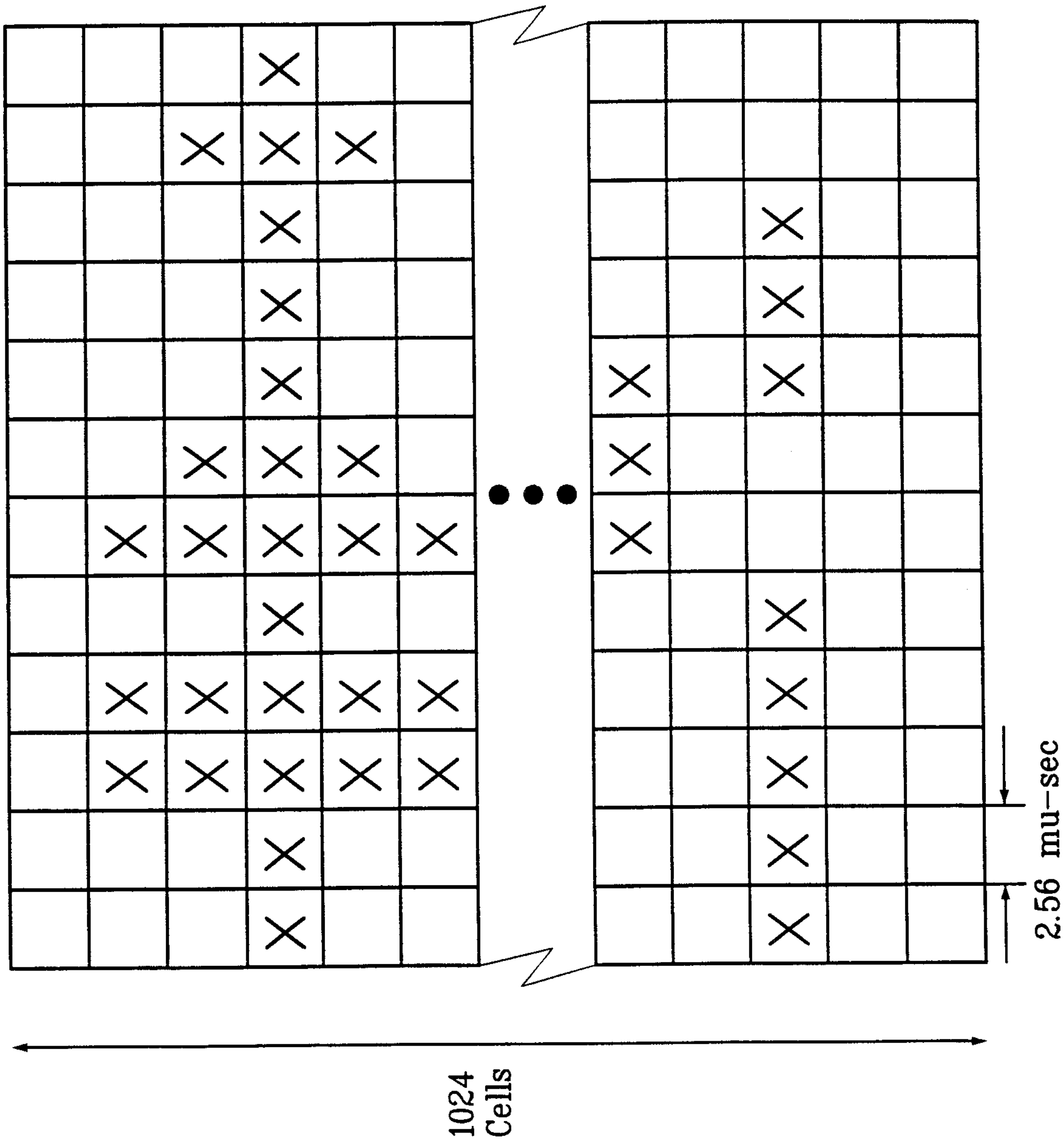

Time
Samples
102
106
WINDOWING
AND
FAST
FOURIER
TRANSFORM
108
THRESHOLD
DETECTOR
110
NOISE
FILTER
112
LOB
FILTER
114
PATTERN
RECOGNITION
Selected
Tags
116
SIGNAL
STORAGE
Signal
Sample
Request
Signal
Samples

