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(54) **METHODS, DEVICES AND SYSTEMS FOR RECEIVING AND DECODING A SIGNAL IN THE PRESENCE OF NOISE USING SLICES AND WARPING**

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(56) **References Cited**

U.S. PATENT DOCUMENTS

3,607,788	A	9/1971	Adolph
3,642,008	A	2/1972	Bolduc

(Continued)

FOREIGN PATENT DOCUMENTS

CN	1588649	3/2005
CN	1991868	7/2007

(Continued)

OTHER PUBLICATIONS

Written Opinion and International Search Report for PCT/US2014/056576, dated Dec. 17, 2014 (13 pages).

(Continued)

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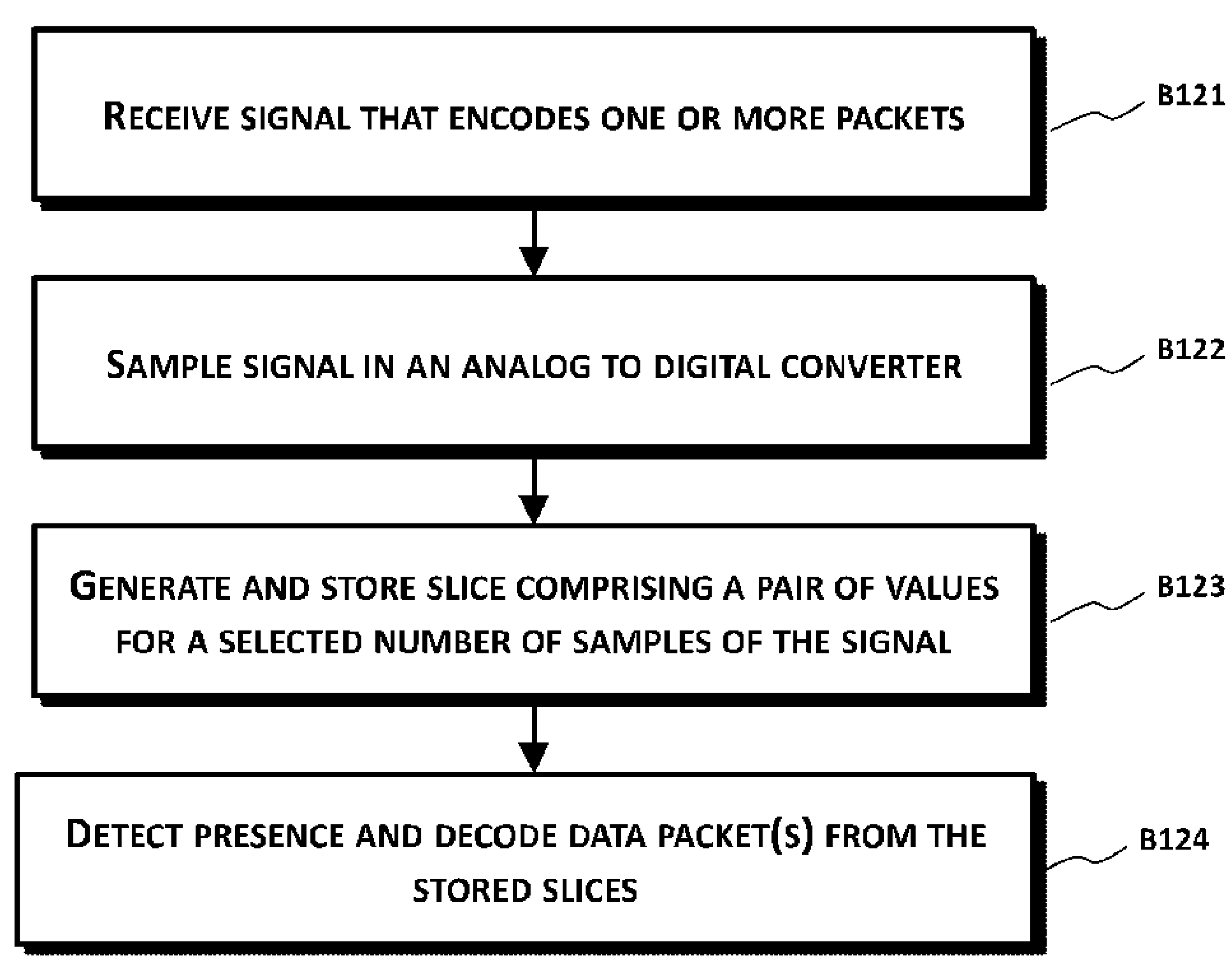
(57) **ABSTRACT**

A method may comprise receiving and sampling a signal. The signal may encode a data packet. A slice may be generated and stored comprising a pair of values for each of a selected number of samples of the signal representing a correlation of the signal to reference functions in the receiver. The presence of the data packet may then be detected and the detected packet decoded from the stored slices. The generating and storing slices may be carried out as the received signal is sampled. The sampled values of the signal may be discarded as the slices are generated and stored. The slice representation of the signal can be manipulated to generate filters with flexible bandwidth and center frequency.

29 Claims, 12 Drawing Sheets



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(56) **References Cited**

U.S. PATENT DOCUMENTS

3,679,480 A 7/1972 Brown et al.
3,682,160 A 8/1972 Murata
3,719,183 A 3/1973 Schwartz
3,828,766 A 8/1974 Krasnow
3,837,339 A 9/1974 Aisenberg et al.
3,989,050 A 11/1976 Buchalter
4,067,014 A * 1/1978 Wheeler et al. 342/418
4,077,397 A 3/1978 Ellis
4,077,398 A 3/1978 Ellis
4,082,087 A 4/1978 Howson
4,090,752 A 5/1978 Long
4,106,348 A 8/1978 Auphan
4,121,573 A 10/1978 Crovella et al.
4,129,125 A 12/1978 Lester
4,166,453 A 9/1979 McClelland
4,185,172 A * 1/1980 Melindo et al. 370/241
4,239,046 A 12/1980 Ong
4,269,189 A 5/1981 Abraham
4,331,654 A 5/1982 Morris
4,333,150 A * 6/1982 Matty et al. 702/74
4,345,588 A 8/1982 Widder et al.
4,418,697 A 12/1983 Tama
4,425,117 A 1/1984 Hugemann
4,494,950 A 1/1985 Fischell
4,512,385 A * 4/1985 Uppgren 164/364
4,559,950 A 12/1985 Vaughan
4,578,061 A 3/1986 Lemelson
4,635,641 A 1/1987 Hoffman
4,654,165 A 3/1987 Eisenberg
4,669,479 A 6/1987 Dunseath
4,725,997 A 2/1988 Urquhart et al.
4,749,575 A 6/1988 Rotman et al.
4,763,659 A 8/1988 Dunseath
4,784,162 A 11/1988 Ricks
4,793,825 A 12/1988 Benjamin et al.
4,809,705 A 3/1989 Ascher
4,844,076 A 7/1989 Lesho
4,858,617 A 8/1989 Sanders
4,896,261 A 1/1990 Nolan
4,975,230 A 12/1990 Pinkhasov
4,987,897 A 1/1991 Funke
5,016,634 A 5/1991 Vock et al.
5,079,006 A 1/1992 Urquhart
5,113,859 A 5/1992 Funke
5,167,626 A 12/1992 Casper
5,176,626 A 1/1993 Soehendra
5,232,383 A 8/1993 Barnick
5,245,332 A 9/1993 Katzenstein et al.
5,261,402 A 11/1993 DiSabito
5,263,481 A 11/1993 Axelgaard et al.
5,281,287 A 1/1994 Lloyd
5,283,136 A 2/1994 Peled et al.
5,318,557 A 6/1994 Gross
5,394,882 A 3/1995 Mawhinney
5,458,141 A 10/1995 Neil et al.
5,485,841 A 1/1996 Watkin et al.
5,511,548 A 4/1996 Riazzi et al.
5,551,020 A 8/1996 Flax et al.
5,596,302 A 1/1997 Mastrocola et al.
D377,983 S 2/1997 Sabri et al.
5,634,466 A 6/1997 Gruner
5,634,468 A 6/1997 Platt
5,645,063 A 7/1997 Straka et al.
5,720,771 A 2/1998 Snell
5,724,432 A 3/1998 Bouvet et al.
5,740,811 A 4/1998 Hedberg
5,792,048 A 8/1998 Schaefer
5,802,467 A 9/1998 Salazar
5,833,716 A 11/1998 Bar-Or
5,845,265 A 12/1998 Woolston
5,862,803 A 1/1999 Besson
5,862,808 A 1/1999 Albarello
5,868,136 A 2/1999 Fox
5,921,925 A 7/1999 Cartmell et al.
5,925,030 A 7/1999 Gross et al.
5,925,066 A 7/1999 Kroll et al.
5,957,854 A 9/1999 Besson et al.
5,974,124 A 10/1999 Schlueter, Jr. et al.
5,981,166 A 11/1999 Mandecki
5,999,846 A 12/1999 Pardey et al.
6,023,631 A 2/2000 Cartmell et al.
6,038,464 A 3/2000 Axelgaard et al.
6,042,710 A 3/2000 Dubrow
6,047,203 A 4/2000 Sackner
6,076,016 A 6/2000 Feierbach
6,081,734 A 6/2000 Batz
6,095,985 A 8/2000 Raymond et al.
6,115,636 A 9/2000 Ryan
6,117,077 A 9/2000 Del Mar et al.
6,122,351 A 9/2000 Schlueter, Jr. et al.
6,141,592 A 10/2000 Pauly
6,200,265 B1 3/2001 Walsh et al.
6,200,625 B1 3/2001 Beckett
6,204,764 B1 3/2001 Maloney
6,206,702 B1 3/2001 Hayden et al.
6,217,744 B1 4/2001 Crosby
6,231,593 B1 5/2001 Meserol
6,238,338 B1 5/2001 DeLuca et al.
6,245,057 B1 6/2001 Sieben et al.
6,275,476 B1 8/2001 Wood
6,285,897 B1 9/2001 Kilcoyne et al.
6,287,252 B1 9/2001 Lugo
6,289,238 B1 9/2001 Besson et al.
6,315,719 B1 11/2001 Rode et al.
6,317,714 B1 11/2001 Del Castillo
6,358,202 B1 3/2002 Arent
6,364,834 B1 4/2002 Reuss
6,366,206 B1 4/2002 Ishikawa et al.
6,371,927 B1 4/2002 Brune
6,374,670 B1 4/2002 Spelman
6,380,858 B1 4/2002 Yarin et al.
6,394,953 B1 5/2002 Devlin et al.
6,394,997 B1 5/2002 Lemelson
6,409,674 B1 6/2002 Brockway et al.
6,426,863 B1 7/2002 Munshi
6,432,292 B1 8/2002 Pinto et al.
6,440,069 B1 8/2002 Raymond et al.
6,441,747 B1 8/2002 Khair
6,477,424 B1 11/2002 Thompson et al.
6,482,156 B2 11/2002 Lliff
6,494,829 B1 12/2002 New et al.
6,496,705 B1 12/2002 Ng et al.
6,526,315 B1 2/2003 Inagawa
6,544,174 B2 4/2003 West
6,564,079 B1 5/2003 Cory
6,577,893 B1 6/2003 Besson et al.
6,579,231 B1 6/2003 Phipps
6,605,038 B1 8/2003 Teller et al.
6,605,046 B1 8/2003 Del Mar
6,609,018 B2 8/2003 Cory
6,612,984 B1 9/2003 Kerr
6,632,175 B1 10/2003 Marshall
6,632,216 B2 10/2003 Houzego et al.
6,643,541 B2 11/2003 Mok et al.
6,654,638 B1 11/2003 Sweeney
6,663,846 B1 12/2003 McCombs
6,673,474 B2 1/2004 Yamamoto
6,680,923 B1 1/2004 Leon
6,689,117 B2 2/2004 Sweeney et al.
6,694,161 B2 2/2004 Mehrotra
6,704,602 B2 3/2004 Berg et al.
6,720,923 B1 4/2004 Hayward et al.
6,738,671 B2 5/2004 Christophersom et al.
6,740,033 B1 5/2004 Olejniczak et al.
6,745,082 B2 6/2004 Axelgaard et al.
6,755,783 B2 6/2004 Cosentino

