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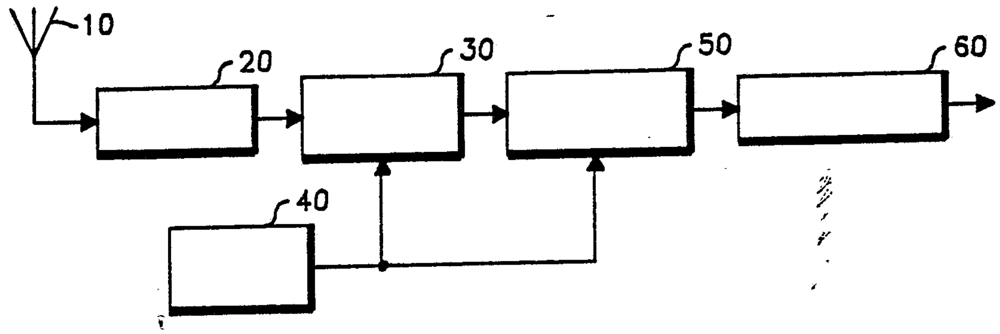

(57) Abstract

A decoder circuit which employs digital sampling and correlation apparatus to detect the presence of a received tone signal exhibiting a predetermined frequency. Samples of received tone signals are taken and, in effect, multiplied by a substantially rectangualr observation window which includes a bite interval of selected duration and location therein. A correlator correlates the windowed samples to detect samples corresponding to the predetermined frequency (main lobe frequency). A significant decrease in undesired side lobe response is thus achieved.

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APPARATUS AND METHOD FOR SUPPRESSING SIDE LOBE RESPONSE IN A DIGITALLY SAMPLED SYSTEM

Background of the Invention

This invention relates to electrical circuits responsive to signals having a predetermined frequency and, more particularly to apparatus for detecting the presence of a signal exhibiting a predetermined frequency.

Description of the Prior Art

One conventional technique for detecting the presence of a signal exhibiting a predetermined frequency is an analog inductor-capacitor type filter tuned to the predetermined frequency and coupled to a threshold detector. When a signal waveform containing the signal exhibiting the predetermined frequency is applied to the analog filter, such signal flows in a substantially unattenuated manner to the output of the filter. Since all other signals are substantially attenuated, only signals having substantial signal energy at or near the predetermined frequency of the tuned filter will reach the threshold detector and be detected thereby. The approach just described constitutes a selective frequency signal detector employing a passive filter. It is known that circuits for detecting signals of predetermined frequency are also implemented by employing active filters.

Digital filters such as the finite impulse response (FIR) filters described in Digital Signal Processing by Oppenheim and Schafer, published by Prentice Hall Inc., 1975, pages 239-250, the text of which is incorporated herein by reference, may be employed to select a signal exhibiting substantial energy at or near a predetermined frequency and to reject signals exhibiting other frequencies. In this approach an input signal is sampled at a predetermined rate to generate signal samples. The conventional digital bandpass filter operates on such samples in a manner such that, in effect, a passband is formed for signals exhibiting energy at or near the desired predetermined frequency and, stop bands are formed for signals exhibiting other frequencies. It is known that increasing the number of samples taken per unit time increases the performance capabilities of the digital filter in terms of maximum allowable input frequency. However, this approach has substantial limitations in that as the number of samples taken increases, the amount of computational time consumed likewise substantially increases.

One digital filtering technique is to observe the samples of the unknown signal during a finite duration window or observation window. One window which may be employed is the rectangular window shown in FIG. 2 and discussed by Oppenheim and Schafer in the aforementioned text. All samples which occur during such a rectangular window are by definition multiplied by a constant weight of 1 throughout the duration of the window. Samples occuring before or after the window are by definition given a weight of 0. Thus, such samples are in effect multiplied by the window. Although this approach is rather simple, it unfortunately results in substantial undesired side lobe response in the Fourier transform of the rectangular window as shown in FIG. 1. This undesired side lobe response corresponds to undesired filter responses in the filter stop-band. If such a filter were to be employed in a frequency detection scheme, it is likely that signals exhibiting frequencies other than the desired filter pass-band would pass through the digital filter at high enough levels to be falsely detected by threshold detection circuitry.

As discussed on pages 241-250 of the Oppenheim-Schafer text, other windows besides the aforementioned rectangular window may be employed to multiply or weight the signal samples thereby in the course of digital filtering to reduce the amplitude of the undesired side lobes. For example, the Bartlett, Hanning, Hamming, Blackman and Kaiser windows may be employed to weight sample values during such respective windows. Although each of these windows substantially reduces the amplitudes of undesired side lobe responses as compared to the main lobe response, implementation of such other nonrectangular windowing techniques consumes extremely large amounts of computational time when employed in a microprocessor, for example, as compared with the rectangular windowing technique. This is true because in the rectangular windowing technique, all samples which occur during the window are multiplied by 1 which is a simple computational task in binary processing. However, in the aforementioned non-rectangular windows, each of the signal samples is weighted by a different value having fractional values between 0 and 1 as is seen for example in the triangular Kaiser type window of Fig. 3. Weighting by such fractional values consumes large amounts of computational processing time.

It is one object of the present invention to attenuate the undesired stop-band response which corresponds to the side lobe response in the Fourier transform of the rectangular observation window.

It is another object of the present invention to more readily detect the presence of signal energy at or near a predetermined frequency.

Another object of the present invention is to detect the presence of a signal exhibiting a frequency within a selected pass-band without consuming large quantities of computational processing time.

These and other objects of the invention will become apparent to those skilled in the art upon consideration of the following description of the invention.

Brief Summary of the Invention

The present invention is directed to providing a decoder circuit for detecting the presence of a signal exhibiting a predetermined frequency.

In accordance with one embodiment of the invention, a decoder circuit for detecting the presence of a signal exhibiting a predetermined frequency includes a timing circuit for generating observation interval signals. The decoder circuit further includes a sampling circuit, which is responsive to the timing circuit for sampling a first signal to produce samples thereof during a substantially rectangular observation interval. The sampling circuit includes apparatus for ignoring a portion of the samples occurring near the beginning or near the end of the observation interval. A correlation circuit is electrically coupled to the sampling circuit for correlating the samples with a predetermined pattern to detect the presence of a signal exhibiting the predetermined frequency within the first signal.

The features of the invention believed to be novel are set forth with particularity in the appended claims. The invention itself, however, both as to organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description taken in conjunction with the accompanying drawings.

Description of the Drawings

FIG. 1 is a representation of the Fourier transform of a rectangular observation window.

FIG. 2 is a representation of a rectangular window.

FIG. 3 is a representation of a non-rectangular, triangular type Kaiser window.

FIG. 4 is a block diagram of the decoding apparatus of the present invention.

FIG. 5 is a amplitude vs. time graph of the observation window employed in the apparatus of the present invention.

FIG. 6A is a representation of the main lobe response and side lobe response obtained when employing the aforementioned conventional rectangular windowing technique.

FIG. 6B is a representation of the main lobe response and improved side lobe response achieved by the present invention.

FIG. 7 is a graphical representation illustrating the amount of improvement in side lobe suppression measured in dB achieved by the present invention as the width of the bite (bite duration) in the observation window of FIG. 5 is varied and as the position of the bite (bite duration) is varied within such observation window.

FIG. 8 is an amplitude vs. time graph of an alternative observation window which may be employed in the present invention.

FIG. 9 is a graphical representation of the amount of improvement in side lobe suppression measured in dB achieved by employing the window of FIG. 8 as a function of the width and the position of the bite in the observation window.

FIG. 10 is a block diagram of one timing circuit which may be employed as the timing circuit shown in the apparatus of FIG. 4.

FIGS 11A-11G are the timing diagrams illustrating the signal waveforms of various test points in the timing circuit of FIG. 8.

FIG. 12 is a block diagram of one correlator circuit which may be employed as the correlator shown in FIG. 4.

FIG. 13 is a flow chart which summarizes the steps in the operation of the present invention.

FIG. 14 is a block diagram of an embodiment of the invention which employs a micro-computer.

FIG. 15 is a more detailed block diagram of the apparatus of FIG. 14.

Detailed Description of the Preferred Embodiment

FIG. 4 illustrates one embodiment of the present invention wherein the decoder of the present invention is advantageously employed to detect the presence of at least one tone signal superimposed or modulated on a radio frequency carrier wave, hereinafter referred to as the incoming signal. The incoming signal is captured by an antenna 10 and applied to the input of a receiver 20. Receiver 20 demodulates the incoming signal such that the radio frequency portion of the incoming signal is separated from the tone portion of the incoming signal which is provided to the output of receiver 20 and is hereinafter designated the received tone signal. The remaining circuitry of FIG. 4 subsequently described operates to detect the presence of received tone signals exhibiting a predetermined frequency, for example, 1,000 Hz.

The output of receiver 20 is coupled to the input of a sampling circuit 30 such that the received tone signal is applied to the input of sampling circuit 30. Sampling circuit 30 samples the received tone signal at a predetermined rate, for example, 10,989 Hz in this embodiment of the invention. A timing circuit 40 is coupled to sampling circuit 30 to cause sampling circuit 30 to conduct its sampling operation during the specially modified, substantially rectangular observation window (observation interval) depicted in FIG. 5. More specifically, the observation window of FIG. 5 determines which samples of the received tone signal occurring during the observation window will be provided to the output of sampling circuit 30. For purposes of discussion and graphic convenience, the observation window of FIG. 5 is "normalized" to have an overall duration T1 of 1 unit of time. However, in one embodiment of the invention, T1 equals 10 msec, for example.

Since sampling circuit 30 provides output to received tone signal samples during the observation interval defined in FIG. 5, sampling circuit 30 passes samples to its output during the T1 observation interval, except for a portion thereof defined as the "bite interval" 70 which in one embodiment of the invention exhibits a time duration of T2 (.12 unit time) defined between .06 and .18 units of time of the T1 observation interval as shown in FIG. 5. Stated alternatively, during the substantially rectangular observation interval or window shown in FIG. 5, each sample taken by sampling circuit 30 during the observation interval occurring between the beginning of the observation interval and the beginning of bite interval 70 are, in effect, multiplied by or weighted 1. Thus, the samples just described are provided to the output of sampling circuit 30. However, those samples occurring during bite interval 70 are, in effect, multiplied by or weighted 0. It is seen that the plurality of signal samples occurring in succession during bite 70 are effectively dropped. Thus, in one embodiment, such samples do not reach the output of sampling circuit 30. As seen in FIG. 5, those samples occurring in the remaining portion of the observation interval after bite interval 70 are, in effect, multiplied by or weighted 1. Thus, such samples are provided output at the output of sampling circuit 30. The samples which thus reach the output of sampling circuit 30 are hereinafter referred to as "windowed samples".

The output of sampling circuit 30 is coupled to the input of an A/D converter 50. In one embodiment of the invention, the output of timing circuit 40 is operatively coupled to A/D converter 50. Converter 50 operates on the windowed samples to convert such samples from an analog to a digital format of 1,0 or -1. A converter output signal of 1 corresponds to a converter input signal greater than zero. A converter output signal of -1 corresponds to a converter input signal of less than or equal to zero. A converter output of zero corresponds to a sample weighted zero.

The output of converter 50 is coupled to the input of a correlator 60. Correlator 60 operates on the windowed samples to determine if such samples result from a received tone signal exhibiting the predetermined frequency of 1,000 Hz, for example. One correlator which may be employed as correlator 60 is described and claimed in United States Patent Number 4,301,817, issued to Gerald LaBedz, entitled "Psuedo-Continuous Tone Detector", and assigned to instant Assignee. United States Patent 4,301,817 is incorporated herein by reference. Another correlator which may be employed as correlator 60 is shown in FIG. 12 and is described later.