FIG. 4

FIG. 5



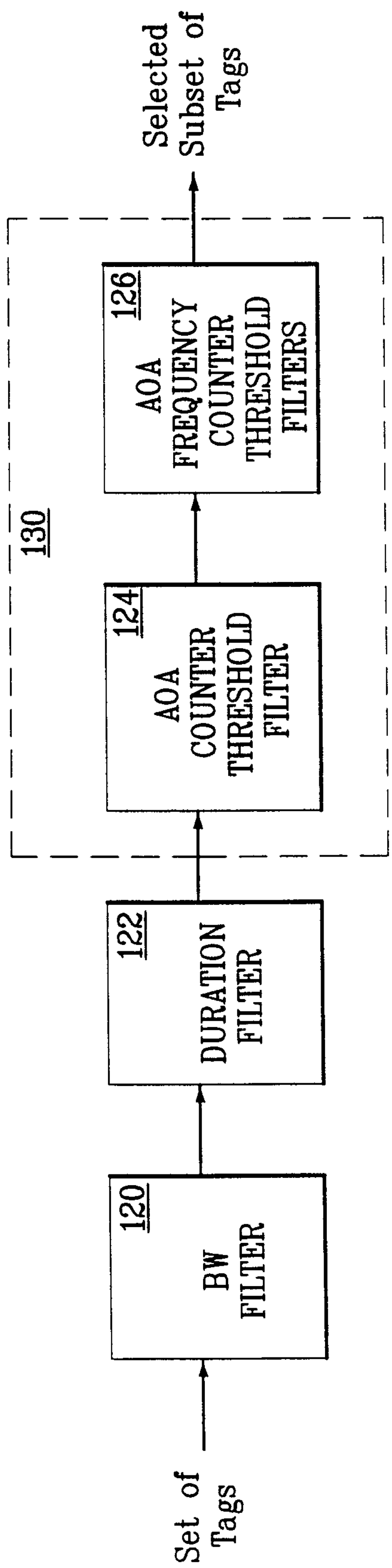
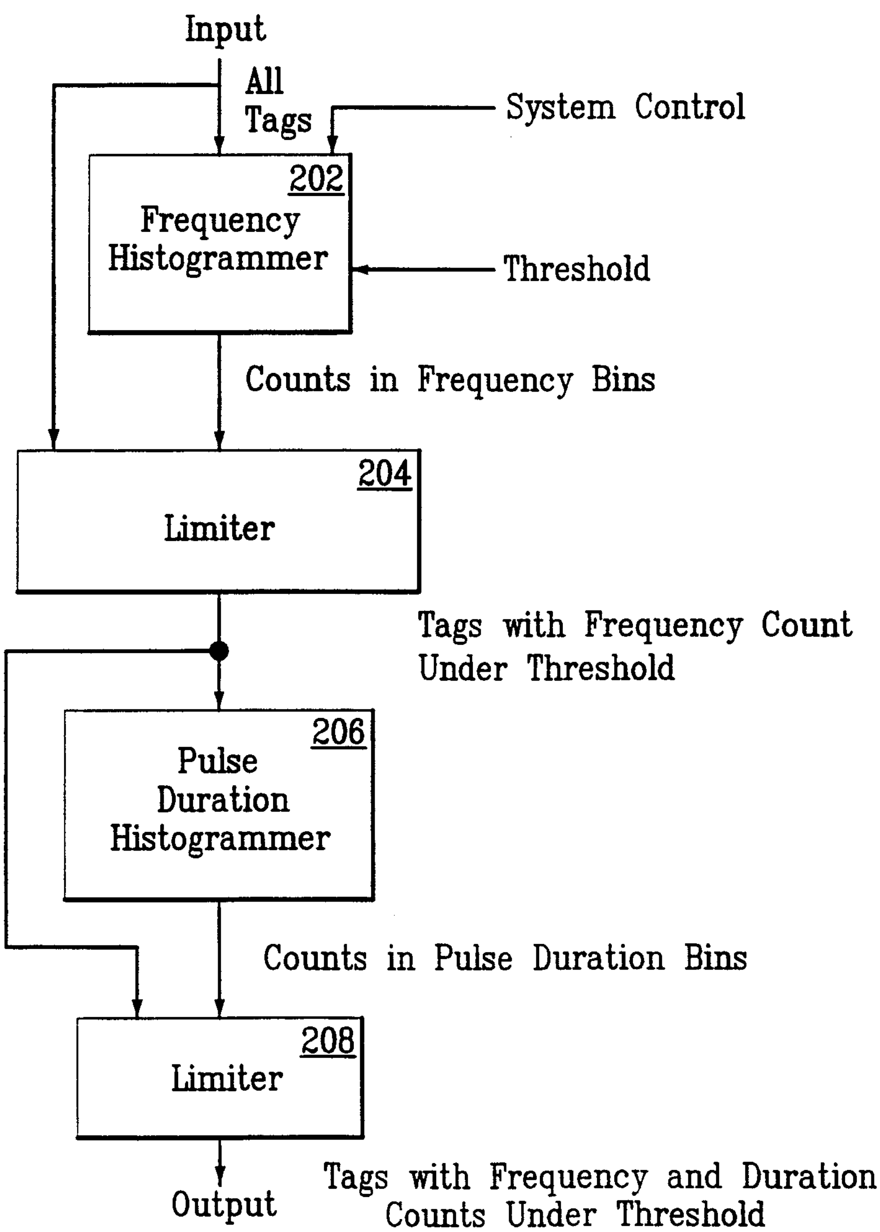