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,757,523	B2	6/2004	Fry
6,800,060	B2	10/2004	Marshall
6,801,137	B2	10/2004	Eggers et al.
6,814,706	B2	11/2004	Barton et al.
6,822,554	B2	11/2004	Vrijens et al.
6,836,862	B1	12/2004	Erekson et al.
6,839,659	B2	1/2005	Tarassenko et al.
6,840,904	B2	1/2005	Goldberg
6,842,636	B2	1/2005	Perrault
6,845,272	B1	1/2005	Thomsen
6,856,832	B1	2/2005	Matsumura et al.
6,864,780	B2	3/2005	Doi
6,879,810	B2	4/2005	Bouet
6,882,881	B1	4/2005	Lesser et al.
6,897,788	B2	5/2005	Khair et al.
6,909,878	B2	6/2005	Haller
6,922,592	B2	7/2005	Thompson et al.
6,928,370	B2	8/2005	Anuzis et al.
6,929,636	B1	8/2005	Von Alten
6,937,150	B2	8/2005	Medema
6,942,616	B2	9/2005	Kerr
6,951,536	B2	10/2005	Yokoi
6,957,107	B2	10/2005	Rogers et al.
6,959,929	B2	11/2005	Pugnet et al.
6,961,601	B2	11/2005	Matthews et al.
6,968,153	B1	11/2005	Heinonen
6,987,965	B2	1/2006	Ng et al.
6,990,082	B1	1/2006	Zehavi et al.
7,002,476	B2	2/2006	Rapchak
7,004,395	B2	2/2006	Koenck
7,009,634	B2	3/2006	Iddan et al.
7,009,946	B1	3/2006	Kardach
7,013,162	B2	3/2006	Gorsuch
7,016,648	B2	3/2006	Haller
7,020,508	B2	3/2006	Stivoric
7,024,248	B2	4/2006	Penner et al.
7,031,745	B2	4/2006	Shen
7,031,857	B2	4/2006	Tarassenko et al.
7,039,453	B2	5/2006	Mullick
7,046,649	B2	5/2006	Awater et al.
7,076,437	B1	7/2006	Levy
7,116,252	B2	10/2006	Teraguchi
7,118,531	B2	10/2006	Krill
7,127,300	B2	10/2006	Mazar et al.
7,139,332	B2	11/2006	Yu et al.
7,146,228	B2	12/2006	Nielsen
7,146,449	B2	12/2006	Do et al.
7,149,581	B2	12/2006	Goedeke et al.
7,154,071	B2	12/2006	Sattler et al.
7,154,916	B2	12/2006	Soloff
7,155,232	B2	12/2006	Godfrey et al.
7,160,258	B2	1/2007	Imran
7,161,484	B2	1/2007	Tsoukalis
7,164,942	B2	1/2007	Avrahami
7,171,166	B2	1/2007	Ng et al.
7,171,177	B2	1/2007	Park et al.
7,171,259	B2	1/2007	Rytky
7,187,960	B2	3/2007	Abreu
7,188,199	B2	3/2007	Leung et al.
7,188,767	B2	3/2007	Penuela
7,194,038	B1	3/2007	Inkinen
7,206,630	B1	4/2007	Tarler
7,209,790	B2	4/2007	Thompson et al.
7,215,660	B2	5/2007	Perlman
7,215,991	B2	5/2007	Besson
7,218,967	B2	5/2007	Bergelson
7,231,451	B2	6/2007	Law
7,243,118	B2	7/2007	Lou
7,246,521	B2	7/2007	Kim
7,249,212	B2	7/2007	Do
7,252,792	B2	8/2007	Perrault
7,253,716	B2	8/2007	Lovoi et al.
7,261,690	B2	8/2007	Teller
7,270,633	B1	9/2007	Goscha
7,273,454	B2	9/2007	Raymond et al.
7,285,090	B2	10/2007	Stivoric et al.
7,289,855	B2	10/2007	Nghiem
7,291,497	B2	11/2007	Holmes
7,292,139	B2	11/2007	Mazar et al.
7,294,105	B1	11/2007	Islam
7,313,163	B2	12/2007	Liu
7,317,378	B2	1/2008	Jarvis et al.
7,318,808	B2	1/2008	Tarassenko et al.
7,336,929	B2	2/2008	Yasuda
7,342,895	B2	3/2008	Serpa
7,346,380	B2	3/2008	Axelgaard et al.
7,349,722	B2	3/2008	Witkowski et al.
7,352,998	B2	4/2008	Palin
7,353,258	B2	4/2008	Washburn
7,357,891	B2	4/2008	Yang et al.
7,359,674	B2	4/2008	Markki
7,366,558	B2	4/2008	Virtanen et al.
7,373,196	B2	5/2008	Ryu et al.
7,375,739	B2	5/2008	Robbins
7,376,435	B2	5/2008	McGowan
7,382,263	B2	6/2008	Danowski et al.
7,387,607	B2	6/2008	Holt
7,388,903	B2	6/2008	Godfrey et al.
7,389,088	B2	6/2008	Kim
7,392,015	B1	6/2008	Farlow
7,395,105	B2	7/2008	Schmidt et al.
7,395,106	B2	7/2008	Ryu et al.
7,396,330	B2	7/2008	Banet
7,404,968	B2	7/2008	Abrams et al.
7,413,544	B2	8/2008	Kerr
7,414,534	B1	8/2008	Kroll et al.
7,415,242	B1	8/2008	Ngan
7,424,268	B2	9/2008	Diener
7,424,319	B2	9/2008	Muehlsteff
7,427,266	B2	9/2008	Ayer et al.
7,471,665	B2	12/2008	Perlman
7,499,674	B2	3/2009	Salokannel
7,502,643	B2	3/2009	Farringdon et al.
7,505,795	B1	3/2009	Lim et al.
7,510,121	B2	3/2009	Koenck
7,512,448	B2	3/2009	Malick
7,515,043	B2	4/2009	Welch
7,523,756	B2	4/2009	Minai
7,525,426	B2	4/2009	Edelstein
7,539,533	B2	5/2009	Tran
7,542,878	B2	6/2009	Nanikashvili
7,551,590	B2	6/2009	Haller
7,554,452	B2	6/2009	Cole
7,575,005	B2	8/2009	Mumford
7,599,003	B2	10/2009	Suzuki et al.
7,616,111	B2	11/2009	Covannon
7,616,710	B2	11/2009	Kim et al.
7,617,001	B2	11/2009	Penner et al.
7,626,387	B2	12/2009	Adachi
7,640,802	B2	1/2010	King et al.
7,647,112	B2	1/2010	Tracey
7,647,185	B2	1/2010	Tarassenko et al.
7,653,031	B2	1/2010	Godfrey et al.
7,668,437	B1	2/2010	Yamada et al.
7,672,703	B2	3/2010	Yeo et al.
7,672,714	B2	3/2010	Kuo
7,673,679	B2	3/2010	Harrison et al.
7,678,043	B2	3/2010	Gilad
7,688,204	B2	3/2010	Yamanaka et al.
7,689,437	B1	3/2010	Teller et al.
7,697,994	B2	4/2010	VanDanacker et al.
7,720,036	B2	5/2010	Sadri
7,729,776	B2	6/2010	Von Arx et al.
7,733,224	B2	6/2010	Tran
7,736,318	B2	6/2010	Cosentino
7,756,587	B2	7/2010	Penner et al.
7,797,033	B2	9/2010	D'Andrea et al.
7,809,399	B2	10/2010	Lu
7,844,341	B2	11/2010	Von Arx et al.
7,904,133	B2	3/2011	Gehman et al.
D639,437	S	6/2011	Bishay et al.
7,978,064	B2	7/2011	Zdeblick et al.
7,983,189	B2	7/2011	Bugenhagen
8,036,748	B2	10/2011	Zdeblick et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,055,334 B2 11/2011 Savage et al.
8,073,707 B2 12/2011 Teller et al.
8,083,128 B2 12/2011 Dembo et al.
8,114,021 B2 2/2012 Robertson et al.
8,123,576 B2 2/2012 Kim
8,140,143 B2 3/2012 Picard et al.
8,170,515 B2 5/2012 Le Reverend et al.
8,180,425 B2 5/2012 Selvitelli et al.
8,184,854 B2 5/2012 Bartsch
8,193,821 B2 6/2012 Mueller
8,200,320 B2 6/2012 Kovacs
8,214,007 B2 7/2012 Baker et al.
8,238,998 B2 8/2012 Park
8,249,686 B2 8/2012 Libbus et al.
8,285,356 B2 10/2012 Bly et al.
8,290,574 B2 10/2012 Feild et al.
8,301,232 B2 10/2012 Albert et al.
8,308,640 B2 11/2012 Baldus et al.
8,315,687 B2 11/2012 Cross et al.
8,332,009 B2 12/2012 McLaughlin et al.
8,360,976 B2 1/2013 Imran
8,369,936 B2 2/2013 Farringdon et al.
8,386,009 B2 2/2013 Lindberg et al.
8,404,275 B2 3/2013 Habboushe
8,440,274 B2 5/2013 Wang
8,471,960 B2 6/2013 Lin et al.
8,514,979 B2 8/2013 Laporte
8,604,974 B2 12/2013 Ganeshan
8,615,290 B2 12/2013 Lin et al.
8,620,402 B2 12/2013 Parker, III et al.
8,754,799 B2 6/2014 Coln et al.
8,773,258 B2 7/2014 Vosch et al.
8,836,513 B2 9/2014 Hafezi et al.
8,858,432 B2 10/2014 Robertson
8,932,221 B2 1/2015 Colliou et al.
8,945,005 B2 2/2015 Hafezi et al.
9,014,779 B2 4/2015 Zdeblick et al.
9,149,577 B2 10/2015 Robertson et al.
2001/0027331 A1 10/2001 Thompson
2001/0031071 A1 10/2001 Nichols et al.
2001/0044588 A1 11/2001 Mault
2001/0051766 A1 12/2001 Gazdzinski
2001/0056262 A1 12/2001 Cabiri et al.
2002/0002326 A1 1/2002 Causey et al.
2002/0026111 A1 2/2002 Ackerman
2002/0040278 A1 4/2002 Anuzis et al.
2002/0077620 A1 6/2002 Sweeney et al.
2002/0132226 A1 9/2002 Nair
2002/0192159 A1 12/2002 Reitberg
2002/0193669 A1 12/2002 Glukhovsky
2002/0198470 A1 12/2002 Imran et al.
2003/0017826 A1 1/2003 Fishman
2003/0023150 A1 1/2003 Yokoi et al.
2003/0028226 A1 2/2003 Thompson
2003/0065536 A1 4/2003 Hansen
2003/0076179 A1 4/2003 Branch et al.
2003/0083559 A1 5/2003 Thompson
2003/0126593 A1 7/2003 Mault
2003/0130714 A1 7/2003 Nielsen et al.
2003/0135128 A1 7/2003 Suffin et al.
2003/0135392 A1 7/2003 Vrijens et al.
2003/0152622 A1 8/2003 Louie-Helm et al.
2003/0158466 A1 8/2003 Lynn et al.
2003/0158756 A1 8/2003 Abramson
2003/0162556 A1 8/2003 Libes
2003/0164401 A1 9/2003 Andreasson et al.
2003/0167000 A1 9/2003 Mullick et al.
2003/0171791 A1 9/2003 KenKnight
2003/0171898 A1 9/2003 Tarassenko et al.
2003/0181788 A1 9/2003 Yokoi et al.
2003/0181815 A1 9/2003 Ebner et al.
2003/0185286 A1 10/2003 Yuen
2003/0187337 A1 10/2003 Tarassenko et al.
2003/0187338 A1 10/2003 Say et al.
2003/0195403 A1 10/2003 Berner et al.
2003/0213495 A1 11/2003 Fujita et al.
2003/0214579 A1 11/2003 Iddan
2003/0216622 A1 11/2003 Meron et al.
2003/0216625 A1 11/2003 Phipps
2003/0216666 A1 11/2003 Ericson et al.
2003/0216729 A1 11/2003 Marchitto
2003/0229382 A1 12/2003 Sun et al.
2004/0008123 A1 1/2004 Carrender et al.
2004/0018476 A1 1/2004 LaDue
2004/0019172 A1 1/2004 Yang et al.
2004/0034295 A1 2/2004 Salganicoff
2004/0049245 A1 3/2004 Gass
2004/0073095 A1 4/2004 Causey et al.
2004/0073454 A1 4/2004 Urquhart et al.
2004/0077995 A1 4/2004 Ferek-Petric
2004/0082982 A1 4/2004 Gord et al.
2004/0087839 A1 5/2004 Raymond et al.
2004/0092801 A1 5/2004 Drakulic
2004/0106859 A1 6/2004 Say et al.
2004/0115507 A1 6/2004 Potter et al.
2004/0115517 A1 6/2004 Fukuda et al.
2004/0121015 A1 6/2004 Chidlaw et al.
2004/0122297 A1 6/2004 Stahmann et al.
2004/0148140 A1 7/2004 Tarassenko et al.
2004/0153007 A1 8/2004 Harris
2004/0167226 A1 8/2004 Serafini
2004/0167801 A1 8/2004 Say et al.
2004/0193020 A1 9/2004 Chiba
2004/0193029 A1 9/2004 Glukhovsky
2004/0193446 A1 9/2004 Mayer et al.
2004/0199222 A1 10/2004 Sun et al.
2004/0215084 A1 10/2004 Shimizu et al.
2004/0218683 A1 11/2004 Batra
2004/0220643 A1 11/2004 Schmidt
2004/0224644 A1 11/2004 Wu
2004/0225199 A1 11/2004 Evanyk
2004/0253304 A1 12/2004 Gross et al.
2004/0260154 A1 12/2004 Sidelnik
2005/0017841 A1 1/2005 Doi
2005/0020887 A1 1/2005 Goldberg
2005/0021103 A1 1/2005 DiLorenzo
2005/0021370 A1 1/2005 Riff
2005/0024198 A1 2/2005 Ward
2005/0027205 A1 2/2005 Tarassenko et al.
2005/0038321 A1 2/2005 Fujita et al.
2005/0043634 A1 2/2005 Yokoi et al.
2005/0055014 A1 3/2005 Coppeta et al.
2005/0062644 A1 3/2005 Leci
2005/0065407 A1 3/2005 Nakamura et al.
2005/0070778 A1 3/2005 Lackey
2005/0092108 A1 5/2005 Andermo
2005/0096514 A1 5/2005 Starkebaum
2005/0096562 A1 5/2005 Delalic et al.
2005/0101843 A1 5/2005 Quinn
2005/0101872 A1 5/2005 Sattler
2005/0115561 A1 6/2005 Stahmann et al.
2005/0116820 A1 6/2005 Goldreich
2005/0117389 A1 6/2005 Worledge
2005/0121322 A1 6/2005 Say et al.
2005/0131281 A1 6/2005 Ayer et al.
2005/0137480 A1 6/2005 Alt et al.
2005/0143623 A1 6/2005 Kojima
2005/0148883 A1 7/2005 Boesen
2005/0154428 A1 7/2005 Bruinsma
2005/0165323 A1 7/2005 Montgomery
2005/0177069 A1 8/2005 Takizawa
2005/0182389 A1 8/2005 LaPorte
2005/0187789 A1 8/2005 Hatlestad et al.
2005/0192489 A1 9/2005 Marshall
2005/0197680 A1 9/2005 DelMain et al.
2005/0228268 A1 10/2005 Cole
2005/0234307 A1 10/2005 Heinonen
2005/0240305 A1 10/2005 Bogash et al.
2005/0245794 A1 11/2005 Dinsmoor
2005/0259768 A1 11/2005 Yang et al.
2005/0261559 A1 11/2005 Mumford
2005/0267556 A1 12/2005 Shuros et al.
2005/0267756 A1 12/2005 Schultz et al.
2005/0277912 A1 12/2005 John

(56) **References Cited**

U.S. PATENT DOCUMENTS

2005/0277999 A1 12/2005 Strother et al.
2005/0285746 A1 12/2005 Sengupta
2005/0288594 A1 12/2005 Lewkowicz et al.
2006/0001496 A1 1/2006 Abrosimov et al.
2006/0036134 A1 2/2006 Tarassenko et al.
2006/0061472 A1 3/2006 Lovoi et al.
2006/0065713 A1 3/2006 Kingery
2006/0074283 A1 4/2006 Henderson
2006/0078765 A1 4/2006 Yang et al.
2006/0095091 A1 5/2006 Drew
2006/0095093 A1 5/2006 Bettesh et al.
2006/0100533 A1 5/2006 Han
2006/0109058 A1 5/2006 Keating
2006/0110962 A1 5/2006 Powell
2006/0122474 A1 6/2006 Teller et al.
2006/0122667 A1 6/2006 Chavan et al.
2006/0136266 A1 6/2006 Tarassenko et al.
2006/0136744 A1 6/2006 Lange
2006/0142648 A1 6/2006 Banet
2006/0145876 A1 7/2006 Kimura
2006/0148254 A1 7/2006 McLean
2006/0149339 A1 7/2006 Burnes
2006/0155174 A1 7/2006 Glukhovsky et al.
2006/0155183 A1 7/2006 Kroecker
2006/0158820 A1 7/2006 Takiguchi
2006/0161225 A1 7/2006 Sormann et al.
2006/0179949 A1 8/2006 Kim
2006/0183993 A1 8/2006 Horn
2006/0184092 A1 8/2006 Atanasoska et al.
2006/0204738 A1 9/2006 Dubrow et al.
2006/0210626 A1 9/2006 Spaeder
2006/0216603 A1 9/2006 Choi
2006/0218011 A1 9/2006 Walker
2006/0235489 A1 10/2006 Drew
2006/0243288 A1 11/2006 Kim et al.
2006/0247505 A1 11/2006 Siddiqui
2006/0253005 A1 11/2006 Drinan
2006/0255064 A1 11/2006 Donaldson
2006/0265246 A1 11/2006 Hoag
2006/0270346 A1 11/2006 Ibrahim
2006/0277097 A1 12/2006 Shafron et al.
2006/0280227 A1 12/2006 Pinkney
2006/0282001 A1 12/2006 Noel
2006/0289640 A1 12/2006 Mercure
2006/0293607 A1 12/2006 Alt
2007/0002038 A1 1/2007 Suzuki
2007/0006636 A1 1/2007 King et al.
2007/0008113 A1 1/2007 Spoonhower et al.
2007/0016089 A1 1/2007 Fischell et al.
2007/0027386 A1 2/2007 Such
2007/0027388 A1 2/2007 Chou
2007/0038054 A1 2/2007 Zhou
2007/0049339 A1 3/2007 Barak et al.
2007/0055098 A1 3/2007 Shimizu et al.
2007/0060797 A1 3/2007 Ball
2007/0073353 A1 3/2007 Rooney et al.
2007/0096765 A1 5/2007 Kagan
2007/0106346 A1 5/2007 Bergelson
2007/0123772 A1 5/2007 Euliano
2007/0129622 A1 6/2007 Bourget
2007/0130287 A1 6/2007 Kumar
2007/0135803 A1 6/2007 Belson
2007/0142721 A1 6/2007 Berner et al.
2007/0156016 A1 7/2007 Betesh
2007/0162089 A1 7/2007 Mosesov
2007/0162090 A1 7/2007 Penner
2007/0167495 A1 7/2007 Brown et al.
2007/0167848 A1 7/2007 Kuo et al.
2007/0173701 A1 7/2007 Al-Ali
2007/0179347 A1 8/2007 Tarassenko et al.
2007/0180047 A1 8/2007 Dong et al.
2007/0185393 A1 8/2007 Zhou
2007/0191002 A1 8/2007 Ge
2007/0196456 A1 8/2007 Stevens
2007/0207793 A1 9/2007 Myer
2007/0213659 A1 9/2007 Trovato et al.
2007/0237719 A1 10/2007 Jones
2007/0244370 A1 10/2007 Kuo et al.
2007/0249946 A1 10/2007 Kumar et al.
2007/0255198 A1 11/2007 Leong et al.
2007/0255330 A1 11/2007 Lee
2007/0270672 A1 11/2007 Hayter
2007/0279217 A1 12/2007 Venkatraman
2007/0282174 A1 12/2007 Sabatino
2007/0282177 A1 12/2007 Pilz
2007/0291715 A1 12/2007 Laroia et al.
2007/0299480 A1 12/2007 Hill
2008/0014866 A1 1/2008 Lipowski
2008/0015421 A1 1/2008 Penner
2008/0015494 A1 1/2008 Santini et al.
2008/0020037 A1 1/2008 Robertson et al.
2008/0021519 A1 1/2008 DeGeest
2008/0021521 A1 1/2008 Shah
2008/0027679 A1 1/2008 Shklarski
2008/0033273 A1 2/2008 Zhou
2008/0045843 A1 2/2008 Tsuji et al.
2008/0046038 A1 2/2008 Hill
2008/0051667 A1 2/2008 Goldreich
2008/0051767 A1 2/2008 Rossing et al.
2008/0058614 A1 3/2008 Banet
2008/0062856 A1 3/2008 Feher
2008/0065168 A1 3/2008 Bitton et al.
2008/0074307 A1 3/2008 Boric-Lubecke
2008/0077015 A1 3/2008 Boric-Lubecke
2008/0077028 A1 3/2008 Schaldach et al.
2008/0077188 A1 3/2008 Denker et al.
2008/0091089 A1 4/2008 Guillory et al.
2008/0091114 A1 4/2008 Min
2008/0097549 A1 4/2008 Colbaugh
2008/0097917 A1 4/2008 Dicks
2008/0099366 A1 5/2008 Niemiec et al.
2008/0103440 A1 5/2008 Ferren et al.
2008/0112885 A1 5/2008 Okunev et al.
2008/0114224 A1 5/2008 Bandy et al.
2008/0119705 A1 5/2008 Patel
2008/0119716 A1 5/2008 Boric-Lubecke
2008/0137566 A1 6/2008 Marholev
2008/0139907 A1 6/2008 Rao et al.
2008/0140403 A1 6/2008 Hughes et al.
2008/0146871 A1 6/2008 Arneson et al.
2008/0146889 A1 6/2008 Young
2008/0146892 A1 6/2008 LeBeouf
2008/0154104 A1 6/2008 Lamego
2008/0166992 A1 7/2008 Ricordi
2008/0183245 A1 7/2008 Van Oort
2008/0188837 A1 8/2008 Belsky et al.
2008/0194912 A1 8/2008 Trovato et al.
2008/0208009 A1 8/2008 Shklarski
2008/0214901 A1 9/2008 Gehman
2008/0214985 A1 9/2008 Yanaki
2008/0243020 A1 10/2008 Chou
2008/0249360 A1 10/2008 Li
2008/0262320 A1 10/2008 Schaefer et al.
2008/0262336 A1 10/2008 Ryu
2008/0269664 A1 10/2008 Trovato et al.
2008/0275312 A1 11/2008 Mosesov
2008/0284599 A1 11/2008 Zdeblick et al.
2008/0288026 A1 11/2008 Cross et al.
2008/0288027 A1 11/2008 Kroll
2008/0294020 A1 11/2008 Sapounas
2008/0300572 A1 12/2008 Rankers
2008/0303638 A1 12/2008 Nguyen
2008/0306357 A1 12/2008 Korman
2008/0306359 A1 12/2008 Zdeblick et al.
2008/0306360 A1 12/2008 Robertson et al.
2008/0306362 A1 12/2008 Davis
2008/0311852 A1 12/2008 Hansen
2008/0312522 A1 12/2008 Rowlandson
2008/0316020 A1 12/2008 Robertson
2009/0009332 A1 1/2009 Nunez et al.
2009/0024045 A1 1/2009 Prakash
2009/0030293 A1 1/2009 Cooper et al.
2009/0030297 A1 1/2009 Miller
2009/0034209 A1 2/2009 Joo

