| (51) International Patent Classification 5 : | | (11) International Publication Number: | **WO 91/03883** |
|---|---|---|---|
| **H04B 1/16** | **A1** | (43) International Publication Date: | 21 March 1991 (21.03.91) |

(54) Title: IMPROVED LOW POWER DSP SQUELCH
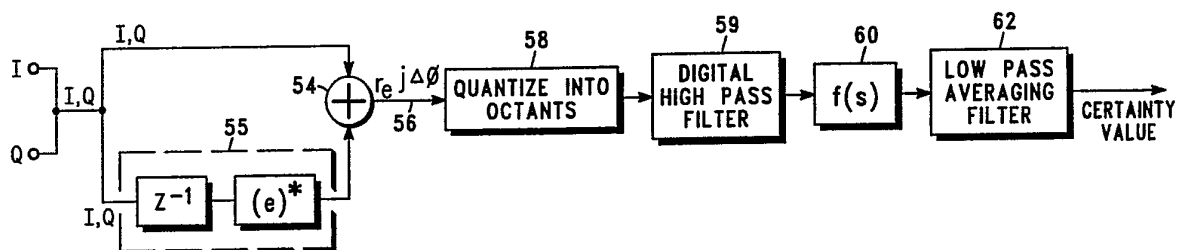
(57) Abstract

An improved method of statistically determining the presence of noise on an FM communications channel permits digital signal processing techniques to more reliably squelch unnecessary segments of an FM receiver reducing noise and power consumption. Digital samples of an FM signal having real (in-phase) (I) and imaginary (phase quadrature) (Q) components representing the real and imaginary components of a phasor rotating about the origin of a Cartesian coordinate system at a rate indicative of a signal on the channel are mathematically operated on. Successive digital samples are multiplied (54) by the complex conjugate (55) of temporally adjacent samples producing a new stream of phasors representative of the phase change between samples. The phase changes between samples are processed (58, 59, 60, 62) to produce a number that indicates the probability of the channel having noise present. This number indicative of the probability of noise content is compared to a threshold value and used to decide whether or not successive receiver stages should be squelched or unsquelched.

* See back of page

## DESIGNATIONS OF "DE"

Until further notice, any designation of "DE" in any international application whose international filing date is prior to October 3, 1990, shall have effect in the territory of the Federal Republic of Germany with the exception of the territory of the former German Democratic Republic.

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5                    IMPROVED LOW POWER DSP SQUELCH


BACKGROUND OF THE INVENTION


10        This invention relates to squelch systems. In particular this
invention relates to squelch systems used in frequency modulation
(FM) receivers to disable stages of the receiver when signal is
absent.


15        Typical squelch circuits in FM receivers test the output of the
discriminator and disable the output of the audio amplifier stage of
the receiver when there is no signal present on the channel. These
squelch circuits therefore require that the discriminator remain
active in the standby mode of the receiver. While squelch circuits
20   principally eliminate unwanted white noise from being heard at the
speaker output they can also substantially extend the life of a battery
powering a portable FM receiver by powering down unneeded stages
in the receiver when signal is absent from the channel.


25        Digital signal processors (DSP's), which use relatively large
amounts of power and which are becoming commonplace in FM
receivers, frequently perform the function of a discriminator, a
function previously performed by relatively low-power analog
circuits. Powering a DSP however to continuously perform a
30   discriminator function to squelch the radio's audio system would
waste substantial amounts of power. Using a DSP squelch
algorithm not requiring the output of a discriminator but
permitting the DSP to be disabled when its not required could
substantially extend the life of a battery powering a portable radio
35   that uses DSP's.

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## SUMMARY OF THE INVENTION

A method of detecting information on an FM channel is disclosed which operates on digital samples of non-demodulated
5      signals. The non-demodulated signal is a stream of digital complex numbers that have real and imaginary components. The real and imaginary components, denoted I and Q, are the in-phase and quadrature components respectively of a phasor that rotates about the origin of a set of Cartesian coordinates having imaginary
10     components along the Y axis and real components along the X axis. (When the FM signal is present on a receiver channel, the phasor rotates about the origin at a rate related to the instantaneous deviation of the FM modulating signal plus the frequency offset of the modulating signal from the center frequency of the channel.)
15     These I and Q components are digitally filtered to reduce noise components in the FM signal. The filtering removes undesired frequency components outside the bandwidth of interest at, for example, the first IF stage.