Set of Tags
120
BW FILTER
122
DURATION FILTER
130
124
AOA COUNTER THRESHOLD FILTER
126
AOA FREQUENCY COUNTER THRESHOLD FILTERS
Selected Subset of Tags

FIG. 6

FIG. 7


Input
All Tags
System Control
202
Frequency Histogrammer
Threshold
Counts in Frequency Bins
204
Limiter
Tags with Frequency Count Under Threshold
206
Pulse Duration Histogrammer
Counts in Pulse Duration Bins
208
Limiter
Output
Tags with Frequency and Duration Counts Under Threshold

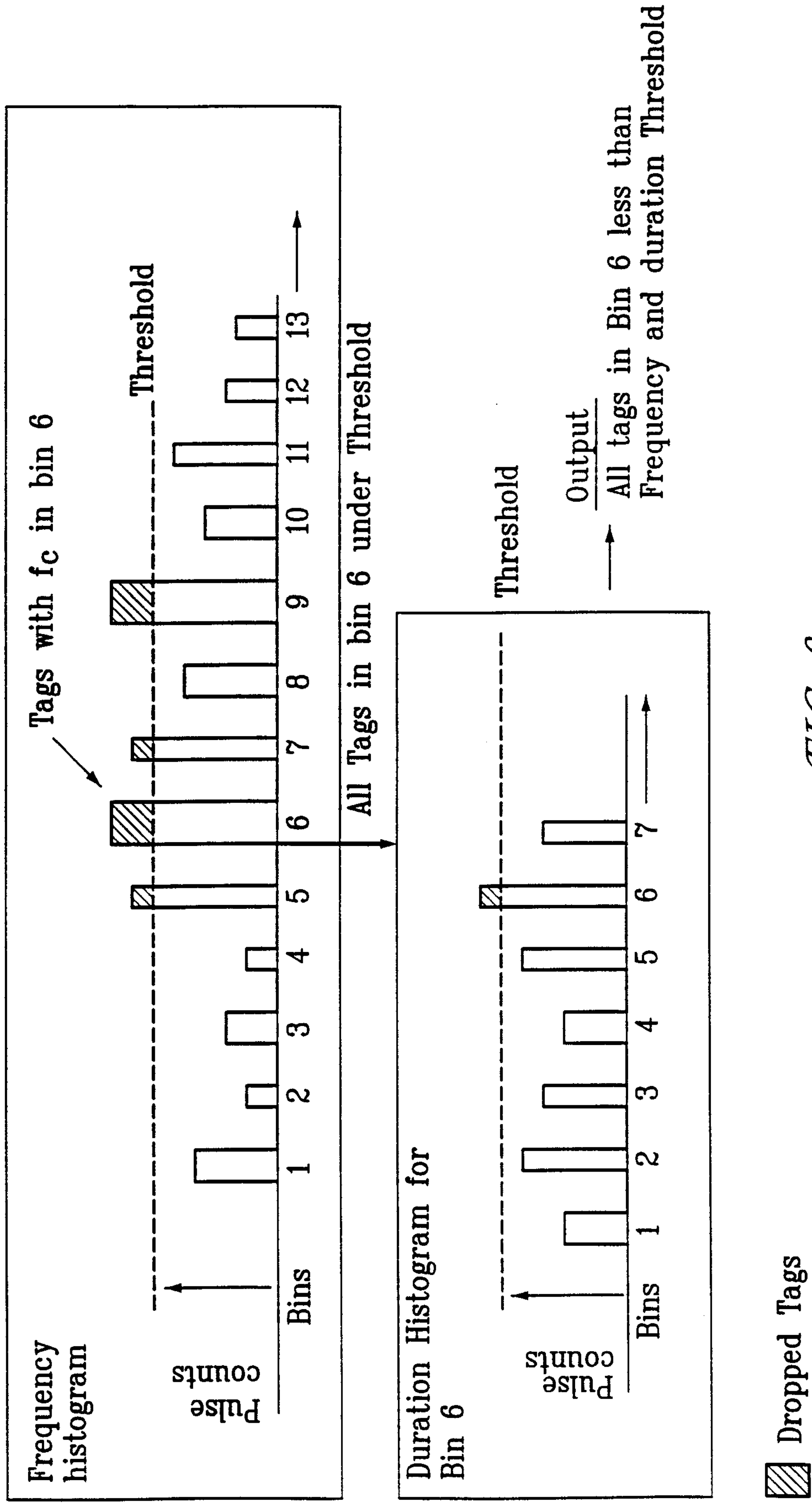

Frequency histogram
Tags with f_c in bin 6
Threshold
Pulse counts
Bins
1 2 3 4 5 6 7 8 9 10 11 12 13
All Tags in bin 6 under Threshold
Duration Histogram for Bin 6
Threshold
Pulse counts
Bins
1 2 3 4 5 6 7
Output
All tags in Bin 6 less than Frequency and duration Threshold
Dropped Tags