(56) **References Cited**

U.S. PATENT DOCUMENTS

2009/0043171	A1	2/2009	Rule
2009/0048498	A1	2/2009	Riskey
2009/0062634	A1	3/2009	Say et al.
2009/0062670	A1	3/2009	Sterling
2009/0069642	A1	3/2009	Gao
2009/0069655	A1	3/2009	Say et al.
2009/0069656	A1	3/2009	Say et al.
2009/0069657	A1	3/2009	Say et al.
2009/0069658	A1	3/2009	Say et al.
2009/0069724	A1	3/2009	Otto et al.
2009/0076340	A1	3/2009	Libbus et al.
2009/0076343	A1	3/2009	James
2009/0076350	A1	3/2009	Bly et al.
2009/0076397	A1	3/2009	Libbus et al.
2009/0082645	A1	3/2009	Hafezi et al.
2009/0088618	A1	4/2009	Ameson
2009/0099435	A1	4/2009	Say et al.
2009/0110148	A1	4/2009	Zhang
2009/0112626	A1	4/2009	Talbot
2009/0124871	A1	5/2009	Arshak
2009/0131774	A1	5/2009	Sweitzer
2009/0135886	A1	5/2009	Robertson et al.
2009/0157113	A1	6/2009	Marcotte
2009/0157358	A1	6/2009	Kim
2009/0161602	A1	6/2009	Matsumoto
2009/0163789	A1	6/2009	Say et al.
2009/0171180	A1	7/2009	Pering
2009/0173628	A1	7/2009	Say et al.
2009/0177055	A1	7/2009	Say et al.
2009/0177056	A1	7/2009	Say et al.
2009/0177057	A1	7/2009	Say et al.
2009/0177058	A1	7/2009	Say et al.
2009/0177059	A1	7/2009	Say et al.
2009/0177060	A1	7/2009	Say et al.
2009/0177061	A1	7/2009	Say et al.
2009/0177062	A1	7/2009	Say et al.
2009/0177063	A1	7/2009	Say et al.
2009/0177064	A1	7/2009	Say et al.
2009/0177065	A1	7/2009	Say et al.
2009/0177066	A1	7/2009	Say et al.
2009/0182206	A1	7/2009	Najafi
2009/0182212	A1	7/2009	Say et al.
2009/0182213	A1	7/2009	Say et al.
2009/0182214	A1	7/2009	Say et al.
2009/0182215	A1	7/2009	Say et al.
2009/0182388	A1	7/2009	Von Arx
2009/0187088	A1	7/2009	Say et al.
2009/0187089	A1	7/2009	Say et al.
2009/0187090	A1	7/2009	Say et al.
2009/0187091	A1	7/2009	Say et al.
2009/0187092	A1	7/2009	Say et al.
2009/0187093	A1	7/2009	Say et al.
2009/0187094	A1	7/2009	Say et al.
2009/0187095	A1	7/2009	Say et al.
2009/0187381	A1	7/2009	King et al.
2009/0192351	A1	7/2009	Nishino
2009/0192368	A1	7/2009	Say et al.
2009/0192369	A1	7/2009	Say et al.
2009/0192370	A1	7/2009	Say et al.
2009/0192371	A1	7/2009	Say et al.
2009/0192372	A1	7/2009	Say et al.
2009/0192373	A1	7/2009	Say et al.
2009/0192374	A1	7/2009	Say et al.
2009/0192375	A1	7/2009	Say et al.
2009/0192376	A1	7/2009	Say et al.
2009/0192377	A1	7/2009	Say et al.
2009/0192378	A1	7/2009	Say et al.
2009/0192379	A1	7/2009	Say et al.
2009/0198115	A1	8/2009	Say et al.
2009/0198116	A1	8/2009	Say et al.
2009/0198175	A1	8/2009	Say et al.
2009/0203964	A1	8/2009	Shimizu et al.
2009/0203971	A1	8/2009	Sciarappa
2009/0203972	A1	8/2009	Heneghan
2009/0203978	A1	8/2009	Say et al.
2009/0204265	A1	8/2009	Hackett
2009/0210164	A1	8/2009	Say et al.
2009/0216101	A1	8/2009	Say et al.
2009/0216102	A1	8/2009	Say et al.
2009/0227204	A1	9/2009	Robertson et al.
2009/0227876	A1	9/2009	Tran
2009/0227940	A1	9/2009	Say et al.
2009/0227941	A1	9/2009	Say et al.
2009/0228214	A1	9/2009	Say et al.
2009/0231125	A1	9/2009	Baldus
2009/0234200	A1	9/2009	Husheer
2009/0243833	A1	10/2009	Huang
2009/0253960	A1	10/2009	Takenaka et al.
2009/0256702	A1	10/2009	Robertson
2009/0264714	A1	10/2009	Chou
2009/0264964	A1	10/2009	Abrahamson
2009/0265186	A1	10/2009	Tarassenko et al.
2009/0273467	A1	11/2009	Elixmann
2009/0281539	A1	11/2009	Selig
2009/0292194	A1	11/2009	Libbus et al.
2009/0295548	A1	12/2009	Ronkka
2009/0296677	A1	12/2009	Mahany
2009/0301925	A1	12/2009	Alloro et al.
2009/0303920	A1	12/2009	Mahany
2009/0312619	A1	12/2009	Say et al.
2009/0318761	A1	12/2009	Rabinovitz
2009/0318779	A1	12/2009	Tran
2009/0318783	A1	12/2009	Rohde
2009/0318793	A1	12/2009	Datta
2010/0010330	A1	1/2010	Rankers
2010/0033324	A1	2/2010	Shimizu et al.
2010/0049006	A1	2/2010	Magar
2010/0049012	A1	2/2010	Dijksman et al.
2010/0049069	A1	2/2010	Tarassenko et al.
2010/0049263	A1	2/2010	Reeve
2010/0056878	A1	3/2010	Partin
2010/0056891	A1	3/2010	Say et al.
2010/0056939	A1	3/2010	Tarassenko et al.
2010/0057041	A1	3/2010	Hayter
2010/0062709	A1	3/2010	Kato
2010/0063438	A1	3/2010	Bengtsson
2010/0063841	A1	3/2010	D'Ambrosia et al.
2010/0069002	A1	3/2010	Rong
2010/0069717	A1	3/2010	Hafezi et al.
2010/0099967	A1	4/2010	Say et al.
2010/0099968	A1	4/2010	Say et al.
2010/0099969	A1	4/2010	Say et al.
2010/0100077	A1	4/2010	Rush
2010/0100078	A1	4/2010	Say et al.
2010/0106001	A1	4/2010	Say et al.
2010/0118853	A1	5/2010	Godfrey
2010/0139672	A1	6/2010	Kroll et al.
2010/0160742	A1	6/2010	Seidl et al.
2010/0168659	A1	7/2010	Say et al.
2010/0179398	A1	7/2010	Say et al.
2010/0191073	A1	7/2010	Tarassenko et al.
2010/0210299	A1	8/2010	Gorbachov
2010/0222652	A1	9/2010	Cho
2010/0228113	A1	9/2010	Solosko
2010/0234706	A1	9/2010	Gilland
2010/0234715	A1	9/2010	Shin
2010/0234914	A1	9/2010	Shen
2010/0245091	A1	9/2010	Singh
2010/0249881	A1	9/2010	Corndorf
2010/0256461	A1	10/2010	Mohamedali
2010/0259543	A1	10/2010	Tarassenko et al.
2010/0268048	A1	10/2010	Say et al.
2010/0268049	A1	10/2010	Say et al.
2010/0268050	A1	10/2010	Say et al.
2010/0274111	A1	10/2010	Say et al.
2010/0280345	A1	11/2010	Say et al.
2010/0280346	A1	11/2010	Say et al.
2010/0298650	A1	11/2010	Moon et al.
2010/0298730	A1	11/2010	Tarassenko et al.
2010/0311482	A1	12/2010	Lange
2010/0312580	A1	12/2010	Tarassenko et al.
2011/0004079	A1	1/2011	Al Ali et al.
2011/0065983	A1	3/2011	Hafezi et al.
2011/0081860	A1	4/2011	Brown et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2011/0124983	A1	5/2011	Kroll et al.
2011/0144470	A1	6/2011	Mazar et al.
2011/0166937	A1	7/2011	Bangera et al.
2011/0237924	A1	9/2011	McGusty et al.
2011/0279963	A1	11/2011	Kumar et al.
2012/0016231	A1	1/2012	Westmoreland
2012/0029307	A1	2/2012	Paquet et al.
2012/0029309	A1	2/2012	Paquet et al.
2012/0071743	A1	3/2012	Todorov et al.
2012/0083715	A1	4/2012	Yuen et al.
2012/0089000	A1	4/2012	Bishay et al.
2012/0101396	A1	4/2012	Solosko et al.
2012/0197144	A1	8/2012	Christ et al.
2012/0299723	A1	11/2012	Hafezi et al.
2012/0310070	A1	12/2012	Kumar et al.
2012/0316413	A1	12/2012	Liu et al.
2013/0030259	A1	1/2013	Thomsen et al.
2013/0057385	A1	3/2013	Murakami et al.
2013/0060115	A1	3/2013	Gehman et al.
2014/0300490	A1	10/2014	Kotz et al.
2015/0080677	A1	3/2015	Thompson et al.
2015/0080678	A1	3/2015	Frank et al.
2015/0080679	A1	3/2015	Frank et al.
2015/0080680	A1	3/2015	Zdeblick et al.
2015/0080681	A1	3/2015	Hafezi et al.
2015/0127737	A1	5/2015	Thompson et al.
2015/0127738	A1	5/2015	Thompson et al.
2015/0131764	A1	5/2015	Kushner et al.
2015/0182170	A1	7/2015	Zdeblick et al.
2015/0248833	A1	9/2015	Arne et al.

FOREIGN PATENT DOCUMENTS

CN	101005470	7/2007
CN	101032396	9/2007
CN	201076456	6/2008
DE	10313005	10/2004
EP	1246356	10/2002
EP	1789128	5/2007
EP	2063535	5/2009
EP	2143369	1/2010
JP	61072712	4/1986
JP	S62112529	5/1987
JP	05228128	9/1993
JP	1014898	1/1998
JP	2000506410	5/2000
JP	2002224053	8/2002
JP	2002282219	10/2002
JP	2002291684	10/2002
JP	2003050867	2/2003
JP	2004007187	1/2004
JP	2004313242	11/2004
JP	2005073886	3/2005
JP	2005304880	4/2005
JP	2005137683	6/2005
JP	2005532841	11/2005
JP	2005532849	11/2005
JP	2006508752	3/2006
JP	2006509574	3/2006
JP	2006177699	7/2006
JP	2007-313340	12/2007
JP	2008011865	1/2008
JP	2008501415	1/2008
JP	2008086390	4/2008
JP	2008191110	8/2008
JP	2009528909	8/2009
KR	927471	11/2009
KR	10-2012-09995	9/2012
TW	553735	9/2003
TW	200724094	7/2007
WO	WO8802237	4/1988
WO	WO9308734	5/1993
WO	WO9319667	10/1993
WO	WO9714112	4/1997
WO	WO9843537	10/1998
WO	WO9959465	11/1999
WO	WO0033246	6/2000
WO	WO0100085	1/2001
WO	WO0147466	7/2001
WO	WO0174011	10/2001
WO	WO0180731	11/2001
WO	WO0245489	6/2002
WO	WO02058330	7/2002
WO	WO02062276	8/2002
WO	WO02087681	11/2002
WO	WO03050643	6/2003
WO	WO2004014225	2/2004
WO	WO2004039256	5/2004
WO	WO2004059551	7/2004
WO	WO2004066834	8/2004
WO	WO2004068748	8/2004
WO	WO2004068881	8/2004
WO	WO2004075751	9/2004
WO	WO2004109316	12/2004
WO	WO2005011237	2/2005
WO	WO2005013503	2/2005
WO	WO2005020023	3/2005
WO	WO2005024687	3/2005
WO	WO2005041767	5/2005
WO	WO2005047837	5/2005
WO	WO2005051166	6/2005
WO	WO2005055448	6/2005
WO	WO2005082436	9/2005
WO	WO2005110238	11/2005
WO	WO2006027586	3/2006
WO	WO2006035351	4/2006
WO	WO2006046648	5/2006
WO	WO2006055892	5/2006
WO	WO2006055956	5/2006
WO	WO2006066566	6/2006
WO	WO2006075016	7/2006
WO	WO2006100620	9/2006
WO	WO2006104843	10/2006
WO	WO2006109072	10/2006
WO	WO2006116718	11/2006
WO	WO2006119345	11/2006
WO	WO2006127355	11/2006
WO	WO2007001724	1/2007
WO	WO2007001742	1/2007
WO	WO2007013952	2/2007
WO	WO2007014084	2/2007
WO	WO2007014527	2/2007
WO	WO2007021496	2/2007
WO	WO2007027660	3/2007
WO	WO2007028035	3/2007
WO	WO2007036687	4/2007
WO	WO2007036741	4/2007
WO	WO2007036746	4/2007
WO	WO2007040878	4/2007
WO	WO2007071180	6/2007
WO	WO2007096810	8/2007
WO	WO2007101141	9/2007
WO	WO2007120946	10/2007
WO	WO2007127316	11/2007
WO	WO2007127455	11/2007
WO	WO2007127879	11/2007
WO	WO2007128165	11/2007
WO	WO2007130491	11/2007
WO	WO2007143535	12/2007
WO	WO2007149546	12/2007
WO	WO2008002239	1/2008
WO	WO2008008281	1/2008
WO	WO2008030482	3/2008
WO	WO2008052136	5/2008
WO	WO2008063626	5/2008
WO	WO2008066617	6/2008
WO	WO2008076464	6/2008
WO	WO2008089232	7/2008
WO	WO2008091683	7/2008
WO	WO2008095183	8/2008
WO	WO2008097652	8/2008
WO	WO2008101107	8/2008
WO	WO2008112577	9/2008

(56) **References Cited**

FOREIGN PATENT DOCUMENTS

WO	WO2008112578	9/2008
WO	WO2008120156	10/2008
WO	WO2008133394	11/2008
WO	WO2008134185	11/2008
WO	WO2008150633	12/2008
WO	WO2009001108	12/2008
WO	WO2009006615	1/2009
WO	WO2009029453	3/2009
WO	WO2009031149	3/2009
WO	WO2009036334	3/2009
WO	WO2009051829	4/2009
WO	WO2009051830	4/2009
WO	WO2009063377	5/2009
WO	WO2009081348	7/2009
WO	WO2009111664	9/2009
WO	WO2009146082	12/2009
WO	WO2010009100	1/2010
WO	WO2010011833	1/2010
WO	WO2010019778	2/2010
WO	WO2010057049	5/2010
WO	WO2010075115	7/2010
WO	WO2010080843	7/2010
WO	WO2010107563	9/2010
WO	WO2010115194	10/2010
WO	WO2010132331	11/2010
WO	WO2010135516	11/2010
WO	WO2012104657	8/2012
WO	WO2012158190	11/2012
WO	WO2013012869	1/2013
WO	WO2015042411	3/2015
WO	WO2015044722	4/2015
WO	WO2015112603	7/2015

OTHER PUBLICATIONS

AADE, "AADE 37th Annual Meeting San Antonio Aug. 4-7, 2010" American Association of Diabetes Educators (2010); http://www.diabeteseducator.org/annualmeeting/2010/index.html; 2 pp.

Arshak et al., A Review and Adaptation of Methods of Object Tracking to Telemetry Capsules IC-Med (2007) vol. 1, No. 1, Issue 1, 12 pp.

"ASGE Technology Status Evaluation Report: wireless capsule endoscopy" American Soc. For Gastrointestinal Endoscopy (2006) vol. 63, No. 4; 7 pp.

Aydin et al., "Design and implementation considerations for an advanced wireless interface in miniaturized integrated sensor Microsystems" Sch. of Eng. & Electron., Edinburgh Univ., UK; (2003); abstract.

Barrie, Heidelberg pH capsule gastric analysis. Texbook of Natural Medicine, (1992), Pizzorno, Murray & Barrie.

Baskiyar, S. "A Real-time Fault Tolerant Intra-body Network" Dept. of Comp. Sci & Soft Eng; Auburn University; Proceedings of the 27th Annual IEEE Conference; 0742-1303/02 (2002) IEEE; 6 pp.

Brock, "Smart Medicine: The Application of Auto-ID Technology to Healthcare" Auto-ID Labs (2002) http://www.autoidlabs.org/uploads/media/MIT-AUTOID-WH-010.pdf.

Carlson et al., "Evaluation of a non-invasive respiratory monitoring system for sleeping subjects" Physiological Measurement (1999) 20(1): 53.

Delvaux et al., "Capsule endoscopy: Technique and indications" Clinical Gastoenterology (2008) vol. 22, Issue 5, pp. 813-837.

Description of ePatch Technology Platform for ECG and EMG, located it http://www.madebydelta.com/imported/images/DELTA_Web/documents/ME/ePatch_ECG_EMG.pdf, Dated Sep. 2, 2010.

Evanczuk, S., "PIC MCU software library uses human body for secure communications link" EDN Network; edn.com; Feb. 26, (2013) Retrieved from internet Jun. 19, 2013 at http://www.edn.com/electronics-products/other/4407842/PIC-MCU-software-library-uses-human-body-for-secure-communications-link; 5 pp.

Fawaz et al., "Enhanced Telemetry System using CP-QPSK Band-Pass Modulation Technique Suitable for Smart Pill Medical Application" IFIP IEEE Dubai Conference (2008); http://www.asic.fh-offenburg.de/downloads/ePille/IFIP_IEEE_Dubai_Conference.pdf.

Gilson, D.R. "Molecular dynamics simulation of dipole interactions", Department of Physics, Hull University, Dec. (2002), p. 1-43.

Given Imaging, "Agile Patency Brochure" (2006) http://www.inclino.no/documents/AgilePatencyBrochure_Global_GMB-0118-01.pdf; 4pp.

Gonzalez-Guillaumin et al., "Ingestible capsule for impedance and pH monitoring in the esophagus" IEEE Trans Biomed Eng. (2007) 54(12: 2231-6; abstract.

Greene, "Edible RFID microchip monitor can tell if you take your medicine" Bloomberg Businessweek (2010) 2 pp.; http://www.businessweek.com/idg/2010-03-31/edible-rfid-microchip-monitor-can-tell-if-you-take-your-medicine.html.

Halthion Medical Technologies "Providing Ambulatory Medical Devices Which Monitor, Measure and Record" webpage. Online website: http://www.halthion.com/; downloaded May 30, (2012).

Heydari et al., "Analysis of the PLL jitter due to power/ground and substrate noise"; IEEE Transactions on Circuits and Systems (2004) 51(12): 2404-16.

Hoover et al., "Rx for health: Engineers design pill that signals it has been swallowed" University of Florida News (2010) 2pp.; http://news.ufl.edu/2010/03/31/antenna-pill-2/.

Hotz "The Really Smart Phone" The Wall Street Journal, What They Know (2011); 6 pp.; http://online.wsj.com/article/SB10001424052748704547604576263261679848814.html?mod=djemTECH_t.

Intromedic, MicroCam Innovative Capsule Endoscope Pamphlet. (2006) 8 pp (http://www.intromedic.com/en/product/productinfo.asp).