20     After filtering, each complex sample in the stream of samples is multiplied by the complex conjugate of a temporally adjacent sample to produce another stream of complex phasors whose angles represent the phase angle difference between the first sample and the temporally adjacent sample of which the complex
25     conjugate was formed.

This product of a first phasor in the stream of phasors and a complex conjugate of a temporally adjacent phasor is performed repetitively on all samples output from the digital-to-analog
30     convertor to produce the second stream of phasors. The phase angles of the phasors formed by the product of the sample and the complex conjugate of an adjacent sample are evaluated statistically to generate a numerical index or value on the probability of the channel content being noise.
35

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The statistical evaluation of the phasors formed by the product of the sample values and the complex conjugate of the sample values numerically weights these phasors according to some appropriate algorithm and accumulates the results obtained
5     by the operation of this algorithm on the phasor samples. The accumulation of results is used to make a decision as to whether or not the FM channel contains signal or noise. If the channel contains noise, other processing in the DSP can be disabled.

10        Several algorithms or weighting functions are possible as detailed below.

BRIEF DESCRIPTION OF THE DRAWINGS

15        Figure 1 shows a subsection of the functional blocks required of the FM receiver of the present invention.

          Figure 2 shows a function block required to perform the invention described herein.
20
          Figure 3 shows a set of Cartesian coordinates having imaginary and real axes.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT
25
          Figure 1 shows the functional elements of an FM receiver front end required by the preferred embodiment of the invention herein. The FM receiver includes an antenna (12), an RF amplifier that amplifies low-level signals (14), a first mixer (16) driven by a
30    local oscillator (18) that shifts the incoming signals to a lower frequency at which the signals are filtered by the first IF (20) to suppress undesired signals and noise in the frequency band of interest.

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The output of the first IF (20) is coupled to a second mixer, (30) which mixes the output o of the first IF (20) with a second oscillator (32) to produce a second IF signal (34) at a frequency at which a practical A/D converter can operate. (Note that faster A/D's might
5    be able to sample the output of the first mixer or even the output of the RF amplifier but would require more power.)

In the preferred embodiment, the second IF signal (34) is sampled by an A/D converter (40) to produce a stream of real digital
10   numbers. The stream of real digital numbers is digitally band-pass filtered (41) and sent to a digital mixer (42) driven by a digital complex oscillator (43), which oscillates at the 2nd IF frequency. The output of the digital mixer (42) is a stream of complex digital numbers at a center frequency of 0 hz. This stream of samples may
15   then be further low-pass filtered and decimated (44) to obtain a suitably low sample rate. (Decimating effectively divides the data rate of samples from the digital mixer (42) so that digital signal processing can be performed by slower devices.) This sample rate should be at least three to four times the maximum frequency
20   deviation of the expected signal; higher sample rates improve speed and reliability at the cost of processing power.

In figure 2, the signal processing of the output of the decimating filter (44) is shown in detail. (All processing shown in
25   figure 2 is in a digital format using a digital signal processor such as a Motorola 56000 DSP Programming details of the Motorola DSP 56000 series of signal processors are available in the 56000 series user's manual, Motorola Publication No. DSP56000UM/AD rev. 1. A listing of the program for the preferred embodiment of the
30   squelch system shown in figure 2 is given below.)

As described above, each complex sample in the stream of samples from the decimator (44) is multiplied (54) by the complex conjugate of a temporally adjacent sample (55) to produce a second
35   stream of phasors (56) whose phase angles represent the differences

between the phases of the two samples multiplied in the multiplier
(54). (The two samples multiplied in the multiplier are actually
pairs of samples, being a first sample and the complex conjugate of
a temporally adjacent second sample. The temporal ordering of the

5    first and second samples from the decimator is arbitrary. The
complex conjugate sample can either temporally precede or follow
the other sample.) These phase differences can be considered to be
the instantaneous deviation of the frequency of the received signal or
noise from the center of the channel. When there is an FM signal

10   on the channel, the deviation is limited by the transmitter and
should be less than the maximum allowable deviation depending on
the channel specification. If there is noise on the channel, the
deviation is not limited since noise does not have the constant-
envelope property of a frequency-modulated signal and the phasor

15   (56) output from the multiplier (54) may even pass through or near
the origin (I=0, Q=0) at any time, resulting in large instantaneous
frequency deviations.