FIG. 6A is an amplitude versus frequency graph of the main lobe and side lobe response of conventional circuitry for detecting the presence of a tone signal which employs the rectangular observation window or interval of FIG. 2 to appropriately sample received tone signals. The main lobe response at frequency F_0 is normalized at 0 dB. It is observed that by employing the rectangular observation window of FIG. 2, a side lobe response is generated which follows a (sin x)/x function. For several frequency detection purposes, this relatively high side lobe response is unacceptable. More specifically, the response exhibited by the first side lobe at a frequency of F_{-1} is -13.26 dB with respect to the main lobe response at a frequency F_0. Thus, due to the relatively high response exhibited at the first side lobe (F_{-1}) a decoder employing the rectangular window of FIG. 2 may tend to yield false indications that a desired signal exhibiting a frequency of F_0 is present when, in reality, a signal exhibiting a frequency of F_{-1} is present. The side lobe response formed by the side lobes at frequencies of F_{-2} and F_{-3} is also shown in FIG. 6A.

FIG. 6B illustrates the improved side lobe response achieved by the decoder apparatus of the present invention which employs the modified substantially rectangular observation interval of FIG. 5 to window the samples taken of the received tone signal by sampling circuit 30. The main lobe response is centered about a frequency of 1,000 Hz F_0' and exhibits a relative peak amplitude of 0 dB. First and second side lobes are shown at frequencies of F_{-1}' and F_{-2}', respectively. It is observed that in the response characteristics shown in FIG. 6B, the peak amplitude of the first side lobe at frequency F_{-1}' is -17.05 dB. In comparison, the peak amplitude of the first side lobe (F_{-1}) for the response of FIG. 6A is -13.26 dB for the rectangular observation window. Thus, it is seen that the decoder apparatus of the present invention achieves an improvement of 3.79 dB in first side lobe response suppression as compared to techniques employing the rectangular observation window of FIG. 2.

The following Table 1 is a listing of the increases in dB's in the suppression of the first side lobe as a function of the time position of bite 70 (bite time position) within the T1 observation interval and as a function of the time duration of the bite (bite duration). Bite duration and bite time position are expressed as fractional portions of the T1 observation interval which is normalized to exhibit an overall duration of unit time 1. Various bite time positions are listed at the top of each column of dB suppression improvement values. Various values of bite duration are expressed as fractional portions of the T1 observation window at the beginning of each row of dB improvement of first side lobe suppression.

TABLE 1

dB IMPROVEMENT

BITE POSITION →

BITE DURATION ↓	.000	.020	.040	.060	.080	.100	.120	.140	.160	.180	.200	.220	.240	.260	.280	.300
0.000	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26
0.010	13.26	13.32	13.39	13.45	13.50	13.54	13.57	13.58	13.58	13.57	13.54	13.50	13.45	13.39	13.33	13.26
0.020	13.26	13.34	13.48	13.62	13.74	13.83	13.88	13.92	13.92	13.89	13.83	13.75	13.64	13.51	13.38	13.23
0.030	13.26	13.32	13.55	13.76	13.95	14.12	14.22	14.28	14.28	14.23	14.13	13.98	13.81	13.61	13.40	13.18
0.040	13.26	13.26	13.58	13.89	14.16	14.40	14.57	14.65	14.66	14.58	14.43	14.21	13.96	13.68	13.39	13.10
0.050	13.26	13.26	13.56	13.96	14.35	14.68	14.92	15.05	15.06	14.94	14.72	14.43	14.10	13.74	13.37	13.00
0.060	13.26	13.26	13.51	14.02	14.50	14.95	15.28	15.47	15.48	15.32	15.02	14.65	14.22	13.77	13.32	12.89
0.070	13.26	13.26	13.41	14.00	14.62	15.19	15.65	15.91	15.92	15.70	15.32	14.85	14.27	13.78	13.25	12.75
0.080	13.26	13.26	13.26	13.95	14.60	15.41	16.02	16.38	16.27	15.54	15.17	14.47	13.83	13.41	13.15	12.59
0.090	13.26	13.26	13.26	13.84	14.68	15.57	16.37	16.74	15.84	15.12	14.75	14.02	13.41	12.98	12.75	12.41
0.100	13.26	13.26	13.26	13.69	14.62	15.66	16.68	16.48	15.47	14.76	14.30	13.64	13.02	12.59	12.35	12.21
0.110	13.26	13.26	13.26	13.50	14.50	15.66	16.92	16.28	15.15	14.44	14.09	13.28	12.65	12.22	11.98	11.92
0.120	13.26	13.26	13.26	13.26	14.32	15.57	17.05	15.91	14.88	14.18	13.75	12.93	12.31	11.88	11.65	11.58
0.130	13.26	13.26	13.26	13.26	14.09	15.30	16.96	15.67	14.65	13.97	13.42	12.61	11.99	11.57	11.33	11.27
0.140	13.26	13.26	13.26	13.26	13.83	15.13	16.62	15.49	14.47	13.81	13.11	12.31	11.70	11.28	11.04	10.99
0.150	13.26	13.26	13.26	13.26	13.55	14.82	16.17	15.34	14.35	13.69	12.83	12.01	11.43	11.02	10.79	10.73
0.160	13.26	13.26	13.26	13.26	13.26	14.50	15.72	15.25	14.27	13.54	12.57	11.79	11.19	10.78	10.55	10.50
0.170	13.26	13.26	13.26	13.26	13.26	14.18	15.30	15.22	14.25	13.28	12.34	11.56	10.97	10.56	10.33	10.30
0.180	13.26	13.26	13.26	13.26	13.26	13.86	14.91	14.96	14.07	13.04	12.12	11.36	10.78	10.37	10.15	10.11
0.190	13.26	13.26	13.26	13.26	13.26	13.55	14.56	14.65	13.84	12.84	11.92	11.18	10.60	10.20	9.99	9.95
0.200	13.26	13.26	13.26	13.26	13.26	13.26	14.24	14.37	13.62	12.66	11.76	11.02	10.45	10.06	9.85	9.81
0.210	13.26	13.26	13.26	13.26	13.26	13.26	13.95	14.13	13.43	12.49	11.61	10.88	10.32	9.94	9.71	9.57
0.220	13.26	13.26	13.26	13.26	13.26	13.26	13.70	13.92	13.27	12.36	11.49	10.77	10.22	9.84	9.64	9.32
0.230	13.26	13.26	13.26	13.26	13.26	13.26	13.47	13.73	13.14	12.25	11.40	10.68	10.14	9.77	9.56	9.08
0.240	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.58	13.04	12.16	11.33	10.62	10.08	9.71	9.52	8.84
0.250	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.46	12.96	12.10	11.27	10.58	10.05	9.68	9.35	8.60
0.260	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.36	12.91	12.07	11.25	10.56	10.03	9.67	9.10	8.36
0.270	13.26	13.26	13.26	13.26	13.26	13.26	13.26	11.30	12.89	12.07	11.25	10.56	10.04	9.56	8.85	8.11
0.280	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	12.90	12.08	11.27	10.59	10.07	9.27	8.61	7.91
0.290	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	12.94	12.14	11.32	10.64	10.13	8.99	8.37	7.69
0.300	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.02	12.21	11.40	10.72	10.21	8.70	8.13	7.47
0.310	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	11.12	12.32	11.50	10.81	10.32	9.99	7.98	7.26
0.320	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	12.45	11.63	10.95	10.46	10.13	7.67	7.05
0.330	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	12.61	11.78	11.11	10.62	10.30	7.45	6.85

From Table 1, it is seen that the improvement in first side lobe suppression achieved by the decoder of the present invention varies with the position of the bite (bite time position) within the T1 observation interval and also with the duration of the bite. Depending on the bite time position and the bite duration of a particular bite in the T1 observation interval, increased side lobe suppression, decreased side lobe suppression or the same amount of side lobe response is achieved, as compared with decoders employing the completely rectangular observation window shown in FIG. 2. More specifically, referring directly to Table 1, it is seen, for example, that for a bite duration of .12 and a bite time position centered about .12 of the unit time 1 of the T1 time window, the peak amplitude of the first side lobe is 17.05 dB below the peak amplitude of the main response. It is recalled that prior decoder techniques employing a completely rectangular window typically result in a first side lobe exhibiting a peak amplitude of approximately -13.26 dB with respect to the main lobe response.

The aforementioned values for bite duration and bite time position are believed to be optimal for the decoder of the present invention. However, as seen from Table 1, a large range of bite durations and bite time positions near the beginning of the T1 observation interval result in an improvement in first side lobe suppression over the 13.26 dB suppression achieved by prior decoders employing rectangular observation windows. Improved values of first side lobe suppression are noted within the solid line forming an irregularly shaped box within Table 1. The corresponding bite durations and bite time positions which cause a particular improved side lobe suppression value within the box are readily determined by selecting a particular value of side lobe suppression and reading horizontally over to the corresponding bite duration and vertically upward to the corresponding bite time position.

It is noted that first side lobe suppression values outside of the box either represent no improvement in side lobe suppression or a decrease in first side lobe suppression. For example, a bite duration of .33 Tl together with a bite time position of .1 Tl yield a first side lobe with a peak amplitude of 13.26 dB. This represents no improvement over the rectangular observation window of conventional decoders. Also by way of example, a bite duration of .33 Tl and a bite time position centered about .32 of the Tl normalized observation interval yield a first side lobe having a peak amplitude of 6.2 dB which is larger and thus less desirable than the first side lobe response achieved by conventional decoders employing a completely rectangular observation window. It is thus seen that it is important to select bite duration and bite time position values corresponding to side lobe suppression values within the box of Table 1 in order to achieve significant amounts of side lobe suppression consistent with the present invention.

FIG. 7 is a three-dimensional representation of increase of first side lobe suppression achieved by the decoder of the present invention as a function of bite duration and bite time position within the normalized Tl observation iterval. In this representation, the bite time position is shown between 0.0 Tl and .33 Tl. For convenience, when plotting the graph of FIG. 7 from the values shown in Table 1, the representation of FIG. 7 concentrates on the values of bite duration and bite time position which result in increases in first side lobe suppression. This is accomplished by portraying all values of side lobe suppression which are not increases of side lobe suppression as a flat plane having a value of 13.26 dB. From FIG. 7, it will be appreciated that certain values of bite duration and a bite time position are more optimal than others in terms of maximizing first side lobe suppression.

FIG. 8 is a representation of an alternative modified rectangular observation window employed in the decoder apparatus of the present invention. FIG. 8 is substantially similar to the observation window of FIG. 5 except that the bite during which sampling circuit 30 is inhibited is now, by symmetry, situated near the end of the T1 time interval instead of near the beginning of the T1 time interval. The bite shown in FIG. 8 is designated bite 80. In an alternative embodiment of decoder apparatus of the present invention, the bite is situated in the manner shown in FIG. 8 for bite 80 as opposed to the manner shown in FIG. 5 for bite 70.

Bite 80 is optimally centered approximately at .88 T1 in the T1 observation interval which exhibits a total unit time of 1. The optimal time duration or bite duration T2 for bite 80 is .12 T1 as shown in FIG. 8. Thus, when the observation interval or observation window shown in FIG. 8 is employed in the decoding apparatus of the present invention, samples taken by sampling circuit 30 from the beginning of the T1 time interval until the beginning of bite 80 are, in effect, multiplied by or weighted by the quantity 1. Samples occurring during bite 80 are weighted or multiplied by 0. Thus, the plurality of samples occurring in succession during bite 80 are effectively dropped. Samples occurring after the end of bite 80 and before the end of the T1 observation interval are weighted or multiplied by 1. Such weighting of samples is implemented for each observation window which is imposed upon the incoming samples of the received tone signal.

The following Table 2 is a table substantially similar to Table 1, except bite time positions between .66 and 1 of the T1 observation interval are used. Thus, Table 2 shows the various amounts of first side lobe suppression improvements (in dB) which occur for bite durations between 0.0 T1 and .33 T1 and for bite positions between .66 T1 and 1.0 T1 of the T1 time interval. In a manner similar to Table 1, a solid line is drawn around all values which represents an improvement in first side lobe suppression to form an irregularly shaped box within Table 2. Each first side lobe suppression value within the box corresponds to a particular bite duration and bite time position.