ISFET—Ion Sensitive Field-Effect Transistor; Microsens S.A. pdf document. First cited by Examiner in Office Action dated Jun. 13 (2011) for U.S. Appl. No. 12/238,345; 4pp.

Jung, S. "Dissolvable 'Transient Electronics' Will Be Good for Your Body and the Environment" MedGadget; Oct. 1 (2012); Onlne website: http://medgadget.com/2012/10/dissolvable-transient-electronics-will-be-good-for-your-body-and-the-environment.html; downloaded Oct. 24, 2012; 4 pp.

Juvenile Diabetes Research Foundation International (JDRF), "Artificial Pancreas Project" (2010); http://www.artificialpancreasproject.com/; 3 pp.

Li, P-Y, et al. "An electrochemical intraocular drug delivery device", Sensors and Actuators A 143 (2008) p. 41-48.

Lifescan, "OneTouch UltraLink™" http://www.lifescan.com/products/meters/ultralink (2010) 2 pp.

Mackay et al., "Radio Telemetering from within the Body" Inside Information is Revealed by Tiny Transmitters that can be Swallowed or Implanted in Man or Animal Science (1991) 1196-1202; 134; American Association for the Advancement of Science, Washington D.C.

Mackay et al., "Endoradiosonde" Nature, (1957) 1239-1240, 179 Nature Publishing Group.

McKenzie et al., "Validation of a new telemetric core temperature monitor" J. Therm. Biol. (2004) 29(7-8):605-11.

Medtronic, "CareLink Therapy Management Software for Diabetes" (2010); https://carelink.minimed.com/patient/entry.jsp?bhcp=1; 1 pp.

Medtronic, "Carelink™ USB" (2008) http://www.medtronicdiabetes.com/pdf/carelink_usb_factsheet.pdf 2pp.

Medtronic "The New MiniMed Paradigm® Real-Time Revel™ System" (2010) http://www.medtronicdiabetes.com/products/index.html; 2 pp.

Medtronic, "MINI MED Paradigm® Revel™ Insulin Pump" (2010) http://www.medtronicdiabetes.com/products/insulinpumps/index.html; 2 pp.

Medtronic, Mini Med Paradigm™ Veo™ System: Factsheet (2010). http://www.medtronic-diabetes.com.au/downloads/Paradigm%20Veo%20Factsheet.pdf ; 4 pp.

Melanson, "Walkers swallow RFID pills for science" Engadget (2008); http://www.engadget.com/2008/07/29/walkers-swallow-rfid-pills-for-science/.

(56) **References Cited**

OTHER PUBLICATIONS

Minimitter Co. Inc. "Actiheart" Traditional 510(k) Summary. Sep. 27, (2005).
Minimitter Co. Inc. Noninvasive technology to help your studies succeed. Mini Mitter.com Mar. 31, (2009).
Mini Mitter Co, Inc. 510(k) Premarket Notification Mini-Logger for Diagnostic Spirometer. Sep. 21, (1999).
Mini Mitter Co, Inc. 510(k) Premarket Notification for VitalSense. Apr. 22, (2004).
Minimitter Co. Inc. VitalSense Integrated Physiological Monitoring System. Product Description. (2005).
Minimitter Co. Inc. VitalSense Wireless Vital Signs Monitoring. Temperatures.com Mar. 31, (2009).
Mojaverian et al., "Estimation of gastric residence time of the Heidelberg capsule in humans: effect of varying food composition" Gastroenterology (1985) 89:(2): 392-7.
"New 'smart pill' to track adherence" E-Health-Insider (2010) http://www.e-health-insider.com/news/5910/new_'smart_pill'_monitors_medicines.
Owano, N., "Study proposes smart sutures with sensors for wounds" PHYS.ORG. Aug. (2012). http://phys.org/news/2012-08-smart-sutures-sensors-wounds.html.
Park, "Medtronic to Buy MiniMed for $3.7 Billion" (2001) HomeCare; http://homecaremag.com/mag/medical_medtronic_buy_minimed/; 2 pp.
Radio Antennae, http://www.erikdeman.de/html/sail018h.htm; (2008) 5 pages.
"RFID "pill" monitors marchers" RFID News (2008) http://www.rfidnews.org/2008/07/23/rfid-pill-monitors-marchers/.
Sanduleanu et al., "Octave tunable, highly linear, RC-ring oscillator with differential fine-coarse tuning, quadrature outputs and amplitude control for fiber optic transceivers" (2002) IEEE MTT-S International Microwave Symposium Digest 545-8.
Santini, J.T. et al, "Microchips as controlled drug delivery-devices", Agnew. Chem. Int. Ed. (2000), vol. 39, p. 2396-2407.
"SensiVida minimally invasive clinical systems" Investor Presentation Oct. (2009) 28pp; http://www.sensividamedtech.com/SensiVidaGeneralOctober09.pdf.
Shawgo, R.S. et al. "BioMEMS from drug delivery", Current Opinion in Solid State and Material Science 6 (2002), p. 329-334.
Shrivas et al., "A New Platform for Bioelectronics-Electronic Pill", Cummins College, (2010).; http://www.cumminscollege.org/downloads/electronics_and_telecommunication/Newsletters/Current%20Newsletters.pdf; First cited in third party client search conducted by Patent Eagle Search May 18, 2010 (2010).
"Smartlife awarded patent for knitted transducer" INNOVATION IN TEXTILES NEWS: http://www.innovationintextiles.com/articles/208.php; 2pp. (2009).
"The SmartPill Wireless Motility Capsule" SMARTPILL, The Measure of GI Health; (2010) http://www.smartpillcorp.com/index.cfm?pagepath=Products/The_SmartPill_Capsule&id=17814.
Solanas et al., "RFID Technology for the Health Care Sector" Recent Patents on Electrical Engineering (2008) 1, 22-31.
Soper, S.A. et al. "Bio-Mems Technologies and Applications", Chapter 12, "MEMS for Drug Delivery", p. 325-346 (2007).
Swedberg, "University Team Sees Ingestible RFID Tag as a Boon to Clinical Trials" RFID Journal Apr. 27, (2010); http://www.rfidjournal.com/article/view/7560/1.
Tajalli et al., "Improving the power-delay performance in subthreshold source-coupled logic circuits" Integrated Circuit and System Design. Power and Timing Modeling, Optimization and Simulation, Springer Berlin Heidelberg (2008) 21-30.
Tatbul et al., "Confidence-based data management for personal area sensor networks" ACM International Conference Proceeding Series (2004) 72.
Tierney, M.J. et al "Electroreleasing Composite Membranes for Delivery of Insulin and other Biomacromolecules", J. Electrochem. Soc., vol. 137, No. 6, Jun. (1990), p. 2005-2006.
Walkey, "MOSFET Structure and Processing"; 97.398* Physical Electronics Lecture 20.
Whipple, Fred L.; "Endoradiosonde," Nature, Jun. 1957, 1239-1240.
Xiaoming et al., "A telemedicine system for wireless home healthcare based on bluetooth and the internet" Telemedicine Journal and e-health (2004) 10(S2): S110-6.
Yang et al., "Fast-switching frequency synthesizer with a discriminator-aided phase detector" IEEE Journal of Solid-State Circuits (2000) 35(10): 1445-52.
Yao et al., "Low Power Digital Communication in Implantable Devices Using Volume Conduction of Biological Tissues" Proceedings of the 28th IEEE, EMBS Annual International Conference, Aug. 30,-Sep. 3, (2006).
Zimmerman, "Personal Area Networks: Near-field intrabody communication" IBM Systems Journal (1996) 35 (3-4):609-17.
Zworkin, "A Radio Pill" Nature, (1957) 898, 179 Nature Publishing Group.

* cited by examiner

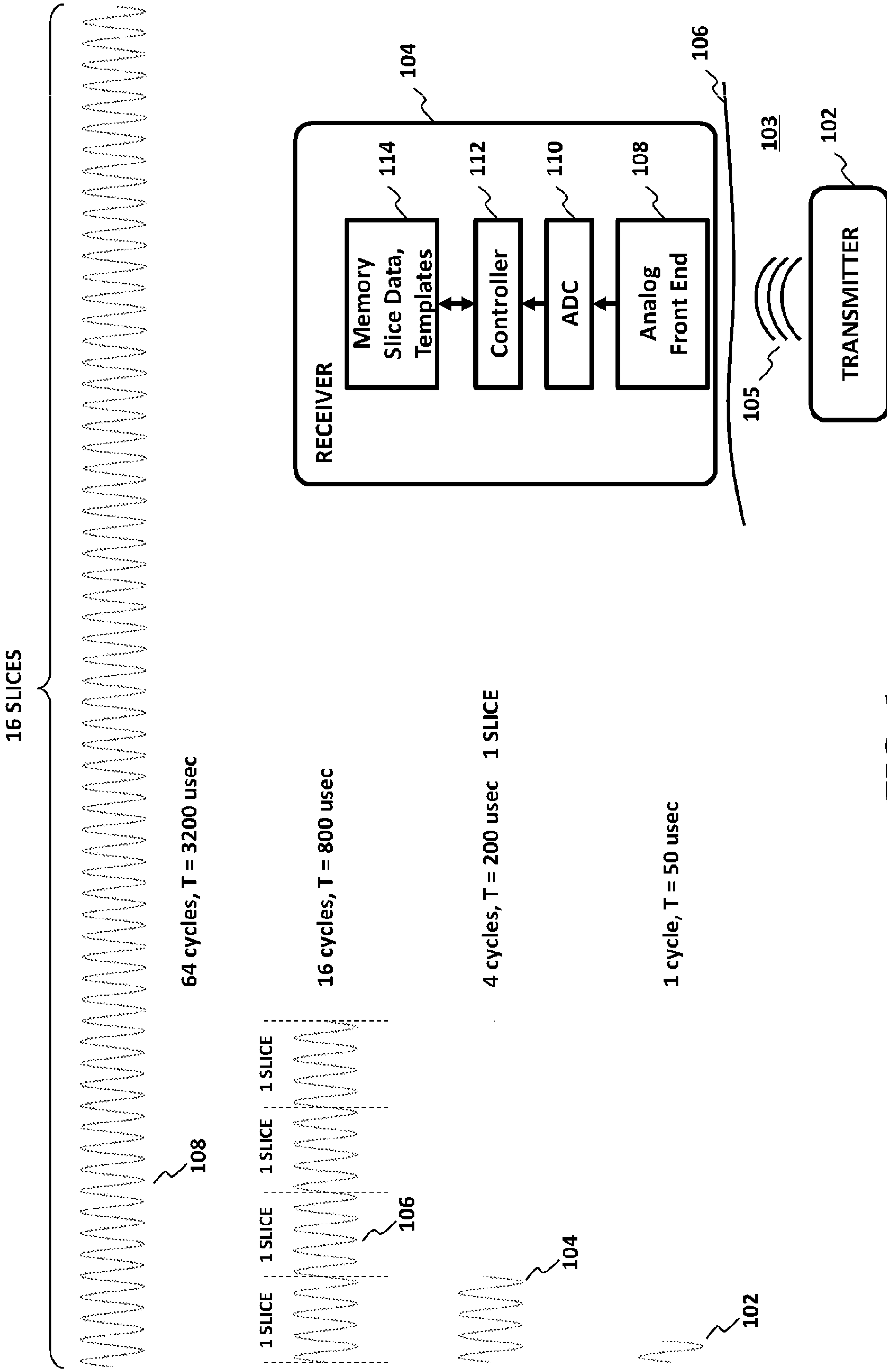
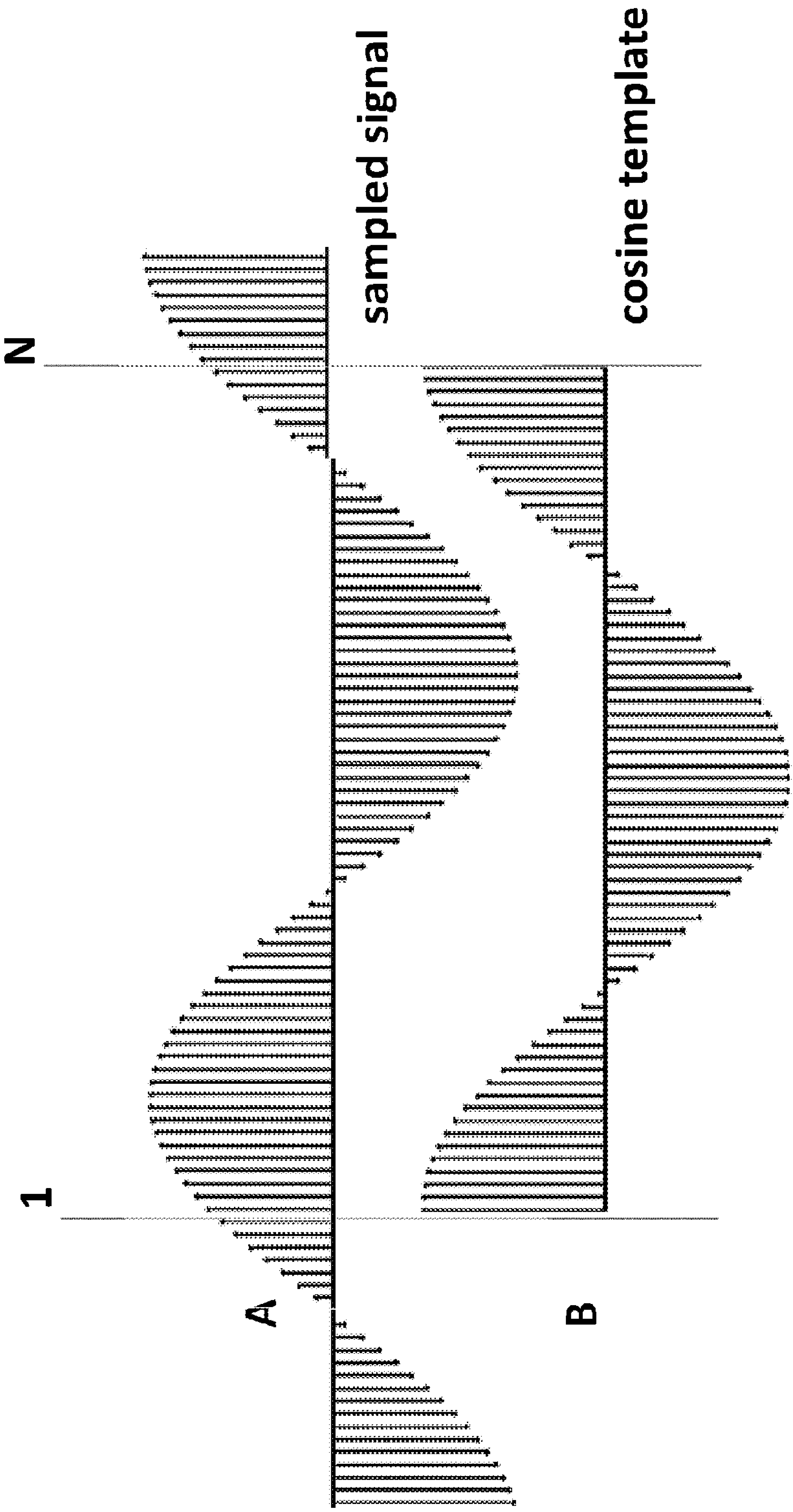

16 SLICES
108
64 cycles, T = 3200 usec
1 SLICE
1 SLICE
1 SLICE
1 SLICE
106
16 cycles, T = 800 usec
104
4 cycles, T = 200 usec 1 SLICE
102
1 cycle, T = 50 usec
104
RECEIVER
114
Memory
Slice Data,
Templates
112
Controller
110
ADC
108
Analog
Front End
106
103
105
102
TRANSMITTER