To determine whether the channel contains noise, this
angular deviation phasor (56) is tested by a digital signal processor

20   using relatively simple instruction cycles to determine the phase
angle of the phasor with respect to the X axis. While it is
burdensome to calculate the exact phase angle of this phasor, it is
adequate to consider a more approximate, or quantized, value
which is considerable easier to calculate. The phase angles of these

25   phasors are quantized (58) into one of eight sectors or octants.
Quantizing the phasors produces a stream of real numbers which
are evaluated to permit predicting that the channel contains noise.
Since these real numbers representing the quantized phasor angles
have finite resolution. In the preferred embodiment, the phase

30   angles of the phasors were quantized into octants of 45° each.

Figure 3 shows a cartesian coordinate system of I and Q axes
divided into eight octants. The octants are numbered 0 through +3,
counterclockwise above the Q axis. Octants below the Q axis are
numbered -0 to -3, clockwise. In the preferred embodiment, the

35   numbering of the octants corresponds to the value assigned to a

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phasor falling anywhere within that octant, thereby quantizing
phasors into one of eight octants.

After being quantized (58) the phasor angles are high-pass
filtered (59) to eliminate DC content in the phasors (56) from small
5    frequency offsets between the transmitter and receiver frequencies.

Statistical analysis of the angles of successive phasors (60)
generates a numerical index which indicates the probability that
the channel contains noise and not information. If many of the
angles of the phasors lie in the positive or negative third or fourth
10   octants (octants 2, 3, -2 and -3 shown in figure 3), there is a
substantial probability that the channel contains noise. If the
angles of the phasors lie predominantly in the first and second
octants (octants 0, 1, -0 and -1) the channel likely contains an FM
modulated signal.

15         Output of the filter (59) is weighted by a mathematical
weighting function (60) which permits more reliable evaluation of
the probability that the channel contains noise. In one embodiment,
the weighting function (60) numerically squares the output of the
filter (59) to produce a second value. Squaring the quantized
20   phasors, some of which have negative values such as -3, -2, or -1,
yields a string of positive numbers. The string of positive numbers
is used to generate a certainty value or number, indicative of the
probability the channel contains noise. Alternatively, the weighting
function could calculate the absolute value of the product of two
25   distinct samples from the filter (59) as implemented in the assembly
language listing appended below. Other weighting functions may
be used depending on the characteristics of the expected signal.

The output of the weighting function (60) is averaged or low-
pass filtered (62) to produce an averaged result. The averaged result
30   is indicative of the probability of noise present in the channel. Using
the weighting functions described above, the value output by the
averaging filter (62) will be lower if signal is present in the channel
than if the channel contains only noise. The detection threshold or
thresholds may be set depending on the sensitivity desires. A value

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above the threshold represents noise on the channel; a value below the threshold indicates the presence of a desired signal.

The output of the integrator circuit (62) may be passed to a digital comparator algorithm (not shown) which can compare 5 accumulated value in the integrator (62) to the aforementioned threshold. Depending upon the value chosen for the reference value in the comparator, a decision can be made to squelch or unsquelch subsequent signal processing circuits in the receiver thereby saving power or to enable the signal processing circuits in the receiver 10 thereby saving power or to enable the signal processing circuits and turn on the output.