TABLE 2

dB IMPROVEMENT

BITE POSITION →

BITE DURATION ↓	.660	.680	.700	.720	.740	.760	.780	.800	.820	.840	.860	.880	.900	.920	.940	.960
0.000	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26	13.26
0.010	13.11	13.18	13.26	13.33	13.39	13.45	13.50	13.54	13.57	13.58	13.58	13.57	13.54	13.50	13.45	13.39
0.020	12.95	13.09	13.23	13.38	13.51	13.64	13.75	13.83	13.89	13.92	13.92	13.89	13.83	13.74	13.62	13.48
0.030	12.77	12.97	13.18	13.40	13.61	13.81	13.98	14.11	14.23	14.28	14.28	14.22	14.12	13.95	13.76	13.55
0.040	12.56	12.82	13.10	13.39	13.68	13.96	14.21	14.43	14.58	14.66	14.65	14.57	14.40	14.16	13.89	13.58
0.050	12.34	12.66	13.00	13.37	13.74	14.10	14.43	14.72	14.94	15.06	15.05	14.92	14.68	14.35	13.96	13.56
0.060	12.10	12.48	12.89	13.32	13.77	14.22	14.65	15.02	15.32	15.48	15.47	15.28	14.95	14.50	14.02	13.51
0.070	11.86	12.28	12.75	13.25	13.78	14.27	14.85	15.42	15.70	15.92	15.91	15.65	15.19	14.62	14.00	13.41
0.080	11.61	12.00	12.59	13.15	13.41	13.83	14.43	15.17	15.54	16.27	16.38	16.02	15.41	14.68	13.95	13.26
0.090	11.36	11.86	12.41	12.75	12.98	13.41	14.02	14.75	15.12	15.84	16.74	16.37	15.57	14.68	13.84	13.26
0.100	11.10	11.62	12.21	12.35	12.59	13.02	13.64	14.39	14.76	15.47	16.40	16.68	15.66	14.62	13.69	13.26
0.110	10.83	11.38	11.92	11.98	12.22	12.65	13.28	14.00	14.44	15.15	16.20	16.92	15.66	14.58	13.59	13.26
0.120	10.56	11.13	11.50	11.65	11.88	12.31	12.93	13.75	14.18	14.88	15.91	17.05	15.57	14.32	13.26	13.26
0.130	10.29	10.88	11.27	11.33	11.57	11.99	12.61	13.42	13.97	14.65	15.67	16.96	15.38	14.09	13.26	13.26
0.140	10.02	10.63	10.99	11.04	11.28	11.70	12.31	13.11	13.81	14.47	15.49	16.62	15.13	13.83	13.26	13.26
0.150	9.75	10.37	10.73	10.70	11.02	11.43	12.03	12.83	13.69	14.35	15.34	16.17	14.02	13.55	13.26	13.26
0.160	9.49	10.12	10.50	10.55	10.78	11.19	11.79	12.57	13.54	14.27	15.25	15.72	14.50	13.27	13.26	13.26
0.170	9.23	9.86	10.30	10.33	10.56	10.97	11.56	12.34	13.28	14.25	15.22	15.30	14.18	13.26	13.26	13.26
0.180	8.97	9.60	10.11	10.15	10.37	10.78	11.36	12.12	13.04	14.07	14.96	14.91	13.86	13.26	13.26	13.26
0.190	8.72	9.35	9.95	9.99	10.20	10.60	11.18	11.92	12.84	13.84	14.65	14.56	13.55	13.26	13.26	13.26
0.200	8.47	9.10	9.81	9.85	10.06	10.45	11.02	11.76	12.66	13.62	14.37	14.24	13.26	13.26	13.26	13.26
0.210	8.22	8.85	9.57	9.73	9.94	10.32	10.88	11.61	12.49	13.43	14.13	13.95	13.26	13.26	13.26	13.26
0.220	7.98	8.61	9.32	9.64	9.84	10.22	10.77	11.49	12.36	13.27	13.92	13.78	13.26	13.26	13.25	13.26
0.230	7.74	8.37	9.08	9.56	9.77	10.14	10.68	11.40	12.25	13.14	13.73	13.47	13.26	13.26	13.26	13.26
0.240	7.51	8.13	8.84	9.52	9.71	10.00	10.62	11.33	12.16	13.04	13.58	13.26	13.26	13.26	13.26	13.26
0.250	7.29	7.90	8.60	9.35	9.68	10.05	10.58	11.27	12.10	12.96	13.46	13.26	13.26	13.26	13.26	13.26
0.260	7.07	7.68	8.36	9.10	9.67	10.03	10.56	11.25	12.07	12.91	13.36	13.26	13.26	13.26	13.26	13.26
0.270	6.86	7.46	8.13	8.85	9.56	10.04	10.56	11.25	12.07	12.89	13.30	13.26	13.26	13.26	13.26	13.26
0.280	6.65	7.25	7.91	8.61	9.27	10.07	10.59	11.27	12.09	12.93	13.27	13.26	13.26	13.26	13.26	13.26
0.290	6.45	7.04	7.69	8.37	8.99	10.13	10.64	11.32	12.14	12.94	13.26	13.26	13.26	13.26	13.26	13.26
0.300	6.25	6.83	7.47	8.13	8.79	10.21	10.72	11.40	12.21	13.02	13.26	13.26	13.26	13.26	13.26	13.26
0.310	6.06	6.63	7.26	7.90	9.99	10.32	10.83	11.50	12.32	13.12	13.26	13.26	13.26	13.26	13.26	13.26
0.320	5.88	6.44	7.05	7.67	10.13	10.46	10.95	11.63	12.45	13.26	13.26	13.26	13.26	13.26	13.26	13.26
0.330	5.70	6.25	6.85	7.45	10.30	10.62	11.11	11.78	12.61	13.26	13.26	13.26	13.26	13.26	13.26	13.26

FIG. 9 is a three-dimensional representation of the improvement in first side lobe suppression as a function of bite duration and bite time position. More specifically, the representation of FIG. 9 is a plot of the side lobe suppression values of Table 2 as a function of bite duration and bite time position during the .66 Tl to 1.0 Tl portion of the Tl observation interval. It is seen that a relatively large number of bite durations and bite time positions will result in the improvements in the suppression of the first side lobe response.

FIG. 10 is a schematic diagram of one timing circuit which may be employed as timing circuit 40 of FIG. 4. Timing circuit 40 generates the substantially rectangular observation interval or observation window shown in FIG. 8 including bite 80 therein centered about .88 Tl of the Tl time interval. Assuming that bite 80 exhibits a bite duration of .12 of the unit time 1, bite 80 commences at .82 Tl and ceases at .94 Tl of the Tl interval as shown in FIG. 8. As shown in FIG. 10, timing circuit 40 includes a one shot monostable multivibrator 42 having an input forming the overall input of timing circuit 40 so as to receive the timing initialization pulse shown in the timing diagram FIG. 11A which commences an observation window. Multivibrator 42 is configured to exhibit an on time equal to that of the observation interval Tl. Thus, when the initialization pulse shown in the timing diagram of FIG. 11A is applied to the input of multivibrator 42, multivibrator 42 turns on and stays on for the entirety of the Tl time interval, that is for one unit of time as shown in the timing diagram of FIG. 11B.

The input of multivibrator 42 is coupled to the input of a one shot monostable multivibrator 44 which transitions from the zero logic state to the one logic state whenever the initialization pulse of FIG. 11A is applied thereto. Multivibrator 44 then returns to the zero logic state after .82 of the T1 unit time interval has elapsed as seen in FIG. 11C which shows the Q output wave form of multivibrator 44. The $\overline{Q}$ output of multivibrator 44 is coupled to the input of a one shot monostable multivibrator 46 such that the waveform shown in FIG. 11D is provided thereto. It is noted that the waveform of 11D is the inverse of the waveform of 11C. Multivibrator 46 is configured to transition from a logical zero output state to a logical one output state at the Q output thereof whenever a positive going transition is provided to the input thereof. Thus, when the positive going transition of the FIG. 11D waveform at .82 of the T1 time interval is provided to the input of multivibrator 46, multivibrator 46 transitions from a logical zero to a logical one for a duration of .12 of the T1 time interval as shown in FIG. 11E. After .12 of the T1 time interval has elapsed, the Q output of multivibrator 46 transitions from a logical one to a logical zero as shown in the waveform of FIG. 11E. FIG. 11F shows the waveform at the $\overline{Q}$ output of multivibrator 46. It is noted that the waveform of FIG. 11F is the inverse of the waveform of 11E.

The Q output of multivibrator 42 and the $\overline{Q}$ output of multivibrator 46 are coupled to the respective inputs of a two input AND gate 48. Thus, the waveform of FIG. 11B and the waveform of FIG. 11F are AND'ed together by AND gate 48 such that the waveform shown in FIG. 11G is generated at the output of AND gate 48. The waveform of FIG. 11G corresponds to one modified substantially rectangular observation interval or window which is employed to control sampling circuit 30 of FIG. 4. The specific connections of timing circuit 40 as shown in FIG. 10 to the remaining portions of the circuitry of the present invention in order to achieve windowing of the samples of the received signals in accordance with the present invention will be discussed in more detail subsequently.

One correlator which may be employed as correlator 60 of FIG. 4 is the correlator shown in FIG. 12. The correlator of FIG. 12 is shown in FIG. 3 of United States Patent 4,216,463 entitled Programmable Digital Tone Detector issued to Backof, Jr. et al. and assigned to the instant Assignee. United States Patent, 4,216,463 is incorporated herein by reference. Such correlator is now described briefly in the discussion of FIG. 12.

A sine wave reference signal $\sin(w_{REF}t)$ is applied via a limiter circuit 61 to one input 62A of a two input multiplier circuit 62, the remaining input of which is designated 62B. Mixer input 62A is coupled via a minus 90° phase shift network 64 to one input 66A of a two input multiplier circuit 66, the remaining input of which is designated 66B. Thus, while a sine wave reference signal is applied to multiplier input 62A, a cosine wave reference signal is applied to multiplier input 66A due to the phase shift action of circuit 64. The samples of the received signal generated by sampling circuit 30 of FIG. 4 are provided to multiplier inputs 62B and 66B via a limiting circuit 50 coupled between sampling circuit output 30 and multiplier inputs 62B and 66B. It is noted that although in the representation of

FIG. 4 timing circuit 40 is shown coupled to sampling circuit 30, timing circuit 40 is shown operatively coupled to converter circuit 50 as well, in a manner so as to appropriately permit samples weighted by a factor of 1 to be supplied to correlator 60 during all portions of the T1 observation interval except for the T2 bite portion thereof during which samples weighted zero are supplied to correlator 60.

Each of the samples reaching multiplier input 62B are multiplied by the sine wave reference signal at multiplier input 62A. The resultant of such multiplication appears at the output of multiplier 62 which is coupled to the input of an integrator 70. Integrator circuit 70 integrates the multiplied samples supplied thereto so as to generate the integral of the multiplied samples at the output thereof. The output of integrator 70 is coupled to an absolute value circuit 80 which generates the absolute value of the integrated multiplied samples and provides the same to one input of a two-input adder circuit 90.

The samples applied to multiplier circuit input 66B are multiplied by the cosine wave reference signal supplied to multiplier input 66A such that the resultant of these two signals is provided to the output of multiplier 66 which is coupled to the input of an integrator circuit 100. Integrator circuit 100 integrates the multiplied samples provided thereto to generate the integral of such multiplied samples at the output thereof. The output of integrator circuit 100 is coupled to the input of an absolute value circuit 110 which generates the absolute value of the integral of the multiplied samples at the output thereof. The output of absolute value circuit 110 is coupled to the remaining input of adder circuit 90. Thus, a signal representing the summation of the absolute value of the integral of received signal samples multiplied by the sine wave reference waveform at multiplier input 62A and the absolute value of the integral of the samples of the received signal multiplied by the cosine reference waveform at multiplier input 66A is generated at the output of adder circuit 90.