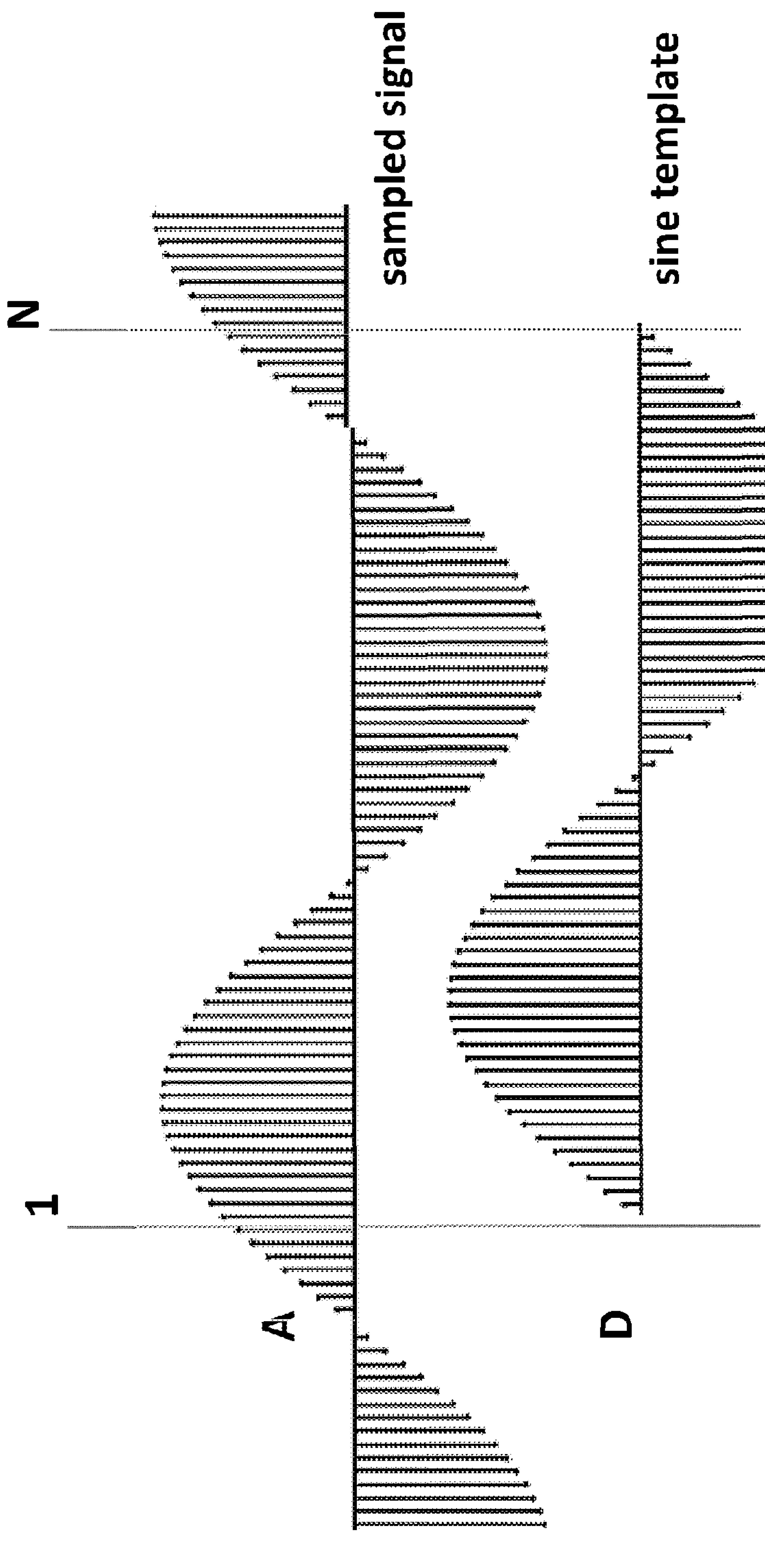
FIG. 1



$$C = A_1 \times B_1 + A_2 \times B_2 + A_3 \times B_3 + \ldots + A_N \times B_N$$

$$C = \sum_{n=1}^{N} A_n \times B_n$$

FIG. 2A



$$S = A_1 \times D_1 + A_2 \times D_2 + A_3 \times D_3 + \ldots + A_N \times D_N$$

$$S = \sum_{n=1}^{N} A_n \times D_n$$

FIG. 2B

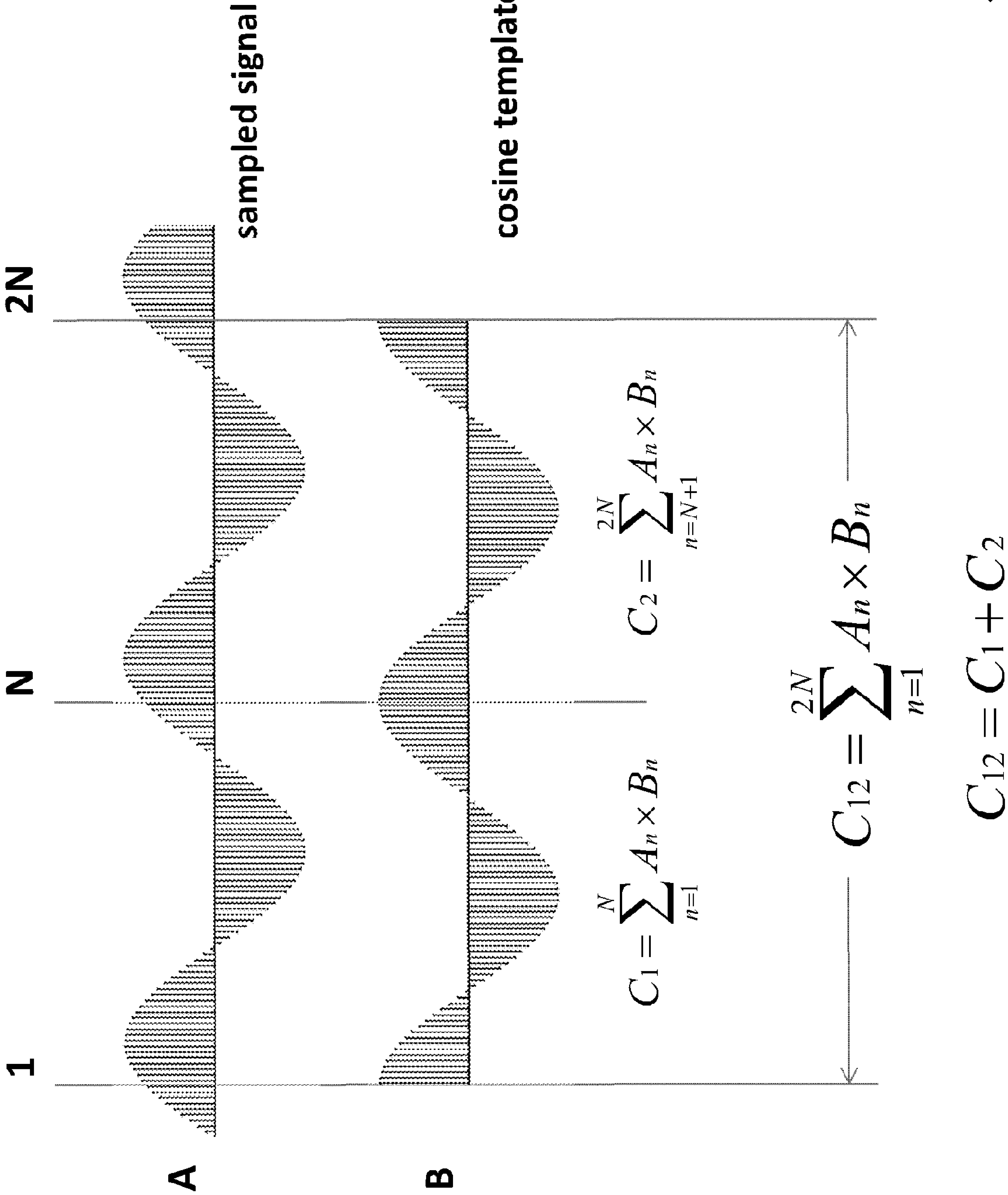

A
B
1
N
2N
sampled signal
cosine template
$C_1 = \sum_{n=1}^{N} A_n \times B_n$
$C_2 = \sum_{n=N+1}^{2N} A_n \times B_n$
$C_{12} = \sum_{n=1}^{2N} A_n \times B_n$
$C_{12} = C_1 + C_2$

FIG. 3

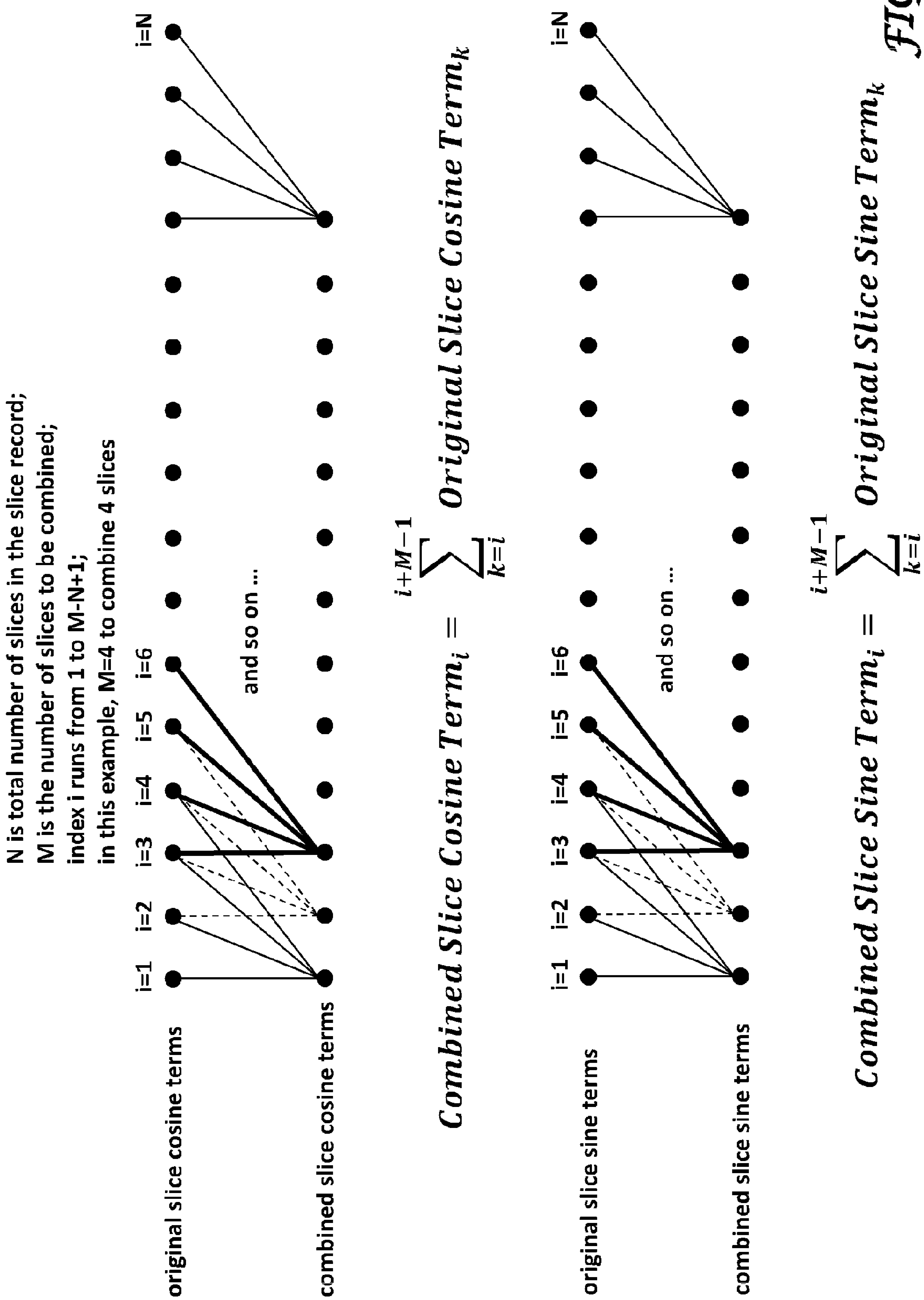

N is total number of slices in the slice record;
M is the number of slices to be combined;
index i runs from 1 to M-N+1;
in this example, M=4 to combine 4 slices
original slice cosine terms
combined slice cosine terms
i=1
i=2
i=3
i=4
i=5
i=6
i=N
and so on ...
$Combined\ Slice\ Cosine\ Term_i = \sum_{k=i}^{i+M-1} Original\ Slice\ Cosine\ Term_k$
original slice sine terms
combined slice sine terms
i=1
i=2
i=3
i=4
i=5
i=6
i=N
and so on ...
$Combined\ Slice\ Sine\ Term_i = \sum_{k=i}^{i+M-1} Original\ Slice\ Sine\ Term_k$