The following source code performs the functions of figure 2.

```
15      ;**************************************************
        ;
        ; This code segment is called as a subroutine
        ;
        ; Inputs:
        ;    - I in accumulator A
20      ;      Q in accumulator B
        ;
        ; Output:
        ;
        ; - Squelch on or off flag.
25      ;
        ; NOTE:
        ;      flag = 1 = > squelch ON (active)   => weak signal => audio OFF
        ;      flag = 0 =>      "     OFF (inactive) => strong  "  => "  ON
        ;
30      ; Algorithm:
        ;   1) Accumulate a function of the number of octant boundaries
        ;   crossed by the RF phasor.
        ;   2) Use 1 to determine whether squelch is open or closed
        ;
35      ; Misc Constants . . .
        ;
        SAMPLES     EQU 167
        SQON        EQU 0

40      ;
        ; Misc. Storage
        ;
              ORG  XL:$0000
        ;
```

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```
        TIMER      DC    SAMPLES
        ACCUM      DC    0
        LO_THR     DC    $40
        HI-THR     DC    $80
5       GPFLAG     DC    0
        OLDOCT     DC    0
        OLDDIFF    DC    0
        OLD_I      DC    0
        OLD_Q      DC    0
10      RESET      DC    SAMPLES
        ;
        ;*******************************************
        ;
        ; Part I) Accumulate a function of the octant crossings
15      ;
              ORG PL:$0040
        ;
        SSQLCH     MOVE        A,XO
              MOVE         B,Y0
20            MOVE         X;OLD_I,X1
              MOVE         X:OLD_Q,Y1
        ;
        ; 1) Compute f[k] = z[k]  times z*[k-1] whose phase equals the RF
        ;  phase change.
25      ;
              MPY X0,X1,A      XO,S;OLD_I
              MAC Y0,Y1,A  Y0,X:OLD_Q
              MPY X1,YO,B
              MAC -X0,Y1,B  #<$7F,X0
30      ;
        ; 2) Determine the octant of {f[k] = A: Re{f[k]} + j B: Im{f[k]}
        ;  and  load the proper bias number.
        ;
        ;     JLE        <OCT3456              ; If re<0 then oct=3,4,5,6
35      ;
        OCT 1278 CMPM B,A   #<$80,A            ;  else is |re| > |im|  ?
              JGT  <OCT18                      ;  if so, otant = 1 or 8
        ;
        OCT27      TST  B     X:<OLDOCT,Y0     ; else is im> 0?, A=-1.0
40            MOVE        #>1,X1               ;X1= |OCT|
              JMP  <CONTIN
        ;
        OCT18      MOVE        #<0,X1
              MOVE X:<OLDOCT,Y0
45            JMP    <CONTIN
        ;
        OCT3456 CMPM  B,A    #<$80,A           ; else is  |re|>|im| ?
              JGT  <OCT45                      ; if so, octant = 4 or 5
        ;
```

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```
OCT36       TST  B      X:<OLDOCT,Y0   ; else is im > 0 ?
            MOVE  #>2,X1
            JMP    <CONTIN
;
OCT45       TST  B      X:<OLDOCT,Y0   ; else is im > 0?
            MOVE  #>3,X1
;
; A=-1.0 X0 = 1.0, X1 =  |Oct|,Y0=Oct [k-1], N bit (CC) = sign of Q
;
CONTIN     TPL  X0,A
            MOVE       A,X0
            MPYR       X0, X1, A    X;<OLDIFF, Y1
            SUB  Y0,A       A,X:<OLDOCT
            ABS  A          X:<ACCUM,X0)
            MOVE       A,Y0
            MPY  Y0,Y1,A   Y0,X:<OLDDIFF
            TFR  X0,A       A0,X1
            ADD  X1,A       X:<TIMER,B
            MOVE       #>1,X1
            SUB X1,B        A,X:<ACCUM
            MOVE       B,X:<TIMER
            JEQ  <DUMP
RTRN               NOP
;
            RTS
;**********************************************************
;
;       Part II - SQUELCH DECISION ROUTINE
;
; PURPOSE
;       This code compares the algorithm's accumulator witht he
; threshold values to determine whether to turn the SQUELCH on
or ;off.
;
;       INPUTS:   A = ACCUMulator
            B = 0
            X1 = 1
;                 a host of miscellaneous values in zero-page memory
;
;       OUTPUTS: GPFLAG (bit 0) = SQUELCH STATE (1 = ON)
;            TIMER gets reset
;
DUMP        MOVE          X:<HI_THR,X0
        CMP XO,A     X:<LO_THR,X0
        JGE  <TURNON
        CMP XO,A     X:<RESET, X0
        JLE  <TURNOFF

DONTCHG MOVE     X0,X:<TIMER
```