The output of adder circuit 90 is coupled to a threshold detector 120. Whenever the input of threshold detector 120 exceeds a predetermined value, detector 120 generates an output signal which indicates that a predetermined degree of correlation has occurred. More specifically, when this occurs, correlator 60 has determined that the tone signal received by receiver 20 and sampled by sampler circuit 30 exhibits a frequency approximately equal to the frequency of the sine wave reference waveform supplied to multiplier input 62A of correlator 60. In the foregoing example, correlator 60 was configured to detect the presence of a 1000Hz received signal. Thus, the sine wave reference waveform supplied to multiplier input 62A equals 1000Hz in this example. However, it is understood that the presence of other received tone signals may be detected as well, for example, received tone signals exhibiting frequencies of 1500Hz and 2000Hz providing that sine wave reference waveforms exhibiting such alternative frequencies are supplied to the input of limiter 61. The circuit of the present invention will operate to reduce the amplitude of the first side lobe for these received tone signals as well, thus permitting the threshold of threshold detector 120 to be set at relatively lower levels resulting in an increase in the probability of tone signal detection. Alternatively, the threshold of threshold detector 120 is not changed to the aforementioned relatively lower level. In such case, the result is a corresponding decrease in the probability of detector 120 responding to tone signals occurring at frequencies corresponding to the first side lobe response.

FIG. 13 is a flow chart describing the operation of the apparatus of the present invention when the T1 observation interval shown in FIG. 8 is employed therein. It is recalled that in accordance with the invention, during such T1 observation interval or observation window, samples of the received tone signal are taken, weighted by a factor of one, and correlated until the time .82 T1 is reached. At such time bite 80 commences during which samples of the received signals are weighted zero or otherwise suppressed or inhibited for the duration of the bite which exists from a time equal to .82 T1 and .94 T1. At the end of bite 80, namely at .94 T1, sampling of the received tone signal continues and weighting of such samples of the received signal by a factor of 1 continues along with correlation thereof until the end of T1 time interval. The flow chart of FIG. 13 illustrates this operation of the invention.

More specifically, the flow chart of FIG. 13 commences with a START statement 200 followed by statement 210 which sets SMPNM equal to zero. SMPNM is a counter representing the number accorded to a particular sample of the received tone signal. After executing block 210, data is sampled and correlated in accordance with block 220. After executing block 220, the counter SMPNM is incremented by 1 such that the apparatus of the invention proceeds to the next (in this case the first) sample in accordance with block 230. After incrementing in accordance with block 230, a decision block 240 is provided which determines whether a particular sample occurs during the bite 80 of the T1 time interval, that is between a time equal to .82 T1 and .94 T1. If SMPNM is between .82 T1 and .94 T1 (which corresponds to being between 82 and 94 in the flow chart of FIG. 13), then the decision block 240 causes operation to return to block 230 where SMPNM is incremented by one. The loop formed between decision block 240 and block 230 continues until SMPNM is no longer between .82 TI and .94 T1, that is when the sample no longer occurs during bite 80. When this occurs, the flow chart proceeds to a decision block 250 which tests to see if SMPNM is greater than 100. If the answer is no, another sample is taken and correlated in accordance with block 220. When SMPNM finally exceeds 100, that is when the T1 observation interval is complete, then the decision reached by decision block 250 is affirmative and the flow chart proceeds to stop at block 260.

Thus, it is seen that by following the above flow chart in accordance with the present invention, an incoming received tone signal is sampled and the samples are correlated during a modified substantially rectangular observation window with a carefully positioned bite therein to detect the presence of a received tone signal exhibiting a predetermined frequency. The sequence of such flow chart is repeated as many times as is necessary while the presence of a received tone signal exhibiting a predetermined frequency is being determined.

FIG. 14 is a simplified blocked diagram of a microcomputer embodiment of a radio frequency receiver incorporating the present invention to detect the presence of a received tone signal exhibiting a predetermined frequency. The many different tone signalling schemes known in the art today require apparatus and methods for distinguishing received toned signals exhibiting a selected frequency from received signals exhibiting other frequencies in order to perform selected functions at the receiver, for example opening a squelch circuit as well as other functions.

The apparatus of FIG. 14 includes an antenna 300 for gathering radio frequency signals incident thereon and providing such signals to a receiver 310 coupled thereto. Receiver 310 demodulates the radio frequency signals coupled thereto and provides the demodulated signals, that is received tone signals to outputs 310A and 310B thereof. A receiver output 310C couples a signal which indicates the presence of a radio frequency carrier signal at receiver 310 to the input of a squelch circuit 320. One output of squelch circuit 320 is coupled to an input of a microcomputer 330. Microcomputer 330 supervises and controls the operation, for example, noise squelch and decoding functions, of the remaining functions of the receiver of FIG. 14. Microcomputer 330 includes a random access memory (not shown) therein for storing digital signal information and includes a plurality of registers (not shown) for facilitating processing of such information.

Another output of squelch circuit 320 is electrically coupled to one input of a receiver audio circuit 340. Receiver output 310A is coupled to an input of receiver audio circuit 340. One output of microcomputer 330 is also coupled to an input of receiver audio circuit 340 to control the operation thereof. Receiver output 310B is coupled to an input of microprocessor 330.

A read only memory 350, also referred to as a code plug, is conveniently encoded with a wide variety of information regarding the operation of the microcomputer controlled receiver of FIG. 14. More specifically, certain functions to be performed by the receiver of FIG. 14 are encoded into read only memory 350. In this embodiment, read only memory 350 contains information which tells the microcomputer 330 which sequence of received audio tones of predetermined frequency must be received and processed by microcomputer 330 before microcomputer 330 will permit squelch circuit 320 to turn on the receiver audio of circuit 340 to provide voice messages subsequent to an encoded tone sequence to reach loudspeaker 345 where such messages are audible to the receiver user. It is apparent that the sampling and correlation of samples of the received signal in accordance with the modified substantially rectangular observation window employed in the present invention is conveniently implemented by microprocessor 330. In this manner, the first side lobe response of each tone signal which the receiver of FIG. 14 is to receive, in sequence or otherwise, is significantly reduced such that the likelihood of signal falsing substantially diminished. From the above discussion, it is clear that the present invention not only applies to reducing the side lobe response of a single tone exhibiting a predetermined frequency, but may also be employed to reduce the first side lobe response to each of a sequence of received tone signals exhibiting respective predetermined frequencies.

Advantageously, during the bite of the observation interval employed in the present invention, microcomputer 330 is now free to perform tasks other than sampling and correlating. This is so because during the bite interval, it is assured that all samples will be weighted zero, a task which can be accomplished all together at the beginning of the bite interval, leaving the remainder of each bite interval of each observation interval free for the performance of other tasks by the microcomputer 330. Such other tasks include monitoring and control of the radio receiver circuits and operating conditions and functions of the same, for example. In lieu of performing such tasks during the remainder of the bite interval, microcomputer 330 assumes an idle mode to decrease power consumption.

FIG. 15 is a more detailed representation of a microcomputer-firmware embodiment of the apparatus of the present invention. The representation of FIG. 15 is substantially identical to the block diagram of FIG. 14 except for the following modifications and additions to detail. A filter 360 and a limiter 370 are coupled together in series between receiver output 310B and an input of microcomputer 330. The Motorola MC147805G2P microcomputer is employed as microprocessor 330 in the firmware embodiment of the invention shown in FIG. 15. The actual pin terminal numbers of microcomputer 330 are shown circled adjacent the periphery of the rectangular block representing microcomputer 330. Further, an associated alphanumeric designation is situated next to each of such circled pin numbers for ease of identification. Those skilled in the art will readily understand how to employ the aforementioned microcomputer to utilize the frequency decoder of the present invention. For detailed information on the operation of the aforementioned microcomputer, reference may be made to the "M6805/M146805 Family Microcomputer/Microprocessor User's Manual" published by Motorola, Inc. 3501 Ed Bluestein Blvd., Austin, Texas 78721, the contents of which are incorporated herein by reference. Even more detailed information regarding this microcomputer is conveniently found in the "Motorola Microprocessor Data Manual" in the section entitled "MC146805G2", the contents of which are also incorporated herein by reference.

Microcomputer pins 19 and 2, respectively designated PB7 and $\overline{INT}$ are electrically coupled to a power supply. Pin 5, designated PA6 is coupled to an input of receiver audio circuit 340. Pin 18 designated PB6 is coupled to limiter circuit 370 as shown in FIG. 15. Pin 8, designated PA3 is coupled to the output of squelch circuit 330.

Terminals 40 (VDD), 22 (PC6), 23 (PC5) and 24 (PC4) are coupled together and to pins 12 (RESET) and 14 (VCC) of read only memory 350 and to a source of appropriate operating voltage designated B+. One read only memory which may be employed as read only memory 350 is the Motorola EEPROM MCM2802P. Pins 4 (VPP), 3 (T1), 5 (S4), 7 (VSS), 8 (S3), 9 (S2), 10 (S1) and 13 (T2) of read only memory 350 are coupled together and to ground and to microcomputer pins 20 (VSS), 37 (TIMER) and 3 (NUM). Microcomputer pins 7 (PA4), 14 (PB2) and 21 (PC7) are coupled to each other and to ground. In this embodiment of the invention, microprocessor 330 is appropriately clocked at a 1 MHz bus frequency.

Table 3 is a hexidecimal core dump of the contents of microprocessor 330. Table 4 is a hexidecimal dump of the contents of read only memory of code plug 350. When microcomputer 330 and read only memory 350 are appropriately programmed by reading the contents of Tables 3 and 4 therein, respectively, microcomputer 330 together with read only memory 350 and the remaining portions of the circuit shown in FIG. 15 cooperate to implement one embodiment of the present invention. Tables 3 and 4 follow.