FIG. 4

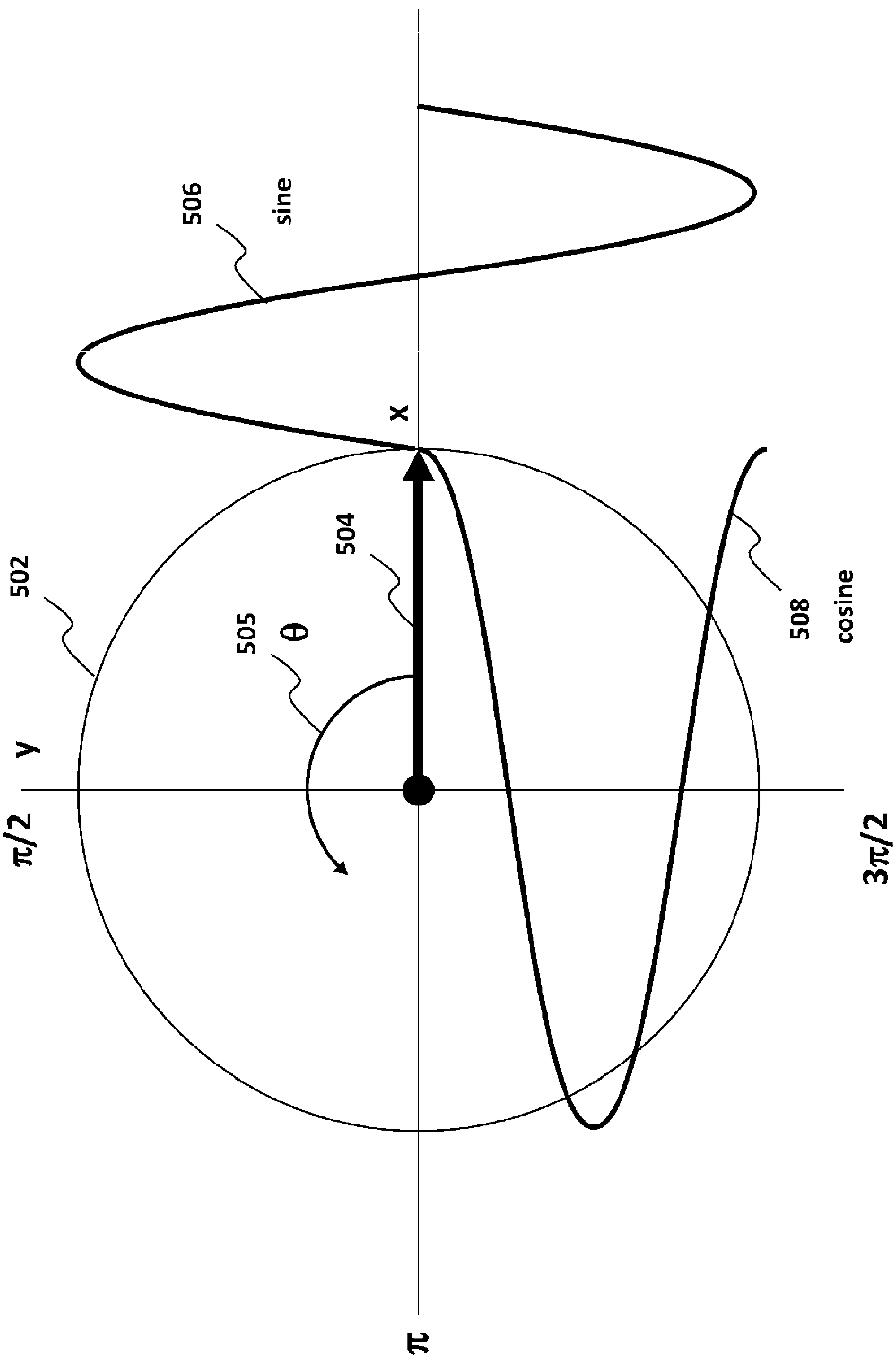


FIG. 5

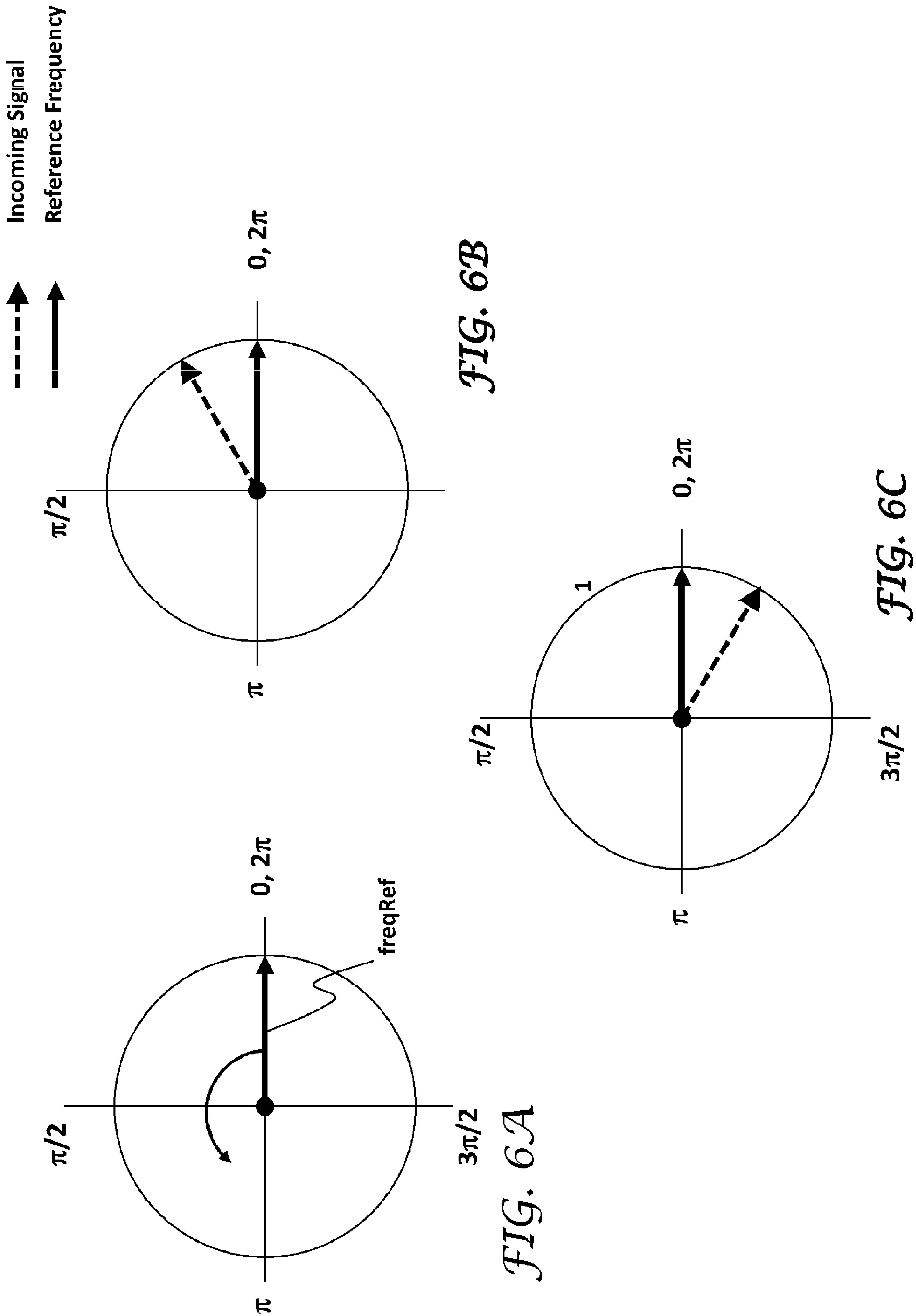


FIG. 6A

FIG. 6B

FIG. 6C


Slice Vectors
Reference Vector

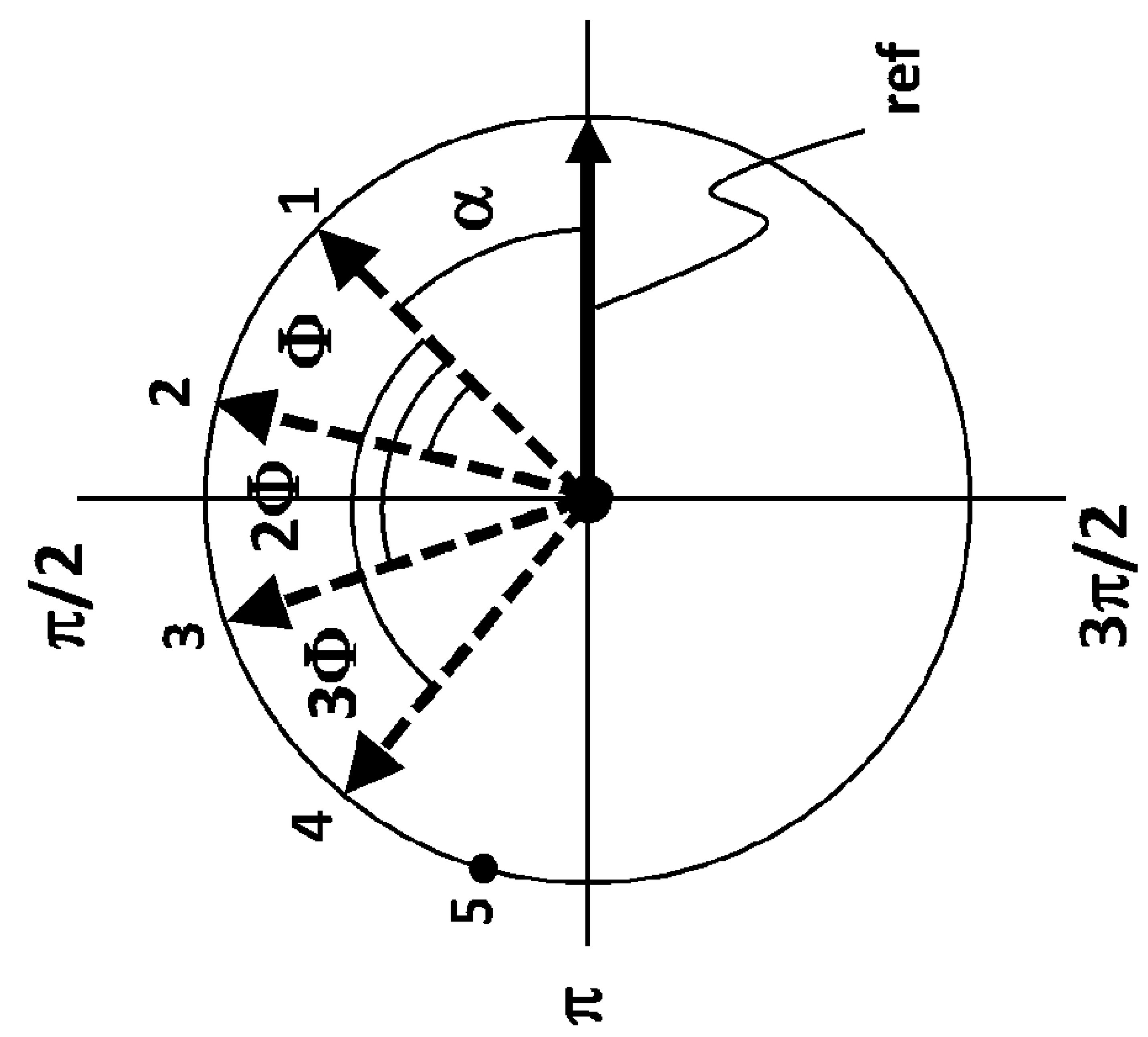

π/2
3π/2
π
ref
α
Φ
2Φ
3Φ
1
2
3
4
5

FIG. 7

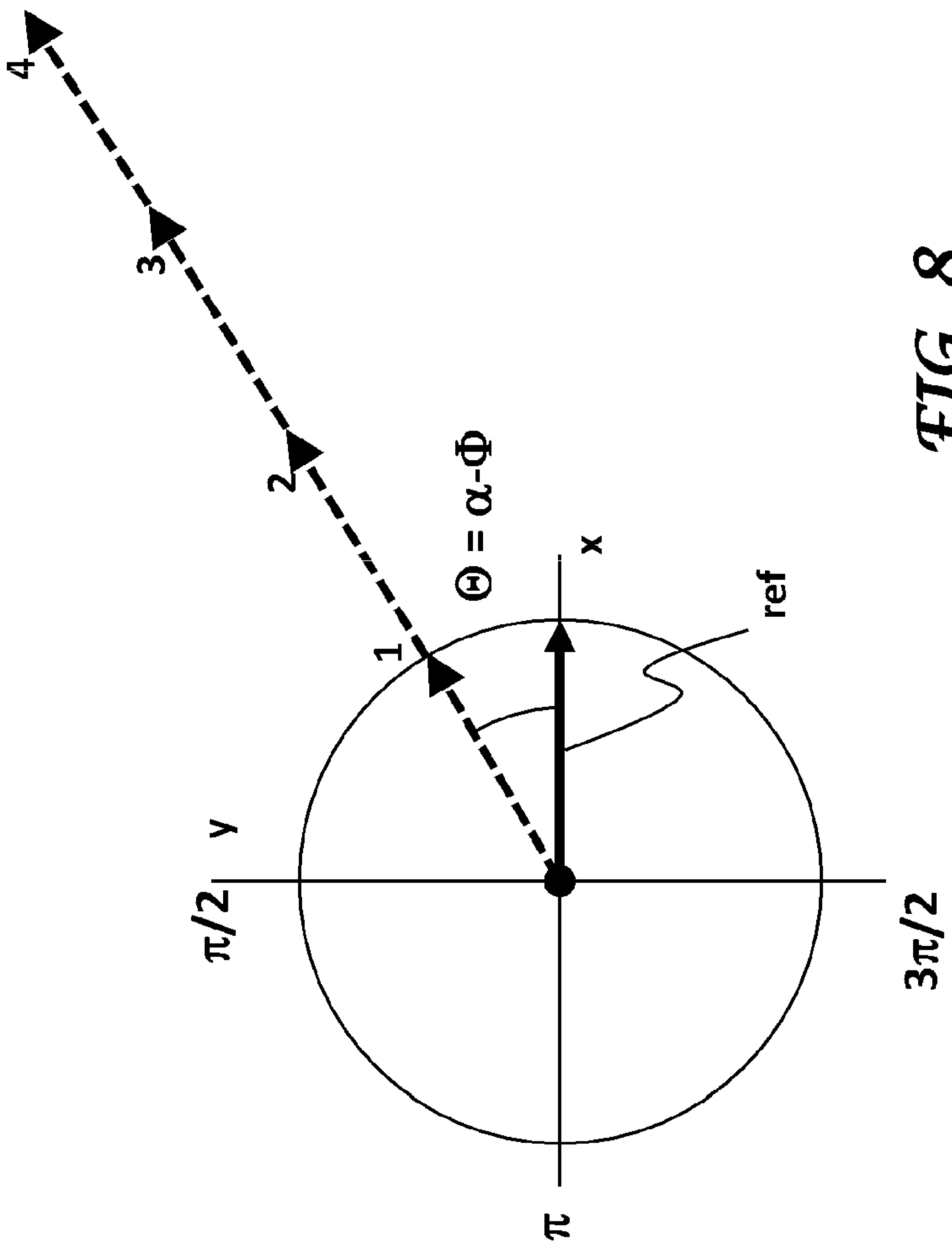

Θ = α-Φ
x
y
ref
π/2
3π/2
π
1
2
3
4

FIG. 8

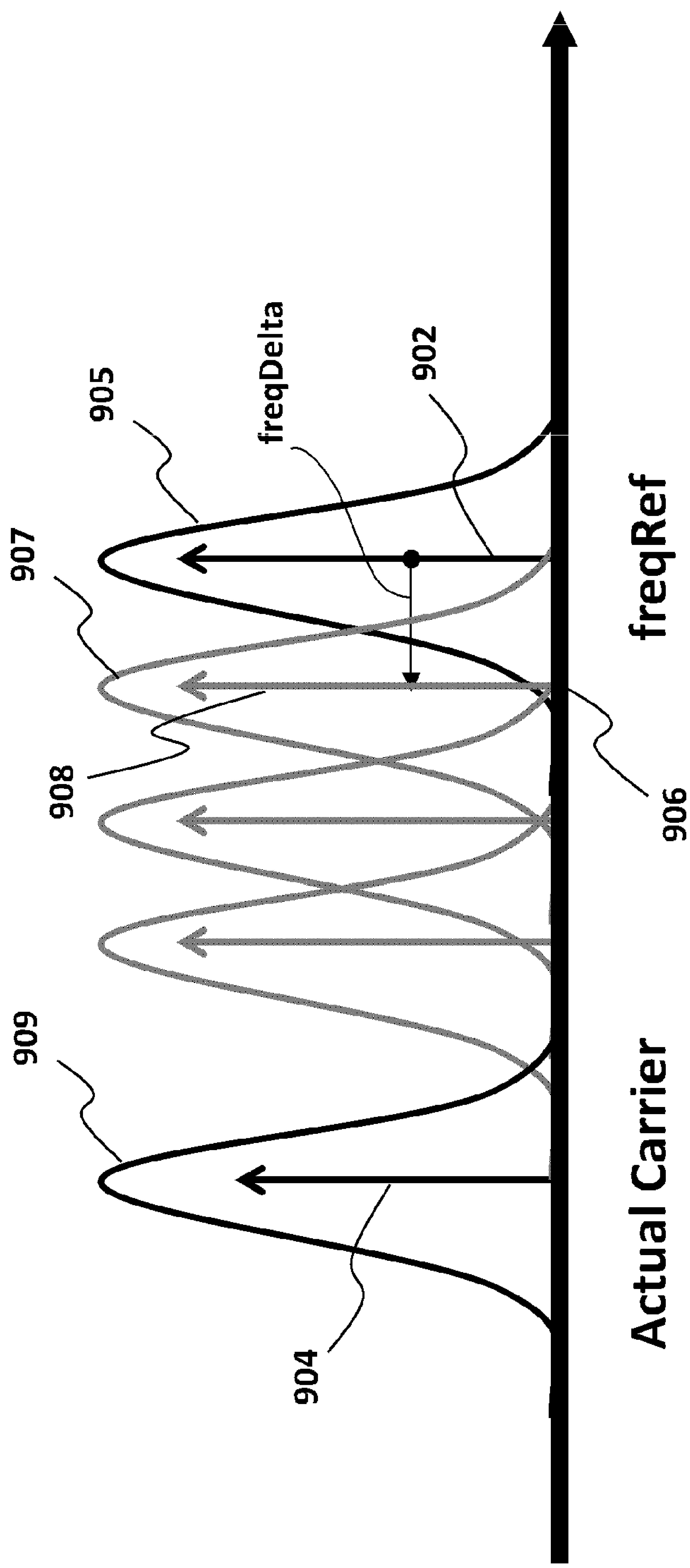

905
freqDelta
902
907
freqRef
908
906
909
Actual Carrier
904

FIG. 9

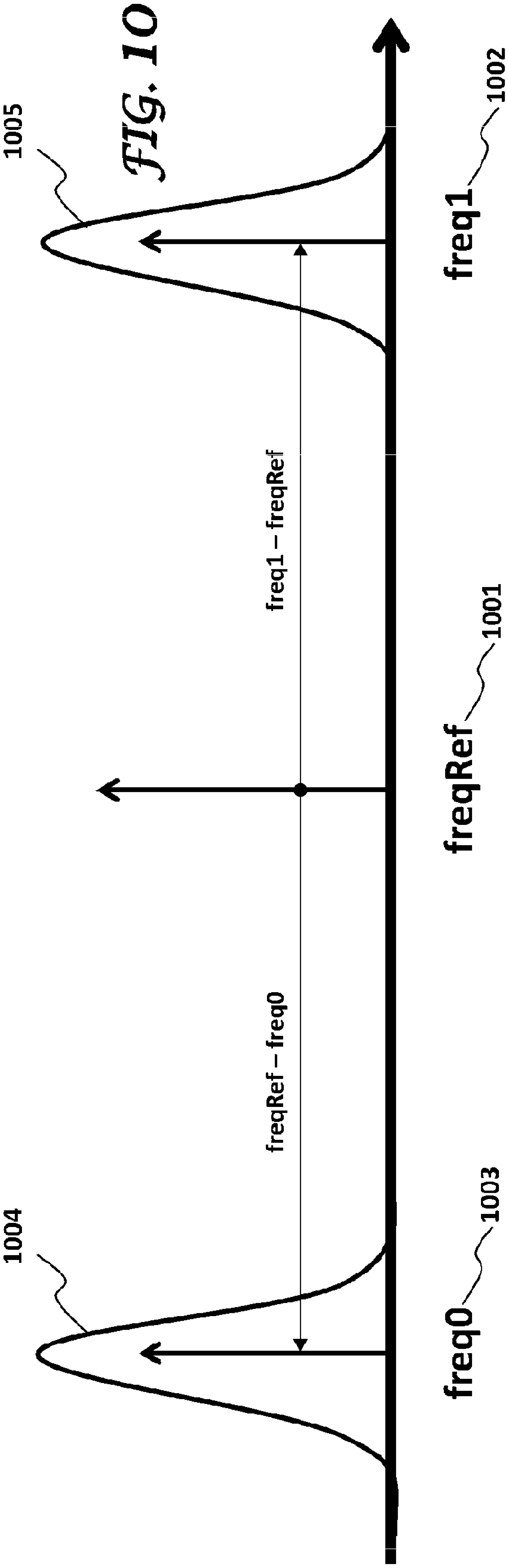

1005
1004
1002
1001
1003
freq1 – freqRef
freqRef – freq0
freq1
freqRef
freq0

FIG. 10

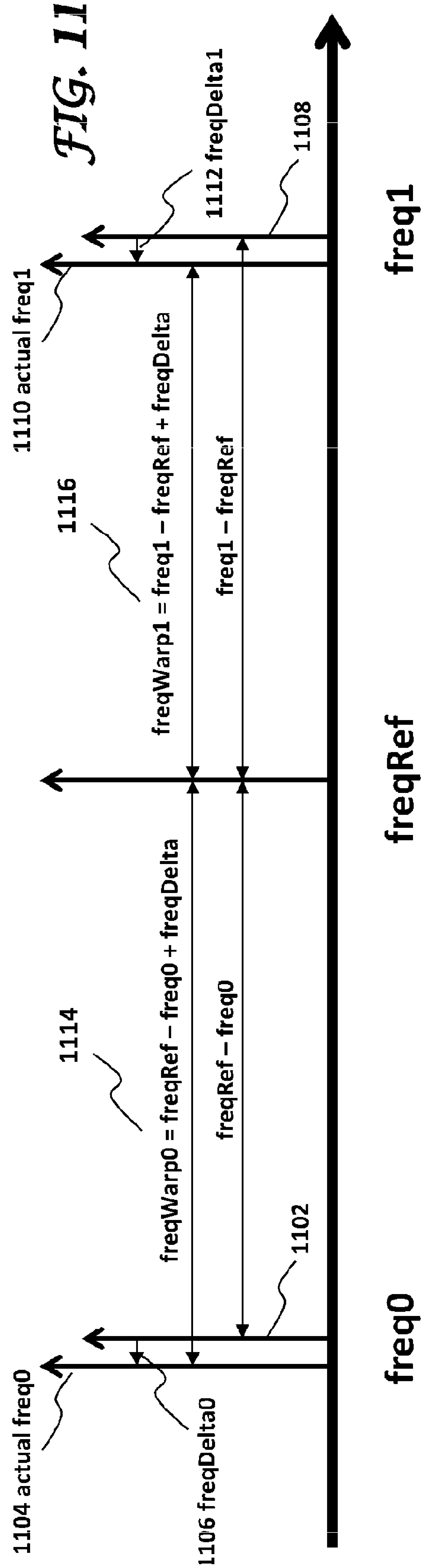

1112 freqDelta1
1108
1110 actual freq1
1116
freqWarp1 = freq1 – freqRef + freqDelta
freq1 – freqRef
1114
freqWarp0 = freqRef – freq0 + freqDelta
freqRef – freq0
1102
1104 actual freq0
1106 freqDelta0
freq1
freqRef
freq0

FIG. 11

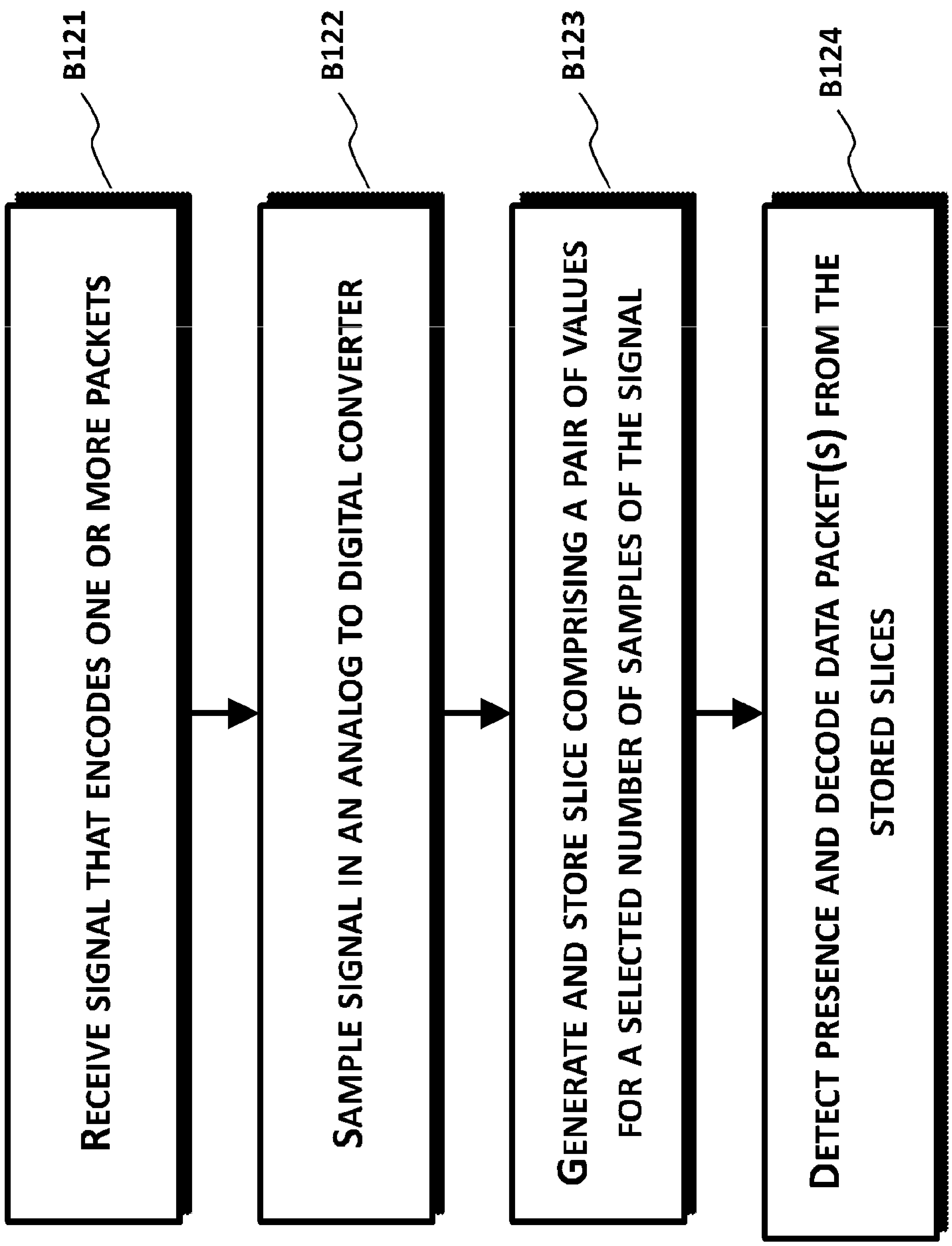

RECEIVE SIGNAL THAT ENCODES ONE OR MORE PACKETS
B121
SAMPLE SIGNAL IN AN ANALOG TO DIGITAL CONVERTER
B122
GENERATE AND STORE SLICE COMPRISING A PAIR OF VALUES FOR A SELECTED NUMBER OF SAMPLES OF THE SIGNAL
B123
DETECT PRESENCE AND DECODE DATA PACKET(S) FROM THE STORED SLICES
B124