FIG. 8

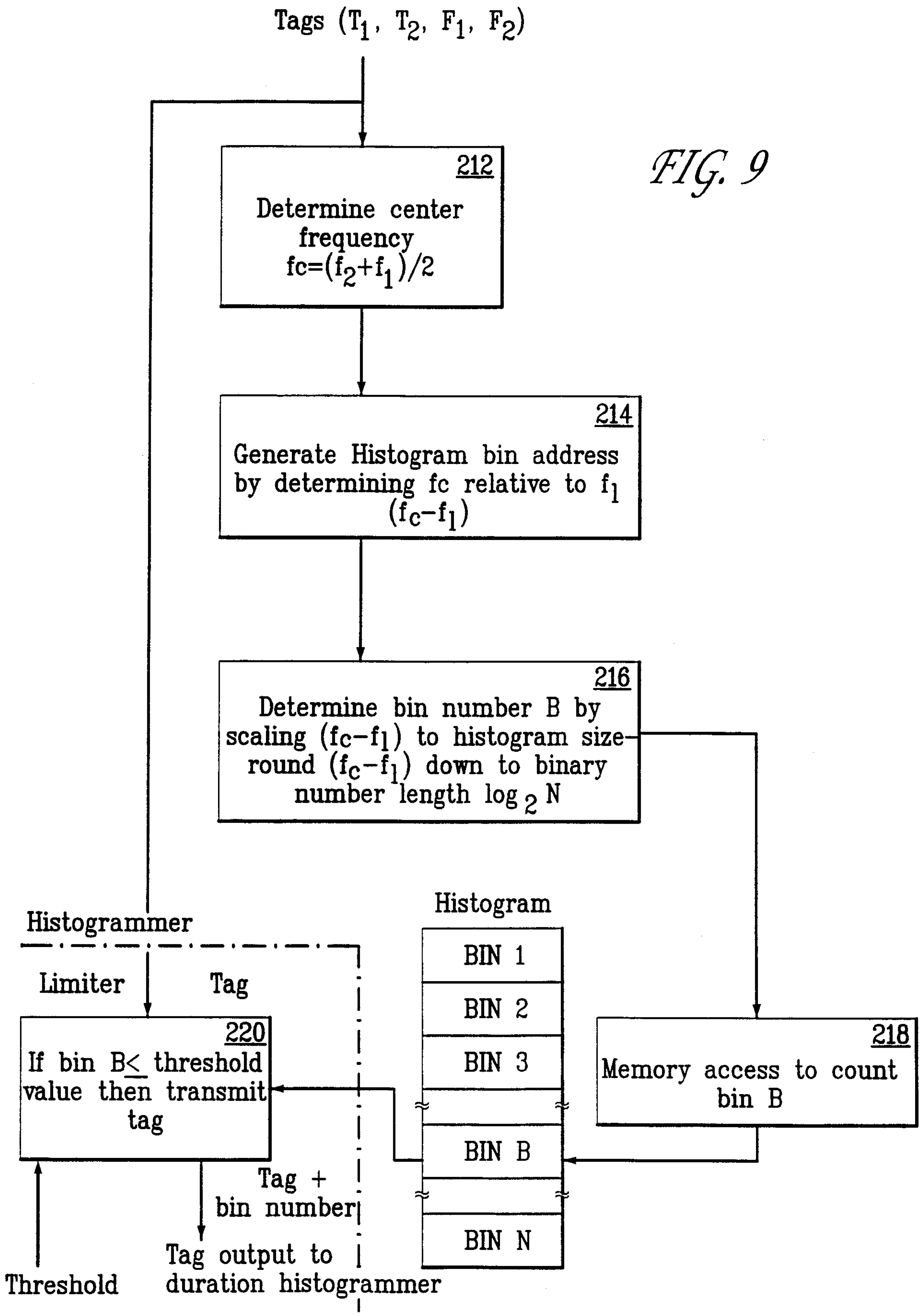

Tags (T1, T2, F1, F2)
212
Determine center frequency fc=(f2+f1)/2
214
Generate Histogram bin address by determining fc relative to f1 (fc−f1)
216
Determine bin number B by scaling (fc−f1) to histogram size-round (fc−f1) down to binary number length log 2 N
Histogram
BIN 1
BIN 2
BIN 3
BIN B
BIN N
218
Memory access to count bin B
Histogrammer
Limiter
Tag
220
If bin B≤ threshold value then transmit tag
Tag + bin number
Tag output to duration histogrammer
Threshold