10

```
        MOVE        B,X:<ACCUM
        JMP  <RTRN
    ;
    TURNON    BSET #SQON,X:<GPFLAG
5       MOVE X:<RESET,XO
        MOVE        XO,X:TIMER
        MOVE        B,X:<ACCUM
        JMP         <RTRN
    ;
10  TURNOFF  BCLR       #SQON,X:<GPFLAG
        MOVE        XO,X:<TIMER
        MOVE        BXK:<ACCUM
        JMP         <RTRN
    ;
15  ;*******************************************
    ;
```

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What is claimed is:

1. In a frequency modulation (FM) receiver receiving FM signals on a
channel, a method of identifying information bearing signals and
identifying non-information bearing noise on said channel comprised of the
steps of:

> converting said FM signals to a stream of digital samples, said
> samples representative of said FM signal, each of said digital
> samples in said stream being complex and having I (real) and Q
> (imaginary) components;

> determining the phase difference between each temporally adjacent
> pair of samples in said stream of samples

> identifying the contents of said FM channel as either signal or noise
> based on statistical evaluation of a plurality of said phase differences.

2. The method of claim 1 including the step of:

> before said determination of phase differences between each
> temporally adjacent pair of samples, filtering said I and Q
> components to produce a stream of filtered samples having reduced
> noise components in said digital signal.

3. The method of claim 1 including the step of:

> determining the phase difference between each temporally adjacent
> pair of samples in said stream of samples by multiplying each
> sample in said signal by the complex conjugate of a temporally
> adjacent sample to produce a stream of phasors, each phasor having
> a phase angle representative of the change in phase between said
> temporally adjacent samples.

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4. The method of claim 1 including the step of activating signal processing in said receiver upon the determination of the presence of desired signal on said channel.

5    5. The method of claim 1 where said statistical evaluation of a plurality of phase angles of said phasors includes the steps of:

producing a second stream of real values of finite resolution representing said phase angles;

10

producing a stream of weighted values from said second stream, each weighted value produced according to a function operating on one or more of the values of the second stream;

15    low pass filtering said stream of weighted values to provide a certainty value representing an estimated of the probability of desired signal being present on the channel;

comparing this certainty value to a threshold value and specifying
20    the channel content as either desired signal or noise based on said comparison.

6. The method of claim 5 where the step of producing a second stream of real values of finite resolution representing said phase angles includes the
25    steps of:

identifying said phase angles as being located in predetermined sectors of a Cartesian coordinate system and assigning numerical values to said samples in said second stream according to the sector
30    in which said phasor lies.

7. The method of claim 5 where the step of producing a stream of weighted values from said second stream includes the steps of:

35    squaring each value in said second stream of values.

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8. The method of claim 5 where the step of producing a stream of weighted values from said second stream includes the steps of:

5        assigning an arbitrary value to each possible value of the second stream dependent upon which sector the phasor lies in.

9. The method of claim 5 where the step of producing a stream of weighted values from said second stream includes the steps of:

10

calculating the absolute value of the product of the value of a first sample in said second stream and the value of a second sample in said second stream.

15   10. The method of identifying information of claim 5 where the second stream of real values is filtered to remove DC offset component in said second stream before the weighting operation.

11. The method of identifying information of claim 1 where filtering said I
20   and Q components to reduce noise reduces undesired information signals and non-informational noise.