TABLE 3

0000	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
0010	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
0020	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
0030	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
0040	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
0050	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
0060	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
0070	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
0080	24	04	16	01	20	02	17	01	18	01	19	01	81	A6	60	B7
0090	09	A6	21	B7	04	AE	10	A6	14	B7	3B	A6	0A	B7	3D	CD
00A0	00	ED	3A	3D	26	F9	B6	10	26	04	9C	CC	06	42	81	B7
00B0	3B	A6	4E	B7	3A	20	06	B7	3B	A6	46	B7	3A	A6	08	B7
00C0	3C	BE	3A	F6	3C	3A	BE	3B	F7	3C	3B	3A	3C	26	F2	81
00D0	4F	05	01	00	49	0F	02	00	49	81	14	72	18	72	05	3F
00E0	05	05	6C	02	1A	68	3F	69	3F	6A	3F	6B	81	1F	03	16
00F0	05	1A	01	17	01	BD	88	BD	88	B6	77	46	BD	80	46	BD
0100	80	B6	3B	B7	3C	38	3C	38	3C	38	3C	A6	08	38	3C	BD
0110	80	4A	26	F9	17	05	A6	20	1B	01	20	02	BD	88	06	01
0120	00	79	69	01	69	02	69	03	4A	26	F1	9F	AB	04	97	3C
0130	3B	1E	03	81	BD	8D	AE	2E	20	04	BD	8D	AE	30	12	72
0140	B6	2D	B7	65	B6	28	B7	3C	20	1E	BD	8D	B6	29	B7	3C
0150	AE	56	B6	2B	20	0E	1A	00	20	2A	BD	8D	B6	2A	B7	3C
0160	AE	5B	B6	2C	27	F0	B7	65	1A	00	A6	02	B7	3D	A6	8C
0170	B7	08	A6	07	B7	09	8F	A6	08	4A	26	FD	3A	3D	26	EE
0180	3A	65	26	E6	A6	60	B7	09	02	72	2A	A6	FF	B7	75	A6
0190	05	B7	44	BF	39	21	FE	BE	39	F6	A4	0F	A1	0F	26	03
01A0	CC	02	62	B1	75	26	08	A6	0F	B7	75	A6	24	20	05	B7
01B0	75	48	AB	10	97	F6	B7	37	B7	45	E6	01	B7	38	0E	72
01C0	3A	A6	FC	B7	07	A6	94	B7	03	B6	38	B7	08	3F	09	8F
01D0	A6	02	9D	4A	26	FD	A6	9C	B7	03	B6	38	B7	08	3F	09
01E0	8F	B6	38	B7	08	3F	09	8F	A6	02	9D	9D	4A	26	FD	01
01F0	72	12	0F	01	0A	A6	60	B7	09	20	65	A6	EC	20	C4	1E
0200	37	9D	20	08	9D	9D	9D	9D	9D	9D	21	FE	A6	84	B7	03
0210	B6	38	B7	08	3F	09	8F	A6	02	9D	4A	26	FD	A6	80	B7
0220	03	B6	38	B7	08	3F	09	8F	B6	38	B7	08	3F	09	8F	21
0230	FE	9D	9D	9D	9D	3A	37	26	0B	3A	3C	27	12	B6	45	B7
0240	37	CC	01	C5	9D	21	FE	9D	9D	9D	9D	9D	CC	01	C5	9D
0250	9D	9D	9D	21	FE	A6	84	B7	03	A6	01	B7	3C	03	72	07
0260	13	72	A6	94	B7	03	81	3A	44	27	F7	3C	39	A6	07	4A
0270	9D	26	FC	CC	01	95	A6	60	B7	09	80	04	68	7B	06	68
0280	03	CC	03	8D	BD	D0	B8	77	27	05	1C	09	CC	06	17	0B
0290	68	08	0B	3F	05	07	00	02	BD	DE	17	68	AE	01	A6	FE
02A0	B7	3D	B7	02	09	02	38	5C	0B	02	34	5C	0D	02	30	5C
02B0	39	3D	B6	3D	B7	02	08	3D	EB	03	68	15	3A	66	26	11
02C0	11	68	13	68	A6	21	B7	04	10	00	0E	68	04	15	6C	3F
02D0	70	81	B7	67	12	68	A6	01	B7	66	81	A6	03	20	F9	BF
02E0	73	9F	03	68	ED	B1	67	26	D3	00	68	EF	3C	66	A6	03
02F0	B1	66	26	DD	10	68	14	68	81	15	68	1D	03	B6	73	A1
0300	0A	27	6E	A1	0C	26	1D	A6	E0	B7	04	B6	76	B7	00	1D
0310	68	AE	55	5C	A3	60	24	4D	F6	2A	F8	BF	74	B6	42	B7
0320	71	18	68	81	A1	0B	26	02	3F	73	09	43	10	B1	63	26
0330	0C	B6	62	B1	74	27	4B	AB	05	B1	74	27	45	0B	43	06
0340	B6	73	B1	61	27	3C	A6	E0	B7	04	B6	76	B7	00	1D	68
0350	09	68	19	B6	73	BE	74	AA	80	F7	5C	A3	60	24	06	F6
0360	2A	F8	BF	74	81	19	68	A6	C0	B7	71	81	B6	42	B7	71
0370	81	0D	04	03	0C	00	15	0D	71	08	1B	72	BD	DA	9C	CC
0380	05	62	A6	E6	B7	04	B6	76	B7	00	1D	68	81	16	68	B6
0390	6A	A4	1E	27	04	1D	07	20	02	1C	07	B6	6C	B7	6D	01
03A0	01	0F	01	6D	08	3A	6E	27	13	10	6C	20	11	3F	6E	20

```
03B0 0B 00 6D F5 3C 6E A6 03 B1 6E 27 ED 11 6C 0F 01
03C0 0F 03 6D 08 3A 6F 27 13 12 6C 20 11 3F 6F 20 0B
03D0 02 6D F5 3C 6F A6 03 B1 6F 27 ED 13 6C 0F 43 12
03E0 08 00 12 05 6D 08 3A 70 27 16 14 6C 20 14 3F 70
03F0 20 0E 08 00 EE 04 6D F2 3C 70 A6 03 B1 70 27 EA
0400 15 6C B6 6D B8 6C 27 62 1B 72 10 04 1D 03 46 24
0410 2D 01 6C 2C 1E 68 BD DE 05 6C 14 07 3F 0B 05 72
0420 19 08 3F 05 08 72 0E 18 72 16 72 B6 43 20 61 14
0430 72 18 72 20 E6 16 72 9C 20 76 14 72 20 1A 1B 68
0440 46 24 09 03 6C 06 1F 04 B6 42 20 44 46 24 1A 1F
0450 68 04 6C 07 14 72 18 72 1D 04 81 15 72 19 72 1C
0460 04 0F 43 03 1D 00 81 1C 00 81 B6 35 48 BB 69 B7
0470 69 4F B9 6A B7 6A 4F B9 6B B7 6B 0C 43 0E B1 60
0480 26 E7 0B 68 E4 1F 68 AD D2 1B 68 81 B6 6A 20 EE
0490 B7 3A 9C A6 21 B7 04 B6 3A A4 0C A1 08 26 3D 06
04A0 72 03 CC 05 39 03 3A 08 00 3A 0B CD 01 34 20 0C
04B0 A6 60 B7 09 20 06 03 01 F2 CD 01 3A 1A 00 1D 03
04C0 A6 FF B7 08 A6 05 B7 09 8F 01 01 0A 3A 6E 26 F0
04D0 17 72 11 6C 20 3F A6 03 B7 6E 20 E4 05 3A 0E 06
04E0 3A 05 CD 01 34 20 06 03 01 F8 CD 01 3A 01 3A 35
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0500 20 13 0F 71 2B CD 01 5A 0D 71 03 CD 01 4A 0A 42
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0570 B7 65 A6 80 B7 72 AE 32 CD 01 68 1B 00 CC 06 17
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05B0 00 A6 5D B7 08 A6 06 B7 09 CD 02 7B 8F 21 FE 0B
05C0 72 0C 0D 68 13 3A 3C 27 05 0C 72 E5 20 38 1B 72
05D0 1D 68 A6 21 B7 04 10 00 0D 72 0C 0D 3F 04 1C 07
05E0 1C 03 BD DA CC 06 6A 0F 3F F8 20 F2 A6 7D B7 3C
05F0 A6 12 B7 3B A6 E4 B7 04 B6 76 B7 00 A6 9C B7 08
0600 A6 06 B7 09 20 B3 3A 3B 26 F2 00 04 E3 A6 07 B7
0610 3B 10 04 10 00 20 E5 9C A6 21 B7 04 A6 01 B7 00
0620 A6 30 B7 05 A6 0F B7 06 A6 CE B7 07 A6 84 B7 03
0630 4F B7 01 B7 02 B7 6C B7 6E B7 6F B7 70 B7 72 B7
0640 68 9A BD D0 B7 77 A6 0A B7 3B AE 3E A6 0A B7 3D
0650 BD ED 3A 3D 26 FA B6 44 BB 45 A1 A5 26 E4 B6 42
0660 B7 71 4F 0F 43 02 A6 C0 B7 76 9C B6 40 B7 45 B6
0670 3E B7 39 3F 37 1D 72 A6 60 B7 09 CD 08 28 3F 3C
0680 3F 3D AE 10 CD 08 17 AE 23 CD 08 17 B6 22 B7 14
0690 B6 20 B7 12 B6 21 B7 13 B6 34 B7 26 B6 35 44 44
06A0 44 B7 27 A6 70 B7 08 3F 09 3F 36 B6 14 B0 27 2B
06B0 12 1A 36 26 04 B6 35 20 0B B7 14 BE 27 B6 35 B7
06C0 27 20 0B 40 B7 27 BE 14 B6 22 B7 14 14 36 8F CD
06D0 07 3C 04 36 03 CD 02 7B B6 36 A4 09 26 05 03 36
06E0 CB 20 87 07 36 05 01 39 02 1C 72 3C 37 34 39 B6
06F0 41 B1 37 26 82 CC 05 80 B6 32 BB 29 B7 29 B6 31
0700 B9 28 B7 28 0D 01 18 2B 0B 0C 28 04 3C 2A 20 27
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0720 0B 0C 28 04 3A 2A 20 0F 3A 2B 20 0B 0C 28 04 3A
```

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0730 2C 20 04 3A 2D 20 00 5A 27 42 21 00 B6 1F BB 16
0740 B7 16 B6 1E B9 15 B7 15 0D 01 18 2B 0B 0C 15 04
0750 3C 17 20 A4 3C 18 20 A0 0C 15 04 3C 19 20 99 3C
0760 1A 20 95 2B 0B 0C 15 04 3A 17 20 8C 3A 18 20 88
0770 0C 15 04 3A 19 20 81 3A 1A CC 06 F8 A6 AD C7 00
0780 08 A6 02 B7 09 B6 1C BB 16 B7 16 B6 1B B9 15 B7
0790 15 B6 2F BB 29 B7 29 B6 2E B9 28 B7 28 05 36 05
07A0 AE 10 CD 07 AE 0B 36 05 AE 23 CD 07 AE 81 E6 0C
07B0 B7 25 E6 08 E0 0A B7 3C E6 07 E0 09 B7 3B BB 3C
07C0 00 25 01 47 B7 3D B6 3B B0 3C 00 25 01 47 B7 3C
07D0 EB 01 2A 01 40 B7 3B B6 3D FB 2A 01 40 BB 3B E1
07E0 0D 23 10 6A 03 26 14 A3 10 26 04 10 36 20 0C 16
07F0 36 20 08 E6 03 E1 11 27 02 6C 03 B6 37 27 15 0A
0800 36 12 3A 12 26 0E A1 01 26 08 B6 20 B7 12 3A 45
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0860 B7 B6 2E B1 3D 26 1A 20 0A B6 2E B1 4E 26 0A A6
0870 1B BD B7 A6 2E BD B7 20 08 A6 1B BD AF A6 2E BD
0880 AF 81 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0890 43 6F 70 79 72 69 67 68 74 20 31 39 38 32 20 20
08A0 4D 6F 74 6F 72 6F 6C 61 20 49 6E 63 2E 20 20 20