FIG. 9

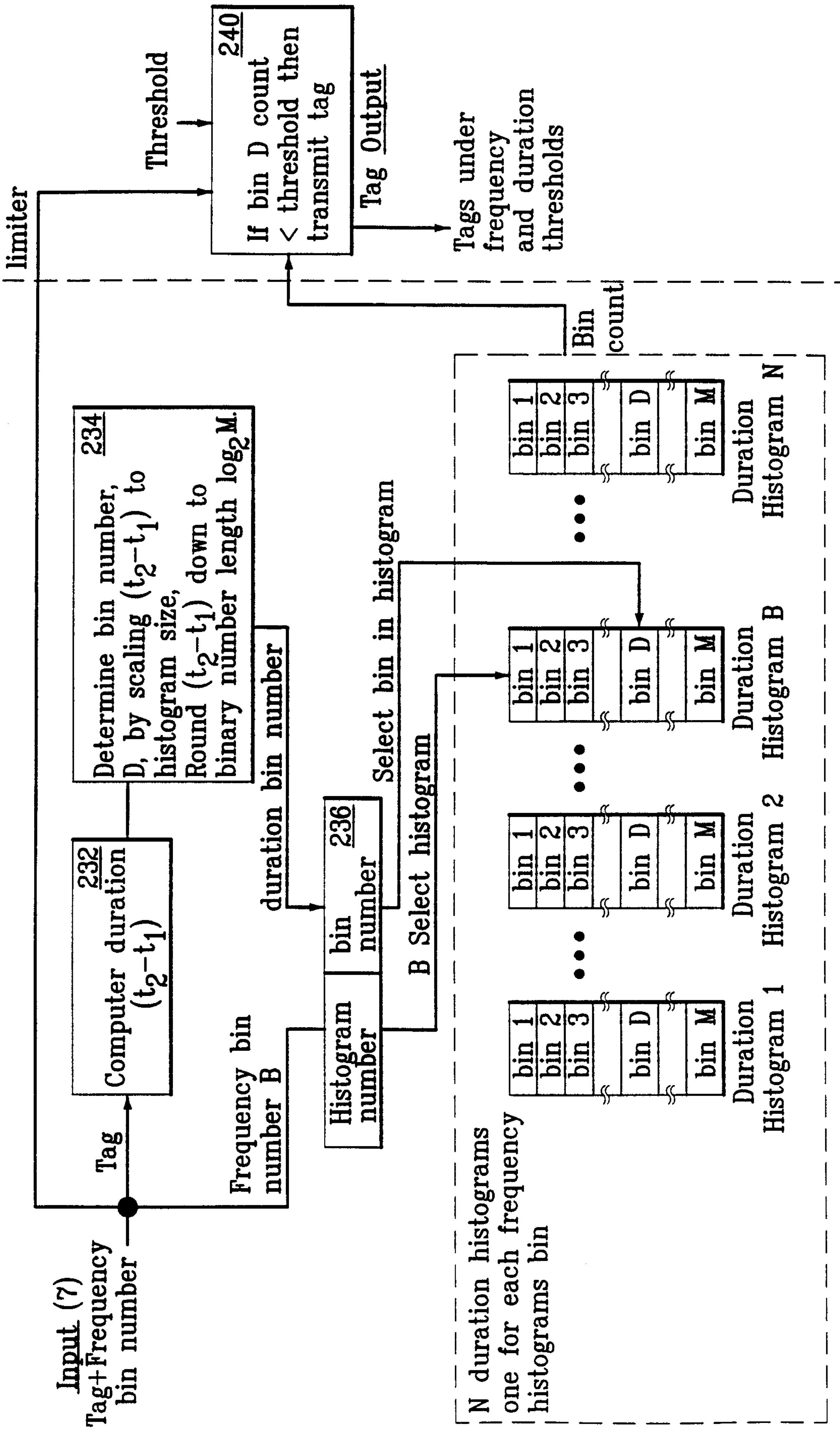

Input (7)
Tag+Frequency bin number
Tag
Frequency bin number B
limiter
Computer duration (t_2-t_1)
232
Determine bin number, D, by scaling (t_2-t_1) to histogram size, Round (t_2-t_1) down to binary number length log_2M.
234
duration bin number
Histogram number
bin number
236
Select bin in histogram
B Select histogram
Threshold
If bin D count < threshold then transmit tag
240
Tag Output
Tags under frequency and duration thresholds
Bin count
bin 1
bin 2
bin 3
bin D
bin M
Duration Histogram 1
Duration Histogram 2
Duration Histogram B
Duration Histogram N
N duration histograms one for each frequency histograms bin

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/29022

A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) :G01S 7/285
US CL :342/13, 195, 159, 162, 192, 196
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 342/13, 195, 159, 162, 192, 196

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EAST: histogram$4, threshold, pulse, frequency, subset, Fourier

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 3,665,512 A (HALL et al) 23 May 1972 (23.05.72), see Abstract for pulse signal characterization using histogram and thresholding signal.	1-10.NON
Y	US 5,583,505 A (ANDERSEN et al) 10 December 1996 (10.12.96) see column 6, lines 1-53 for pulse analysis with threshold.	1-10.
Y	US 5,381,150 A (HAWKINS et al) 10 January 1995 (10.01.95) see Abstract and Figure 1 for pulse signal analysis using spectrum analyzer, and pulse parameters.	1-10.

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
07 MARCH 2000

Date of mailing of the international search report
21 APR 2000

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/29022

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,092,343 A (SPITZER et al) 03 March 1992 (03.03.92) see Abstract and Figures 1 and 2b, and column 7, line 26 to column 8, line 14 for waveform analysis with histogram signal processing.	1-10.
A	US 4,209,835 A (GUADAGNOLO) 24 June1980 (24.06.80) see Abstract and Figure 1for signal waveform analyzer using pulse parameters.	1-10