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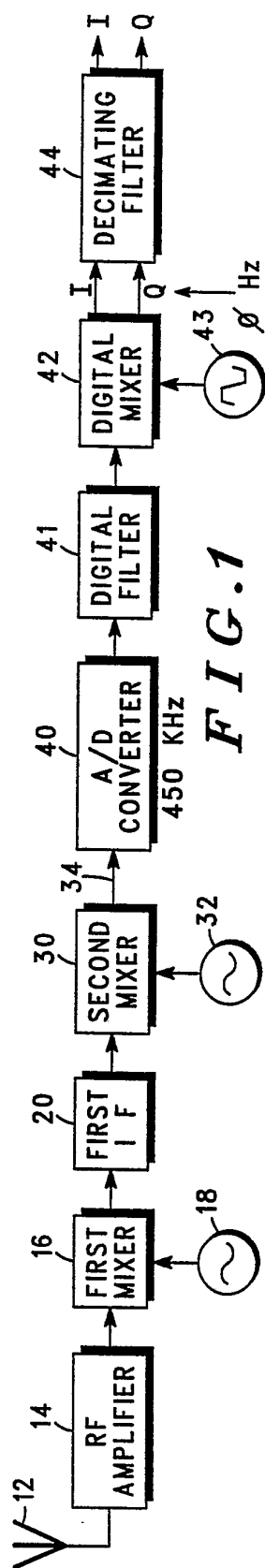


FIG.1
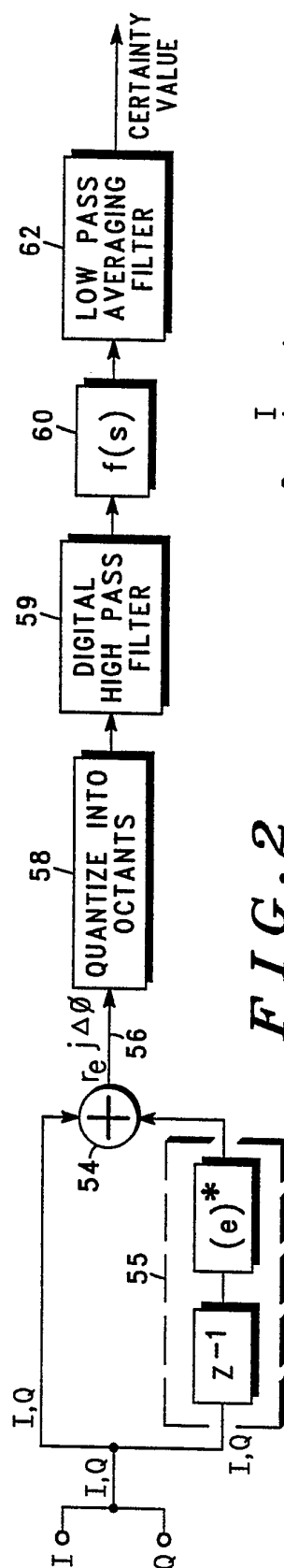


FIG.2
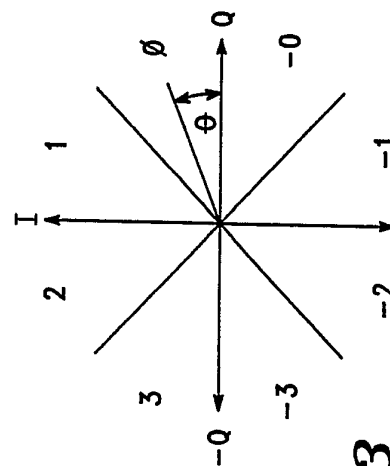


FIG.3

# INTERNATIONAL SEARCH REPORT

International Application No **PCT/US90/04306**

## 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. (5):  H04B 1/16

U.S. CL·  : 455/224, 336  329/325  375/104

## II. FIELDS SEARCHED

Minimum Documentation Searched 4

| Classification System | Classification Symbols |
|---|---|
| U.S. | 455/212, 213, 214, 215, 224, 225, 218, 336, 337<br>375/102, 104  329/319-321, 325, 327 |

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, 4,117,410, BENDER  26 September 1978<br>see entire document. | 1-4, 11 |
| Y | US, A, 4,603,300, WELLES, II Et AL.  29 July 1986 | 1-4, 11 |
| A | US, A, 4,618,967, VANCE ET AL.  21 October 1986 | |
| A | US, A, 4,704,582, DIXON ET AL.  03 NOVEMBER 1987 | |

* Special categories of cited documents: 15

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"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 |
|---|---|
| 20 OCTOBER 1990 | 24 JAN 1991 |
| International Searching Authority 1 | Signature of Authorized Officer 20 |
| ISA/US | CURTIS A KUNTZ  INTERNATIONAL DIVISION |

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