1FF0 00 00 00 00 00 00 02 76 06 17 05 67 06 17 06 17
```

TABLE 4

9A	01	29	33	40	0D	04	5C	9A	01	29	33	40	0D	04	5C
9A	01	29	33	40	0D	04	5C	9A	01	29	33	40	0D	04	5C
9A	01	29	33	40	0D	04	5C	00	2E	01	05	C0	0A	A0	05
E4	91	2A	3C	92	0D	04	55	BF	49	26	37	E9	0D	04	55
80	80	09	09	09	0A	01	09	09	09	05	AA	AA	AA	00	00
A7	0D	4A	64	51	57	59	4A	62	3E	6B	34	75	2B	80	22
8D	1A	9A	13	B7	07	C3	03	05	01	01	04	04	04	54	52
54	52	0A	05	09	09	09	00	00	00	00	00	00	00	00	79

From the above description, it is clear that the invention includes a method of processing a particular signal to determine if such particular signal exhibits a predetermined frequency. This method, although described above in detail, is now briefly summarized. The method includes the step of generating an observation interval signal. The method further includes the step of sampling the particular signal during the observation window established by the observation interval signal to produce samples of the particular signal. The present method includes the step of ignoring a portion of the samples of the particular signal occurring in time near the beginning, or alternatively, near the end of said observation window, and the step of correlating the samples of the particular signal with a predetermined pattern to detect the presence of a signal exhibiting the predetermined frequency.

The foregoing describes a digitally sampling decoder circuit which detects the presence of a signal exhibiting a predetermined frequency in a manner achieving a substantial response at a selected predetermined frequency while diminishing the undesired side lobe response. The presence or absence of a signal exhibiting the predetermined frequency is determined without consuming large quantities of computational processing time.

While only certain preferred features of the invention have been shown by way of illustrations, many modifications and changes will occur to those skilled in the art. It is, therefore, to be understood that the present claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

What is claimed is:

Claims

1. A decoder circuit for detecting the presence of a signal exhibiting a predetermined frequency comprising:

timing means for generating observation interval signals;

sampling means, responsive to said timing means, for sampling a first signal to produce samples thereof during a substantially rectangular observation interval, said sampling means including means for ignoring a portion of said samples occurring near the beginning, or alternatively, near the end of said observation interval, and

correlation means, electrically coupled to said sampling means, for correlating said samples with a predetermined pattern to detect the presence of a signal exhibiting said predetermined frequency within said first signal.

2. The circuit of claim 1 wherein said means for ignoring further includes means for dropping a plurality of successive samples within a bite interval occurring in a portion of said observation interval occurring between approximately .02 T1 and .28 T1, wherein T1 is defined to be the time duration of the observation interval, whereby undesirable side lobe response is reduced.

3. The circuit of claim 1 wherein said means for ignoring further includes means for dropping a plurality of successive samples within a bite interval occurring in a portion of said observation interval occurring between approximately .72 T1 and .98 T1, wherein T1 is defined to be the time duration of the observation interval, whereby undesirable side lobe response is reduced.

4. The circuit of claim 1 including means for performing operations other than said sampling and said correlating during times at which said ignoring means is ignoring samples.

5. The circuit of claim 4 wherein said means for performing includes means for assuming an idle mode for purposes of reducing circuit power consumption.

6. The circuit of claim 1 wherein said means for ignoring establishes a bit interval occurring within said observation interval between approximately .06 T1 and approximately .18 T1, wherein T1 is defined to be the time duration of the observation interval, whereby undesirable side lobe response is reduced.