FIG. 12

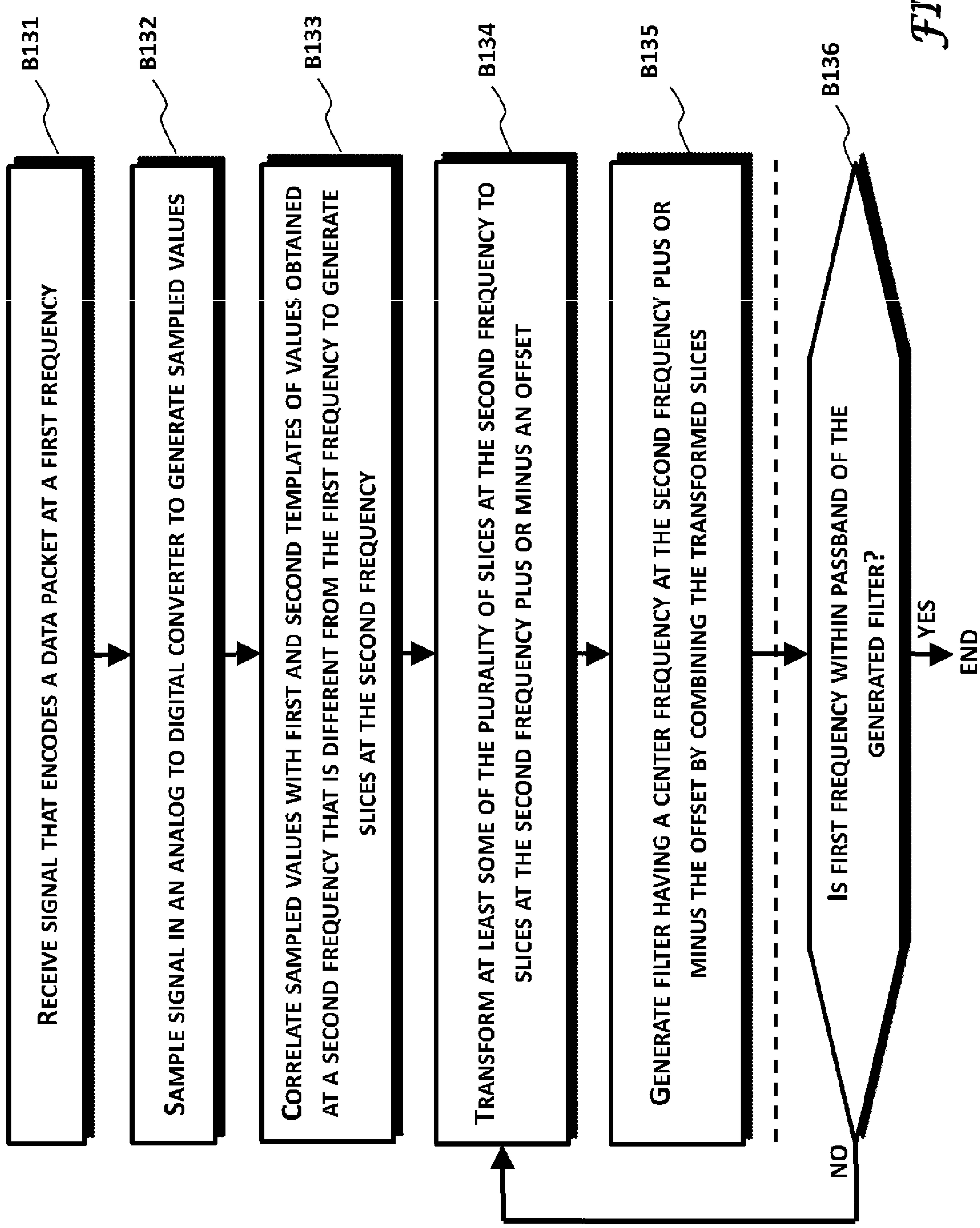

B131
RECEIVE SIGNAL THAT ENCODES A DATA PACKET AT A FIRST FREQUENCY
B132
SAMPLE SIGNAL IN AN ANALOG TO DIGITAL CONVERTER TO GENERATE SAMPLED VALUES
B133
CORRELATE SAMPLED VALUES WITH FIRST AND SECOND TEMPLATES OF VALUES OBTAINED AT A SECOND FREQUENCY THAT IS DIFFERENT FROM THE FIRST FREQUENCY TO GENERATE SLICES AT THE SECOND FREQUENCY
B134
TRANSFORM AT LEAST SOME OF THE PLURALITY OF SLICES AT THE SECOND FREQUENCY TO SLICES AT THE SECOND FREQUENCY PLUS OR MINUS AN OFFSET
B135
GENERATE FILTER HAVING A CENTER FREQUENCY AT THE SECOND FREQUENCY PLUS OR MINUS THE OFFSET BY COMBINING THE TRANSFORMED SLICES
B136
IS FIRST FREQUENCY WITHIN PASSBAND OF THE GENERATED FILTER?
YES
END
NO

FIG. 13

METHODS, DEVICES AND SYSTEMS FOR RECEIVING AND DECODING A SIGNAL IN THE PRESENCE OF NOISE USING SLICES AND WARPING

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit under 35 USC §119(e) of U.S. Provisional Application No. 61/880,786 titled "Methods, Devices and Systems for Receiving and Decoding a Signal in the Presence of Noise Using Slices and Warping," filed Sep. 20, 2013, the disclosure of which application is herein incorporated by reference.

INTRODUCTION

Ingestible sensors may comprise a low power communicator whose transmissions are received by a receiver that may be worn outside of the body. Conventional 'body communication systems' should be capable of processing high-speed raw data in a predetermined amount of time, with considerations to available power consumption and memory size. In a conventional receiver, the incoming signal passes through an 'analog front-end' circuit comprising analog filters and analog electronic amplifiers. The analog filter typically has a wide bandwidth, to allow for the detection of all possible transmitted frequencies, as determined by the manufacturing tolerance of the transmitter carrier frequency. The filtering provided in the analog front-end is modest, and allows a significant amount of noise to get through along with the desired signal. After analog amplification and filtering, the signal is digitized by an analog-to-digital converter (ADC). The remainder of the processing of the received signal may be carried out in digital hardware, such as an embedded microprocessor, state machine, logic gate array, among others. The now-digitized signal may pass through one or more narrowband digital filters to remove as much noise as possible before decoding is attempted.

In cases in which the receiver's estimate of the carrier frequency has a significant amount of uncertainty, the receiver is required to start with a wider-bandwidth digital filter and to, therefore, admit a greater amount of noise. The greater amount of noise means that a weak signal may be missed entirely. To reject the most noise, however, the receiver may apply a digital filter with a narrow bandwidth. But, if the narrow filter is centered on the incorrect carrier frequency, the incoming signal may be missed entirely. For efficient detection and decoding of the incoming signal, therefore, a balance must be achieved between narrow-bandwidth filters to remove as much noise as possible and filters having a greater bandwidth to increase the likelihood that the signal's carrier frequency will be captured when the receiver's knowledge of the incoming carrier frequency is imprecise. The receiver, therefore, may be configured to iteratively adjust the center frequency of the narrow filter, move it to a new center and to thereafter again attempt detection. This process of searching for the carrier with a narrow bandwidth filter is both time consuming and power intensive. Significantly, to re-filter at the new center frequency, the receiver either must retain a copy of the original data record in memory, or, if the original data is not available, capture an entirely new data record. This process not only requires significant memory resources (especially using high resolution ADCs) but also expends a significant amount of device battery life merely to identify the carrier frequency of the incoming signal.

SUMMARY

The present invention in its first aspect provides a method as specified in the appended claims.

The present invention in a further aspect provides a program. Such a program can be provided by itself or carried by a carrier medium. The carrier medium may be a recording or other storage medium. The transmission medium may be a signal.

According to one embodiment, a method may comprise receiving and sampling a signal. The signal may encode a data packet. A slice may be generated and stored comprising a pair of values for each of a selected number of samples of the signal. The presence of the data packet may then be detected and the detected packet decoded from the stored slices. The samples of the signal may represent a correlation of the signal to reference functions in the receiver. The generating and storing slices may be carried out as the received signal is sampled. The sampled values of the signal may be discarded as the slices are generated and stored. The slice representation of the signal can be manipulated to generate filters with flexible bandwidth and center frequency.

According to one embodiment, a method of detecting and decoding a signal arriving at a receiver may begin with the receiver receiving an incoming signal, optionally carrying out some analog pre-processing (e.g. amplifying and filtering) at an analog front-end, after which the pre-processed data may be sampled in an ADC. The sampled raw data, according to one embodiment, then may be compared against internal reference templates stored in memory, using, for example, a correlation algorithm. One exemplary technique comprises correlating the sampled incoming signal with predetermined reference templates over a time period.

Embodiments address the problems inherent in capturing and storing a great many high-speed samples, which strains both computational capability and memory size. Embodiments solve both problems by capturing "slices". The slice data representation, according to one embodiment, contains sufficient information to efficiently and compactly represent the incoming signal and to implement filters of most any bandwidth. According to one embodiment, slices may be subject to a warping operation, by which sets of slices are transformed in useful ways to complete the detection process. Indeed, slices may be combined, according to one embodiment, to create filters having selectably wide or narrow passbands. According to embodiments, the warping operation may be configured to transform slices captured at one frequency to slices at another nearby frequency. This warping operation may be carried out by an algorithm configured to find an incoming carrier frequency and to find evidence of data packets in a noisy environment. The slice representation of signal data, coupled with the warping function, according to embodiments, represent a novel and highly efficient way to perform sophisticated detection algorithms with modest hardware and memory resources.

Further features of the present invention will become apparent from the following description of exemplary embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows various waveforms and an example slice, according to one embodiment. FIG. **1** also shows a system comprising a transmitter and a receiver configured according to one embodiment.

FIG. 2A illustrates correlation of two sampled waveforms.

FIG. 2B illustrates shows the manner in which one term (the sine term, in this case) is calculated, according to one embodiment.

FIG. 3 illustrates aspects of a method of calculating a combined slice term (the cosine term, in this case), according to one embodiment.

FIG. 4 shows aspects of a method of combining sine and cosine slice terms to form a longer correlation, according to one embodiment.

FIG. 5 shows the phase of a signal depicted as a rotating vector in a polar coordinate system.

FIG. 6A shows a rotating vector at a reference frequency in a polar coordinate system.

FIG. 6B shows a rotating vector at a reference frequency and a rotating vector of a signal at a frequency that is greater than the reference frequency, in a polar coordinate system.

FIG. 6C shows a rotating vector at a reference frequency and a rotating vector of a signal at a frequency that is lower than the reference frequency, in a polar coordinate system.

FIG. 7 shows aspects of warping, according to one embodiment.

FIG. 8 shows slices warped, aligned and ready for combination, according to one embodiment.

FIG. 9 shows aspects of a method for searching for a carrier frequency using warping of slices, according to one embodiment.

FIG. 10 shows aspects of Frequency Shift Keying (FSK) carrier detection, according to one embodiment.

FIG. 11 shows aspects of fine tuning FSK carrier detection, according to one embodiment.

FIG. 12 is a logic flow of a method of detecting a signal, according to one embodiment.

FIG. 13 is a logic flow of a method according to one embodiment.

DETAILED DESCRIPTION

FIG. 1 shows a system comprising a low-power oscillating transmitter **102** and a receiver **104**, according to one embodiment. As shown therein, the oscillating transmitter **102** may be separated from the receiver **104** by a communication channel **103**. For example, the oscillating transmitter **102** may be disposed within an ingestible sensor whose transmissions **105** are received by a receiver patch comprising the receiver **104** that may be worn outside of the body, such as on the skin **106**. In this case, the communication channel **103** may comprise the aqueous environment of the body. The receiver **104** may comprise an analog front-end in which the received signal may be pre-processed, before being input to an ADC **110**, which may generate a time-series of raw digital samples. The samples may be represented as binary numbers, from 1 to 24 bits in size, for example. The receiver **104** also may comprise a controller **112**, which may be coupled to a memory **114**. The memory **114** may be configured to store, as detailed below, slice data, reference templates and other temporary values as needed by controller **112**. The receiver may also comprise a communication interface (not shown), to enable decoded payload of packets encoded in the received signal to be communicated to the outside world.

According to one embodiment, a computer-implemented method of detecting and decoding a signal arriving at a receiver **104** may begin with the receiver **104** receiving an incoming signal **105**, carrying out some analog pre-processing (e.g. amplifying and filtering) at analog front-end **108**, after which the pre-processed data may be sampled in ADC **110**. The sampled raw data, according to one embodiment, then may be compared by the controller **112** against internal reference templates stored in memory **114**, using a correlation algorithm. One technique comprises correlating the sampled incoming signal with predetermined reference templates over a time period.

Embodiments address the problems inherent in capturing and storing a great many high-speed samples, which strains both computational capability and memory size. Embodiments solve both problems by capturing "slices". The slice data representation, according to one embodiment, contains sufficient information to efficiently and compactly represent the incoming signal and to implement filters of most any bandwidth. According to one embodiment, slices may be subject to a warping operation, by which sets of slices are transformed in useful ways to complete the detection process. Indeed, slices may be combined, according to one embodiment, to create filters having selectably wide or narrow passbands. According to embodiments, the warping operation may be configured to transform slices captured at one frequency to slices at another nearby frequency. This warping operation may be carried out by an algorithm configured to find an incoming carrier frequency and to find evidence of data packets in a noisy environment. The slice representation of signal data, coupled with the warping function, according to embodiments, represent a novel and highly efficient way to perform sophisticated detection algorithms with modest hardware and memory resources. For example, one or more microcontrollers, one or more Field Programmable Gate Arrays (FPGAs) or Application Specific Integrated Circuits (ASICS) may be used to carry out the processing disclosed herein. A Digital Signal Processor (DSP) may also be used to good advantage.

SLICE: According to one embodiment, a slice construct is introduced. Short correlations, achieved through correlating a relatively short portion of the incoming signal (e.g. approximately 4-8 cycles), are denoted as slices herein. A slice interval, according to one embodiment, may be defined as a predetermined period of time. FIG. **1** shows various segments of a 20,000 Hz signal. As shown, reference **102** shows a single cycle of such a 20,000 Hz signal, whose period T is $\frac{1}{20{,}000}$ Hz or 50 μsec. Reference **104** shows a single slice interval, defined as a time equal to 4 cycles of the 20,000 Hz signal, or 200 μsec. Herein, a slice interval is arbitrarily defined as 4 cycles of the incoming signal. A slice interval, however, may comprise a different amount of time or number of cycles. For example, a slice interval may comprise the time equal to 8 cycles. Below, unless specifically noted, a slice interval is defined as comprising 4 cycles of the incoming signal, it being understood that other slice intervals may readily be implemented. For example, the slice definition may be expressed in cycles, but is not required to be a multiple of full cycles of any signal or template. A slice may be any defined amount of time. The slice time may be changed in the receiver as needed. For example, the receiver could implement two slice routines to capture two slice streams simultaneously, one at 20 kHz and another at 12.5 kHz, for example. The two slice computations could use different slice times suitable for each channel. As shown at **106** in FIG. **1**, four slice intervals may comprise 16 cycles and have a period of 800 μsec. Lastly, 64 cycles of the reference frequency may be divided into 16 slice intervals as shown at **108**. The number of samples of the incoming signal included in one slice is governed by the definition of the slice interval and the sampling rate of the ADC:

$$\text{samples per slice} = \text{ADC sample rate} \cdot \text{slice interval}.$$

The ADC sampling rate may be at least as often as the Nyquist theorem call for; namely, at least twice the frequency of interest. According to one embodiment, the ADC sample rate may be chosen to be higher, such as five or more times the frequency of interest of the incoming signal. Other sampling rates may be utilized. In one embodiment, the ADC in the receiver (adhered to a patient's abdomen, for example) may be configured to carry out forty or more samples per second. The starting times of consecutive slices may advantageously be selected to be periodic according to some fixed, for example, interval. However, acceptable results may also be obtained even when there are brief periods of time when no sampling is being carried out.