7. The circuit of claim 1 wherein said means for ignoring establishes a bite interval occurring within said observation interval between approximately .82 Tl and approximately .94 Tl, wherein Tl is defined to be the time duration of the observation interval, whereby undesirable side lobe response is reduced.

8. The circuit of claim 1 wherein said means for ignoring establishes a bite interval centered at approximately .12 Tl in the observation interval wherein Tl is defined to be the time duration of the observation interval, whereby undesirable side lobe response is reduced.

9. The circuit of claim 1 wherein said means for ignoring establishes a bite interval centered at approximately .88 Tl in the obervation interval wherein Tl is defined to be the time duration, whereby undesirable side lobe response is reduced.

10. A decoder for detecting the presence of a signal exhibiting a predetermined frequency comprising:

microcomputer means for processing digital signal information including a random access memory and a read only memory for storing information therein, and including a plurality of registers for facilitating processing of such information, said microcomputer means further including

sampling means for sampling a first signal to produce samples thereof during a substantially rectangular observation window,

ignoring means, responsive to said sampling means, means for ignoring a portion of said samples occuring near the beginning, or alternatively, near the end of said observation window, and

correlation means for correlating said samples with a predetermined pattern to detect the presence of a signal exhibiting said predetermined frequency within said first signal.

11. The decoder of claim 10 wherein said ignoring means further includes means for dropping a plurality of successive samples within a bite interval occuring in a portion of said observation window occuring between approximately .02 Tl and .28 Tl, wherein Tl is defined to be the time duration of the observation interval, whereby undesirable side lobe response is reduced.

12. The decoder of claim 10 wherein said ignoring means further includes means for dropping a plurality of successive samples within a bite interval occurring in a portion of said observation window occurring between approximately .72 Tl and .98 Tl, wherein Tl is defined to be the time duration of the observation interval, hereby undesirable side lobe response is reduced.

13. The decoder of claim 10 including means for performing operations other than said sampling and said correlating during times at which said ignoring means is ignoring samples.

14. The decoder of claim 13 wherein said means for performing includes means for assuming an idle mode for purposes of reducing decoder power consumption.

15. A method of processing a particular signal to determine if said particular signal exhibits a predetermined frequency comprising the steps of:

generating an observation interval signal;

sampling said particular signal during the observation window established by said observation interval signal, to produce samples of said particular signal;

ignoring a portion of the samples of said particular signal occurring in time near the beginning or, alternatively near the end of said observation window, and

correlating the samples of said particular signal which are not ignored with a predetermined pattern to detect the presence of a signal exhibiting said predetermined frequency.

16. The method of claim 15 wherein said ignoring step includes wighting samples by the quantity zero when such samples occur within a bite interval defined to be near the beginning, or alternatively, near the end of said observation window.

17. The method of claim 16 wherein said observation window exhibits a time duration of T1 units of time and said bite interval exhibits a bite position within the range of approximately .06 T1 and approximately .18T1.

18. The method of claim 16 wherein said observation window exhibits a time duration of T1 units of time and said bite interval exhibits a bite position within the range of approximately .82T1 and approximately .94 T1.

Fig. 1

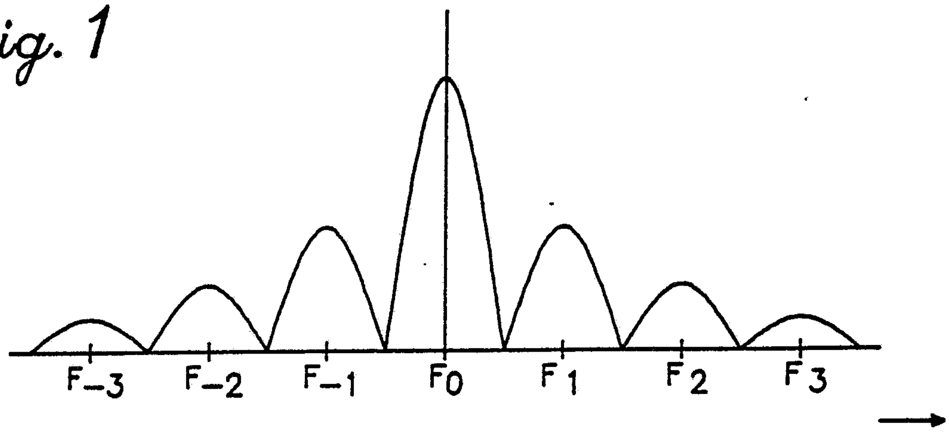


Fig. 2

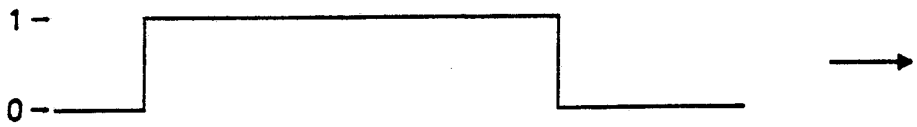
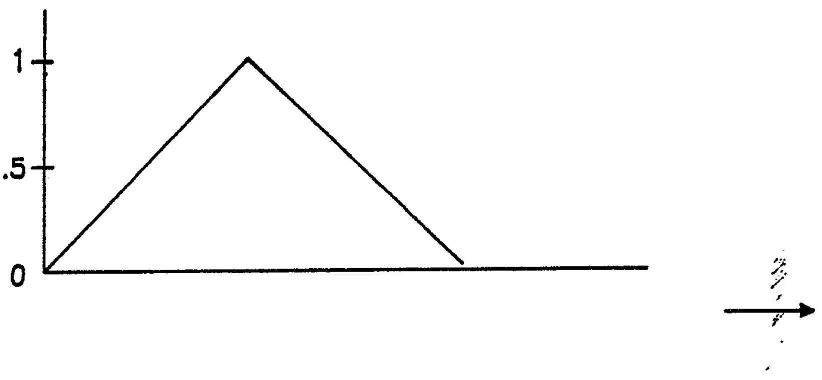


Fig. 3



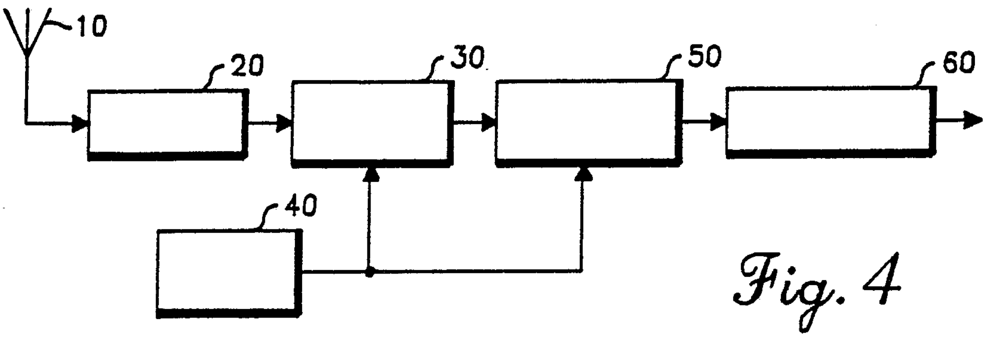


Fig. 4

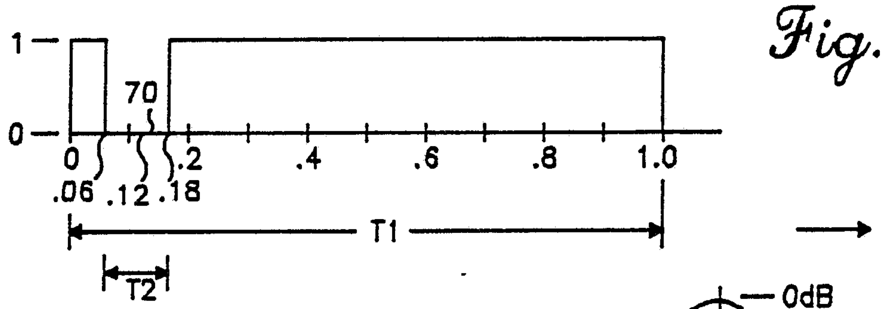


Fig. 5

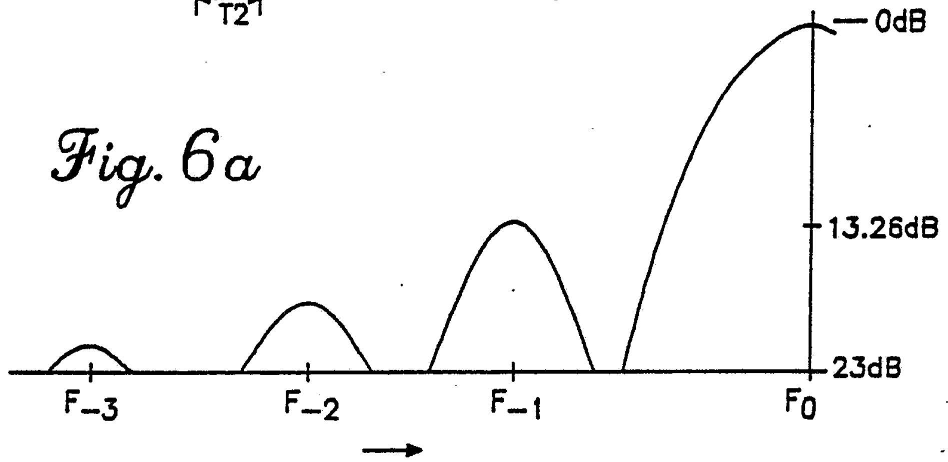


Fig. 6a

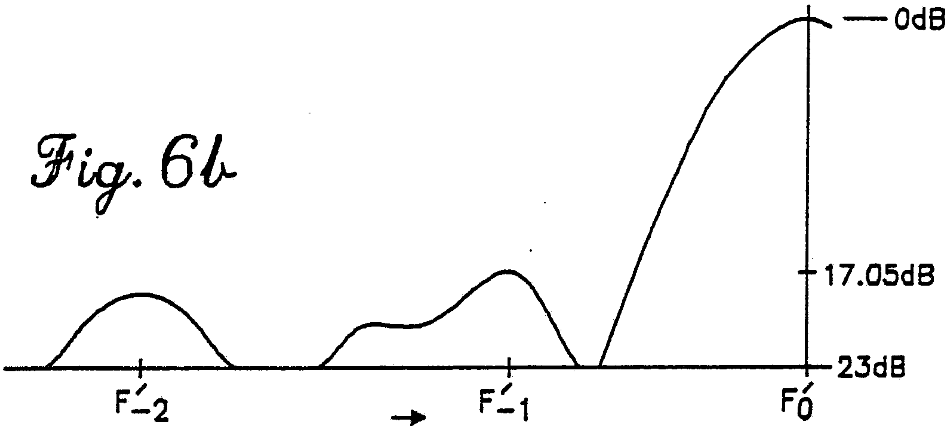


Fig. 6b

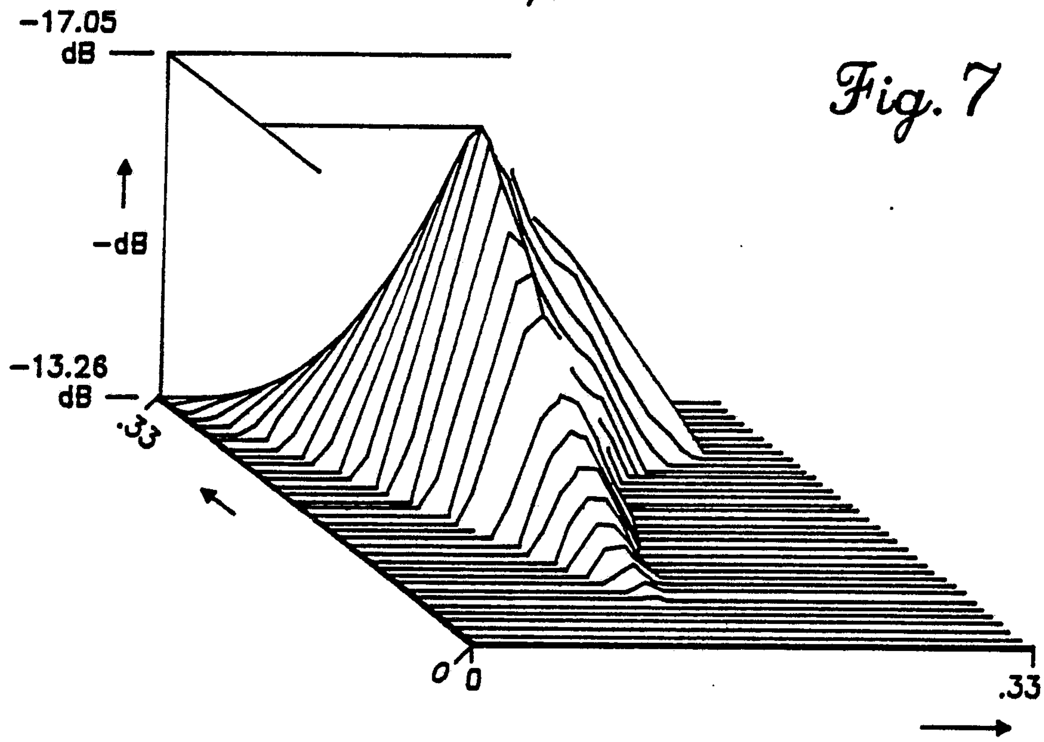


Fig. 7

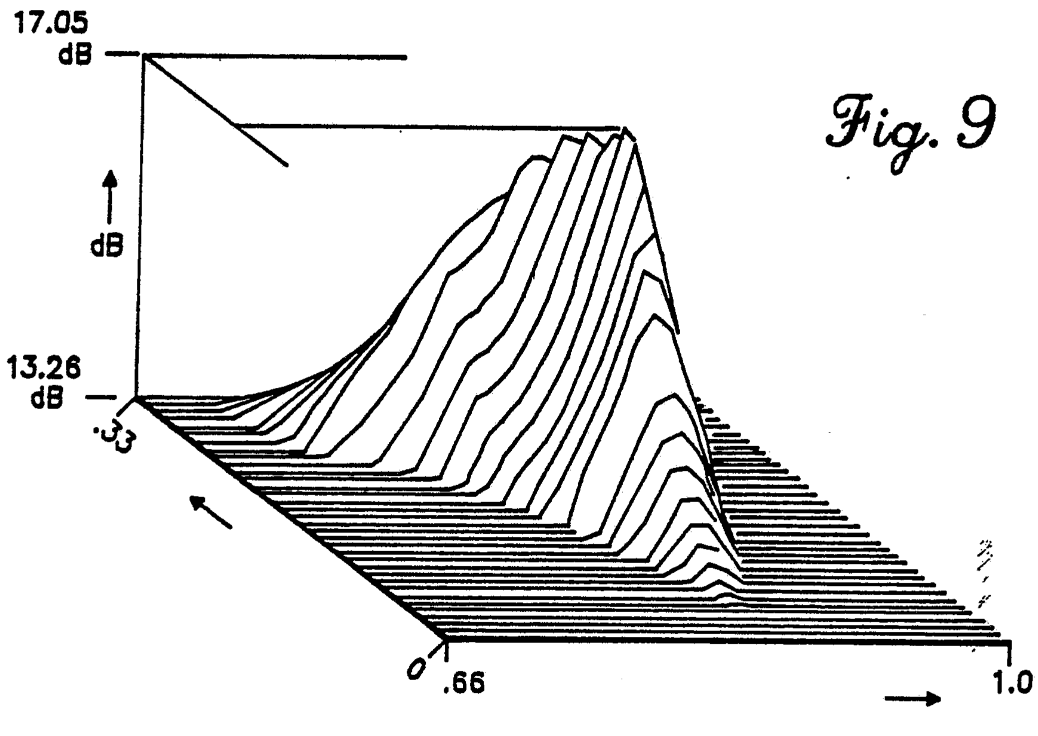


Fig. 9

Fig. 8

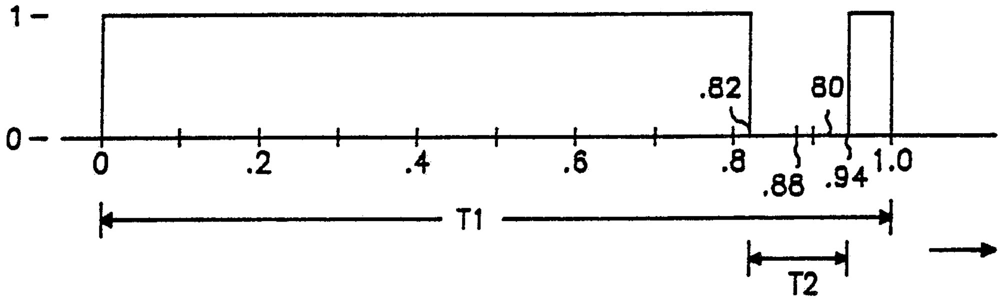


Fig. 10

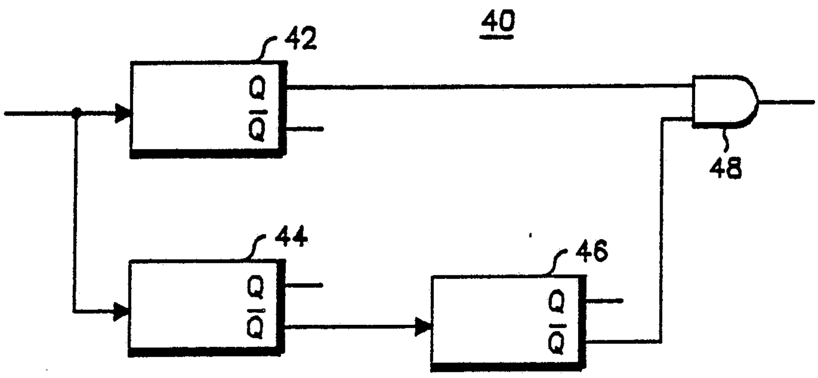


Fig. 11a

Fig. 11b

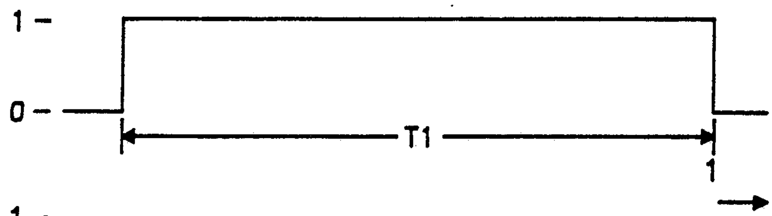


Fig. 11c

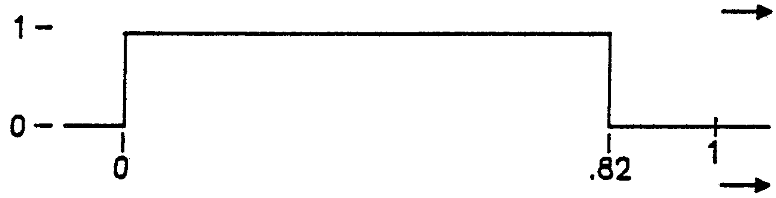


Fig. 11d

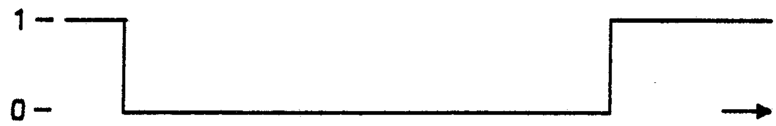


Fig. 11e

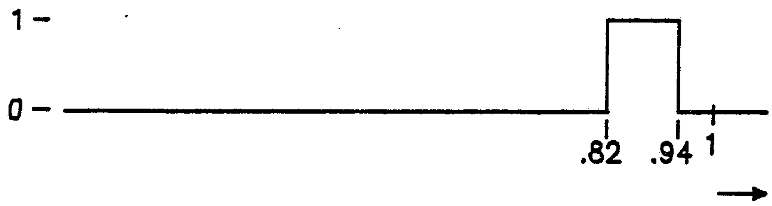


Fig. 11f

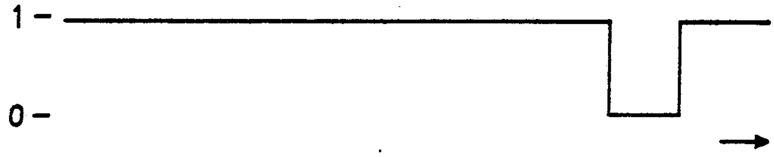
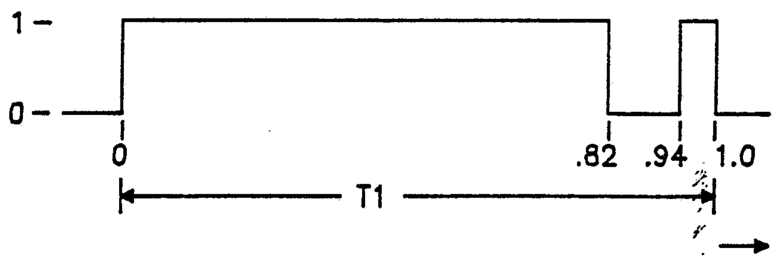
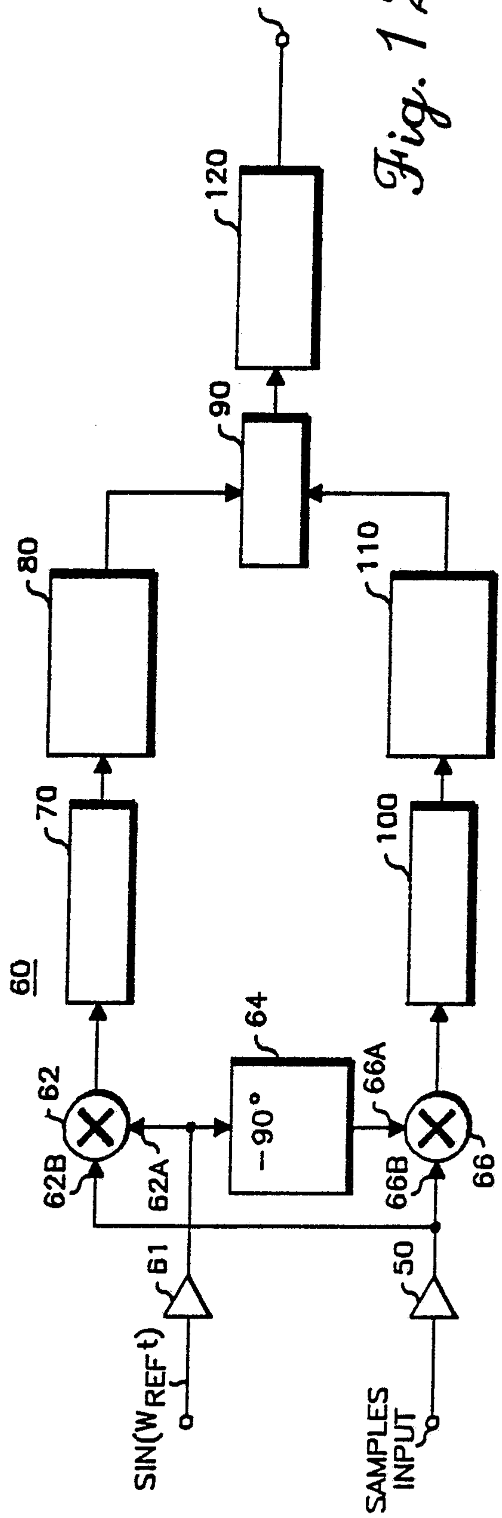


Fig. 11g




60
62
62A
62B
64
-90°
66
66A
66B
50
61
SIN(WREF t)
SAMPLES INPUT
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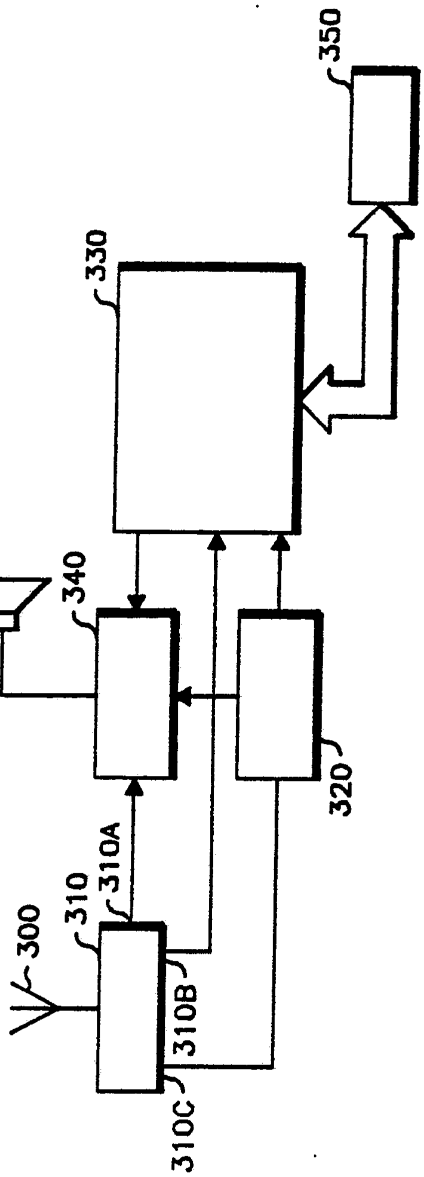
80
90
100
110
120

Fig. 12


300
310
310A
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310C
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340
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350

Fig. 14

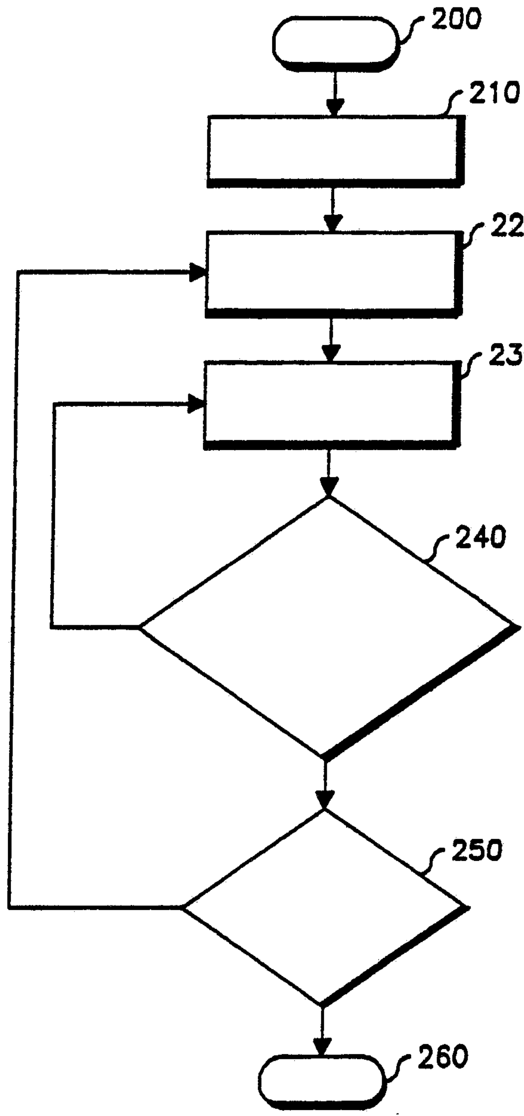
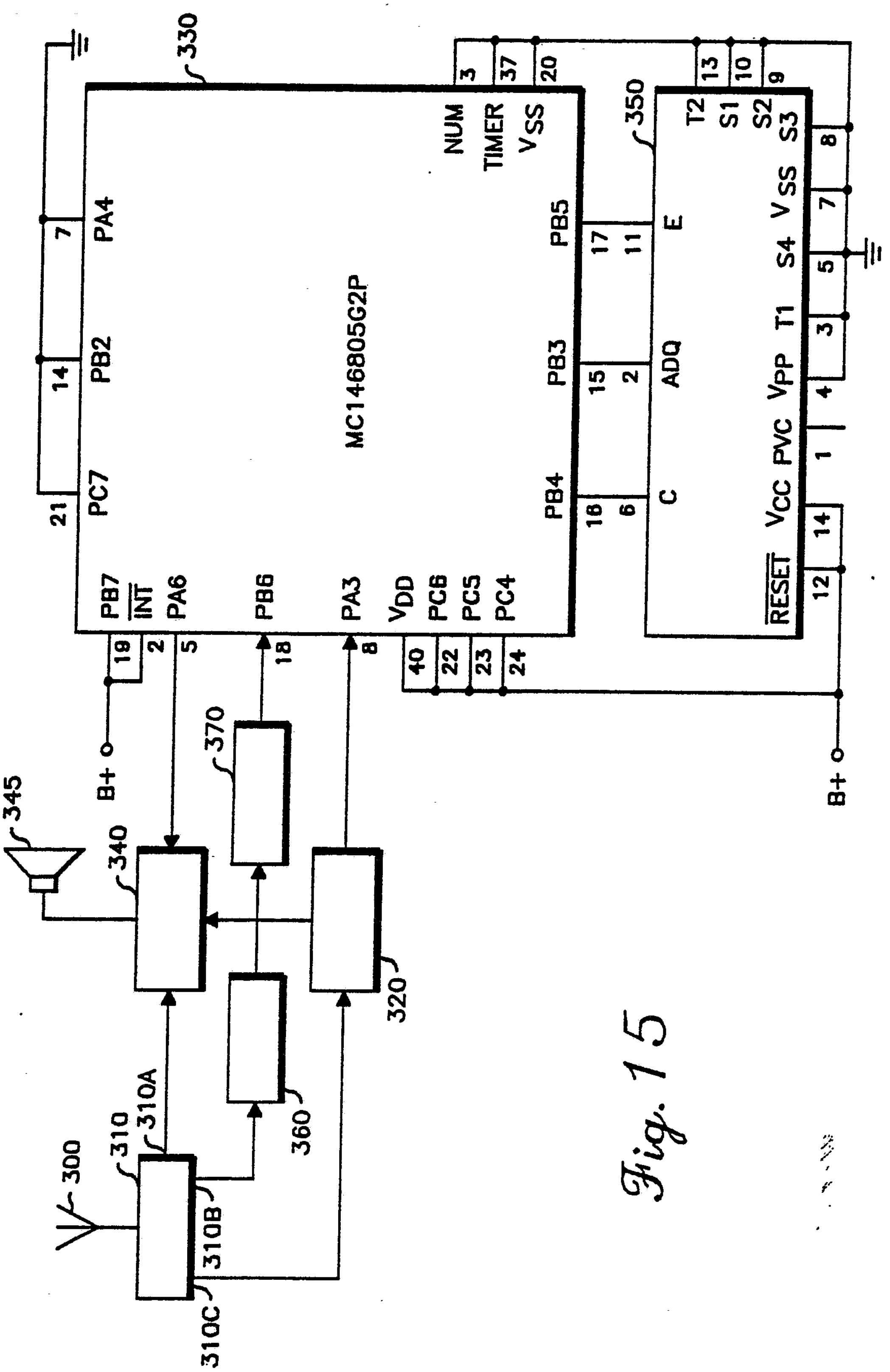


Fig. 13

SUBSTITUTE SHEET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PB5
PB3
PB4
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$\overline{INT}$
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PB6
PA3
V_{DD}
PC6
PC5
PC4
21
14
7
3
37
20
17
15
18
19
2
5
18
8
40
22
23
24
350
T2
S1
S2
S3
E
ADQ
C
V_{SS}
S4
T1
V_{PP}
PVC
V_{CC}
$\overline{RESET}$
13
10
9
8
7
5
3
4
1
14
12
11
2
6
B+
B+
345
340
370
360
320
300
310
310A
310B
310C

Fig. 15

INTERNATIONAL SEARCH REPORT

International Application No PCT/US84/00069

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

INT. CL. 3 G06F 15-31
U.S. CL. 364/572,724 343/379 333/166

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S.	364/572,574,724,726; 33/166; 343/379; 367/905

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
Y	US, A, 4,302,817, (LABEDZ), 24 November 1981	1,10,15,16
A	US, A, 4,216,463, (BACKOF, JR. ET AL), 05 August 1980	
A	US, A, 4,291,396, (MARTIN), 22 September 1981	
A	US, A, 4,259,650, (DONAHUE), 31 March 1981	
A	US, A, 4,156,876, (DEBUISSER), 29 May 1979	
A	US, A, 4,095,225, (ERIKMATS), 13 June 1978	
A	US, A, 4,057,802, (DOLLINGER), 08 November 1977	
Y	N, PROCEEDINGS OF THE IEEE, VOL. 66, NO. 1 ISSUED JANUARY 1978. F. J. HARRIS "ON	1,10,15,16

* Special categories of cited documents: [15]

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

"E" earlier document but 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

"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

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
23 MAR 1984	05 APR 1984
International Searching Authority [1]	**Signature of Authorized Officer [20]**
ISA/U.S.	Gareth C. Shaw

Form PCT/ISA/210 (second sheet) (October 1981)

International Application No. PCT/US84/00069

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

	THE USE OF WINDOWS FOR HARMONIC ANALYSIS WITH THE DISCRETE FOURIER TRANSFORM" PAGES 51-83	
A	N, DIGITAL FILTER DESIGN TECHNIQUES, PUBLISHED 1975, OPPENHEIM AND SCHAFER "DESIGN OF FIR FILTERS USING WINDOWS" PAGES 239-250	

V.☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [10]

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1.☐ Claim numbers________, because they relate to subject matter [12] not required to be searched by this Authority, namely:

2.☐ Claim numbers________, because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out [13], specifically:

VI.☐ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [11]

This International Searching Authority found multiple inventions in this international application as follows:

1.☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2.☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3.☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

4.☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.