To determine the similarity between digitized samples of an incoming signal and a reference template, a dot product (the sum of the products of corresponding samples) or correlation operation may be carried out. FIG. **2**A shows such a correlation operation of a digitized incoming signal with a cosine template. Here, A may represent the digitized incoming signal and B may represent a template of a first reference function such as, for example, a cosine template at the reference frequency (e.g. 20,000 Hz). In other words, the cosine template B, according to one embodiment, is a representation of what the receiver **104** expects the cosine component of the received signal to look like and the correlation operation determines the degree of similarity between signal A and cosine template B. As shown, samples of signal A are multiplied with the corresponding samples of the cosine template B, and the results of these additions summed over the number of samples N. Stated more formally, C is the scalar product of A and B and may be expressed as:

$$C = A_1 \times B_1 + A_2 \times B_2 + A_3 \times B_3 + \ldots + A_N \times B_N$$

$$C = \sum_{n=1}^{N} A_n \times B_n$$

Similarly, FIG. **2**B shows correlation with a sine template. Here, A may represent the digitized incoming signal and D may represent a template of a second reference function in quadrature with the first reference function. For example, the template of the second reference function may be, for example, a sine template at the reference frequency (e.g. 20,000 Hz). As shown, samples of signal A are multiplied with the corresponding samples of the sine template D, and the results of these additions summed over the number of samples N. Stated more formally, S is the scalar product of A and D and may be expressed as:

$$S = A_1 \times D_1 + A_2 \times D_2 + \ldots + A_N \times D_N$$

$$S = \sum_{n=1}^{N} A_n \times D_n$$

The orthogonal cosine and sine templates are in a quadrature phase relationship. The two correlation results, C and S, when taken together, represent a slice. In complex polar notation, C+j·S is a vector with an angle indicating the phase between the incoming signal and the receiver's reference templates. In practice, the slice may be thought of as a 1/(slice interval) filter.

According to one embodiment, the scalars C and S may be scaled by a scaling factor. For example, C and S may be scaled such that they may assume a range of values between, for example, 0 and 1. Other scaling factors and ranges may be accommodated.

As shown and discussed herein, the reference templates are sine templates and cosine templates. Other periodic shapes, however, may be used as the reference templates such as, for example, sawtooth, triangle or square signals. Selecting non-sinusoidal waveforms for the reference templates may result in some information being discarded, but the signal of interest may still be extracted from the received signal. Moreover, even though having the reference templates 90 degrees out of phase with one another (in quadrature), reference templates having other phase relationships with one another may be used. For example, the two reference templates could be 89 degrees or 91 degrees out of phase with one another, without substantial ill effect.

According to one embodiment, slice correlations (or, simply, slices) may be calculated from the raw digitized samples generated by the receiver's ADC **110**. These raw digitized samples may be correlated against samples of both cosine and sine reference templates at the reference frequency (freqRef) stored in the receiver **104**. The cosine term and sine term of a slice, according to one embodiment, may be defined as:

$$SliceCosTerm = \sum_{n=1}^{N} signal_n \times referenceCos_n$$

$$SliceSinTerm = \sum_{n=1}^{N} signal_n \times referenceSin_n$$

where N is the number of samples in one slice.

The vector magnitude of a slice may be computed in Root Mean Square (RMS) fashion:

$$\text{Slice Magnitude} = \sqrt{\text{SliceCosTerm}^2 + \text{SliceSinTerm}^2}$$

The Slice Magnitude quantity is a scalar indicative of the magnitude of the combined slices.

The vector angle of a slice thereof (Slice Angle), is given by

$$\text{Slice Angle} = \arctan\left(\frac{SliceSinTerm}{SliceCosTerm}\right)$$

COMBINING SLICES: FIG. **3** is a diagram showing the scalar dot product of signal A and template B over two slice intervals (where, in this figure, the slice interval encompasses one cycle of the cosine template), and shows the additive nature of the correlation. According to one embodiment, for slices to be combinable, each of the reference signals of each reference template should be coherent, meaning in phase with one another. As shown, the correlation or dot product of A and B over two slice intervals (2N samples, in this case) corresponds to the simple scalar sum (accumulation) of the correlation over the first N cycles with the correlation over the second N cycles of A and B. Or,

$$C_1 = \sum_{n=1}^{N} A_n \times B_n$$

$$C_2 = \sum_{n=N+1}^{2N} A_n \times B_n$$

-continued

$$C_{12} = \sum_{n=1}^{2N} A_n \times B_n$$

$$C_{12} = C_1 + C_2$$

Moreover, to compute the correlation for a time interval corresponding to 3 slice intervals of A and B, it is not necessary to re-compute C1 and C2. Simply, compute the correlation C3, and add the result to C12 to generate the correlation (dot product of vectors A and B over a signal length of 3 slice intervals) C13. As a slice is equivalent to a 1/(slice interval) filter, as slices are combined into longer correlations, the filter bandwidth is correspondingly reduced, as further detailed below.

According to one embodiment, slices are treated as complex pairs, comprising both a cosine term and a sine term. The cosine term of a slice, according to one embodiment, represents the correlation between the sampled incoming signal and a cosine template stored in the receiver **104** at the reference frequency (freqRef). Similarly, the sine term of a slice, according to one embodiment, represents the correlation between the sampled incoming signal and a sine template stored in the receiver **104** at freqRef. FreqRef can be set to the expected or nominal frequency at which the transmitter is specified to transmit, but which may vary due to manufacturing variations (which may occur in both the transmitter and the receiver), ambient conditions such as the temperature of the transmitter and receiver, distortion through the communication channel (e.g. the aqueous and physiologic environments of the human body such as the salinity of the stomach and surrounding tissues Other factors may include, for example, variations in the frequency calibration process used on the transmitter and receiver, which may not be very accurate, or might have large frequency steps in their adjustment method.

According to embodiments, once the slice calculations have been carried out and the slice terms stored in memory **114**, the original raw samples generated by the ADC (and from which the slices were generated) now may be discarded, as all subsequent packet detecting, frequency determination and payload decoding steps may be based on the stored slice data, without the need to ever consult or re-generate the digitized samples generated by the ADC. According to embodiments, the slice calculation and the storage of the slice data in memory **114** may be carried out 'on-the-fly' in real time by a suitable controller provided within the receiver **104**. According to one embodiment, the slice correlation data may be calculated and stored in memory **114** by the receiver's controller **112** in the controller command execution cycles available between ADC sample times. Accordingly, there may be no need to store the raw digitized sample stream from the ADC **110** in memory **114**, which represents a significant efficiency.

According to embodiments, significant reductions in the amount of data stored by the receiver **104** may be achieved. For example, the reference frequency of the carrier may be 20,000 Hz and the sample rate of the ADC may be 3.2 million samples per second (SPS), which corresponds to 160 ADC samples per cycle of the carrier. The sample rate of the ADC, however, may be freely chosen. For example, the sample rate of the ADC may be selected to be in the thousands of samples per second. For example, the sample rate of the ADC may be chosen to be about 200 kSPS, which corresponds to 10 ADC samples per cycle of the carrier. A controller **112** may be configured to execute, for example, 16 million instructions per second. If a slice interval were to be defined as 4 cycles of the reference frequency, at a sample rate of 200 kSPS, there are 10·4 or 40 ADC samples in each slice. There are 16,000,000/20,000 or 80 processor cycles available between each ADC sample, which is generally sufficient to generate and store the slice record. According to one embodiment, each individual new sample may be incorporated into the accumulating slice cosine and sine dot products and stored within these available processor cycles, thereby enabling the controller **112** to generate the slice data while keeping pace with the samples as they are generated by the ADC. The result of the slice correlation calculation is two numbers (a cosine term and a sine term), which represents a compression, per slice (e.g. 4 cycles of the incoming signal) of 40:2 or a compression factor of 20 relative to the raw sample stream. In this particular example, this represents over an order of magnitude reduction in memory requirements. Increasing the slice time or increasing the sampling rate linearly increases this compression rate. In one embodiment, a sampling rate of 760 kSPS allows for 21 processor cycles between samples, which is sufficient computational power to generate slice data while keeping pace with the samples as they arrive. Each cycle is represented by 760/20 or 38 samples, so each slice represents 4·38 or 152 samples of the incoming signal. The resulting compression factor is 152:2 or a compression factor of 71.

ANALOG SLICE PROCESSING—According to one embodiment, the incoming signal may be multiplied by two analog multipliers (e.g. quadrature mixers) with two reference signals. Each of the product signals may then be summed (e.g. by analog integration using a capacitor or an active circuit based on stored capacitor charge) for a period of time and then sampled at a much lower frequency. Each such sample pair represents a slice pair. Such an analog embodiment may enable power consumption advantages to be realized.

COMBINING SLICES, FILTERING—Effectively, the slice correlation calculation represents a filter with a bandwidth of 1/(slice interval) which, in the example case of a reference frequency of 20,000 Hz and 4 cycles per slice, works out to 1/200 µsec or 5,000 Hz, which is a filter having a relatively broad bandwidth. According to one embodiment, the constituent cosine components of the slice pair may be combined and the constituent sine components of the slice pair may be combined, thereby increasing the slice time and creating a filter having a narrower bandwidth. Due to the inverse relationship between slice interval and filter bandwidth, according to one embodiment, a narrower bandwidth filter may be achieved through combining slice terms. Indeed, slice correlations computed over short periods of time may be extended to longer correlations by combining such short periods of time; that is, by combining slices. Combining slice terms, according to one embodiment, may be carried out by summing a number of sequential cosine slice terms, summing the same number of sequential sine slice terms. The resulting two new terms, when paired together form a combined slice representing a longer correlation.

According to embodiments, such a slice combination calculation may be performed at every slice index (i.e., without skipping to every N^{th} slice index). FIG. **4** is a graphical representation of combining previously-computed and stored slice pairs of cosine and sine components. As shown, the original cosine components of the stored slice data are labeled as "original slice cosine terms" and the original sine components of the slice data are labeled "original slice sine terms". To combine four slices, the first four cosine terms (i=1, 2, 3, 4) are summed into a "combined slice cosine term" with slice index 1. Likewise, the first four sine components of the slice data are summed into a "combined slice sine term", starting with the current index 1. Therefore, on the first iteration, i=1 and the previously computed cosine terms indexed at i=1, i=2, i=3 and i=4 are summed to form Slice Cos Term_1, and the previously computed sine terms indexed at i=1, i=2, i=3 and i=4 are combined to form Slice Sin Term_1, whereupon i is incremented to 2. Slice Cos Term_2 may then be formed by the four consecutive slice cosine terms, starting with the current i=2 slice index; namely, i=2, i=3, i=4 and i=5. Likewise, Slice Sin Term_2 may then be formed by a similar computation. This operation may be carried out for the entire slice record. By varying the number of slices over which the combining is carried out, the bandwidth of the resultant filter may be selected at will. This ability to rapidly and simply generate different filters is a generally useful capability in a receiver. By way of a simple example, when the receiver **104** is searching for the carrier frequency of the received signal, a small number of slice cosine and sine terms may be combined to generate what is, in effect, a filter having a relatively wide bandwidth, thereby increasing the probability that the carrier will be present somewhere within the frequency range encompassed by the wide bandwidth filter. However, such a wide bandwidth filter also admits a correspondingly large amount of noise, which may render detection of especially weak signals difficult. Alternatively, a larger number of slice terms may be combined to generate what is, in effect, a filter having a correspondingly narrow bandwidth. Such a narrow bandwidth filter, however, does not admit a large amount of noise, which may facilitate the detection of the carrier frequency.

According to embodiments, one result of combining slices is a digital filter having reduced bandwidth, while maintaining the time resolution of the original slices. It is to be noted that such filters may be constructed using only the slice data stored in memory **114**, as the original raw ADC data may have already been discarded and may be, therefore unavailable. According to embodiments, slice combinations over a greater number of slices may be implemented. Moreover, slice combinations may be repeatedly performed over different numbers of slices (hence implementing filters of different bandwidths) using the original slice data or using previously combined slice records, without re-referencing the original raw ADC samples (which may have been previously discarded anyway) and without re-acquiring the incoming signal and re-generating new raw ADC samples. Because of the high level of compression represented by slice data (i.e., over an order of magnitude in the example being developed herewith), long recordings of slice data may be stored in, for example, controller memory, even in the face of strict memory size constraints. The memory **114** shown in FIG. **1** may be external to the controller **112** or internal thereto.

According to one embodiment, one need not combine slices if the original slice interval is defined to be as long a period of time as a combined slice would be, had the slices been combined. For example, the slice interval may be defined to be longer than 4 cycles, which is the exemplary implementation discussed herein. This may be desirable in systems in which there is good crystal control of the transmitter and the receiver. In such cases, warping (as discussed herein below) need be carried out over only a narrow frequency range to find the carrier frequency and/or to detect the presence of a packet in a noisy environment. Therefore, according to one embodiment, the originally-captured set of slices may be used to form a filter, without the need to combine slices as described herein.

As the slice combining calculations described and shown herein are largely composed of additions, such combining calculations may be carried out efficiently. Also, as the slice combining operation may operate only on the indexed slice cosine and sine terms stored in memory **114**, the combining operation need not be carried out in real time, as the raw samples arrive, as it may be carried out after all slice pairs have been generated from the raw ADC samples of the incoming signal and stored in memory **114**. Moreover, as the combining operations do not, according to one embodiment, alter the stored indexed slice pairs, the slice combining operations may be repeated any number of times, depending on the needs of the overall detection and decoding algorithms. That is, the original slice data may be reused many times at will. Alternatively, the slice combining operation may be performed on slices that themselves are the result of a combining operation. For example, a combination of four slices (a '4-slice' slice record) may be achieved either by 1) Combining four original slices to generate a 4-slice slice record, or 2) Combining two original slices into a 2-slice slice record, and then combine two slices from the 2-slice slice record to generate the desired 4-slice record. Such flexibility can be exploited to, for example, conserve memory in the processor.

SUMMARY: SLICE AND SLICE COMBINING—To review the slice representation up to this point in the discussion, an incoming signal can be captured by a sequence of short correlations against reference templates. The templates may comprise a first reference function and a second reference function. According to one embodiment, the first and second reference functions are in quadrature. For example, the first reference function may be or comprise a cosine function and the second reference function may be or comprise a sine function. The length of the correlation may be conveniently selected to be a few periods (or more) of the template functions. The result of a correlation is two scalar terms that can be thought of as representing a complex number: cos term+j·sin term. Each correlation result is herein referred to as a slice, and a number of slices are captured in memory in a slice record. One operation that may be applied to a slice record is slice combination as described above. Combining slices is performed with simple additions of the individual slice terms. Combining slices results in a new slice record representing a filter of narrower bandwidth than the original slice record. This capability is highly useful in receiving and filtering a signal embedded in noise.

To this point in the discussion, the center frequency of the combined-slice narrow-band filter is the frequency of the reference template functions. This choice of only a single center frequency is a significant limitation to the slice capture and slice combining operations described to this point. The following sections describe a method, according to one embodiment, to move the slice record to any nearby frequency, thereby significantly increasing the utility of the slice representation.

WARP—An important function in any signal processing device is the ability to respond to variations in the transmitted signal frequency. For systems capturing a signal in the slice representation described above, the same need applies. After capturing a signal in slice form using correlation to reference templates, it may be desirable to create filters at a frequency other than the reference frequency, (e. g. at a frequency freqRef plus a frequency delta (freqDelta). The frequency delta may be either a positive or negative offset from freqRef. According to one embodiment, such a new narrow-band filter centered at freqRef+freqDelta may be created by a) capturing slice records at a reference frequency (freqRef), b) transforming (also denoted as "warping" herein) the original slice record into a new warped slice record using a complex vector rotation operation in which the rotation angle is governed or determined by a so-called warping function (WF), and c) combining the warped slices to generate a narrow-band filter now centered at frequency freqRef+freqDelta.

One embodiment, therefore, enables slice data taken at one frequency (e.g. freqRef) to be warped to slice data at another frequency, say freqRef+freqDelta. This may be carried out, according to one embodiment, without acquiring new data and without the need to re-use the original samples generated from the ADC **110** at the analog front end of the receiver **104**, as such original data stream may be discarded—or may simply never be stored. According to one embodiment, therefore, a warping method may be configured to shift the center frequency of a digital filter without re-acquiring new data and without re-using the original samples generated by the ADC **110** to which the (processed) incoming signal is input.

POLAR NOTATION—FIG. **5** shows a vector **504** of length 1 in a polar coordinate system **502**. As shown, any point in the polar coordinate system **502** may be represented as a complex pair, namely (x, y). Equivalently, any point in the polar coordinate system **502** can be represented by a magnitude **504** and angle, (r, θ) where θ (**505**) is the angle of the vector **504** relative to the positive x-axis. Points z in the complex plane may be defined as those points satisfying the equation $z=r\cos\theta+j\cdot r\sin\theta$. The coordinates of any point comprises both a cosine term: r cos θ (**508**) and a sine term: r sin θ (**506**).

As shown in FIG. **6**A, a reference frequency freqRef, such as the frequency of a reference template used in a correlation operation, may be represented as a rotating vector in a polar coordinate system. Ideally, the frequency of a signal received by a receiver would be exactly the same frequency that was transmitted, the reference frequency. Practically, however, such is not often the case. The frequency of the received incoming signal may be higher than that of the reference frequency freqRef. In that case, using the rotating vector representation of FIG. **5**, the vector representing the incoming signal would lead (rotate faster than) the vector representing the reference frequency freqRef, as shown in FIG. **6**B. Similarly, the frequency of the received incoming signal may be lower than that of the reference frequency freqRef. In that case, the vector representing the incoming signal would lag (rotate slower than) the vector representing the reference frequency freqRef, as shown in FIG. **6**C.

In the example of FIG. **7**, the incoming signal is shown as a higher frequency than the reference frequency. With reference to FIG. **7**, a polar coordinate system is illustrated, with the x-axis corresponding to the cosine term and the y-axis corresponding to the sine term. A reference signal (freqRef, solid line) is shown, by convention, as a vector pointing along the positive x-axis (cosine axis). Slice data generated from an incoming signal are shown as dashed vectors representing slices 1, 2, 3, 4, etc. In this static representation, it can be seen that the vector representing the first slice establishes an arbitrary (0 to 2π radian) phase angle α with respect to the reference frequency vector. In this example, the subsequent slice vectors having slice indices 2, 3, 4, etc., lead (i.e., rotate faster than) the reference vector by an ever-increasing angle. The observation central to the warping concept is that the angle for each successive slice increases by a constant angle for all slices,Φ. That is, the second slice vector is at an angle Φ relative to the first slice vector, the third slice vector is at an angle of Φ relative the second slice vector, or equivalently 2Φ relative to the first slice vector, and the fourth slice is located at an angle Φ relative to the third slice, or equivalently 3Φ relative to the first slice vector. The angle Φ, and multiples thereof, therefore, may be thought of as the amount of lead or lag from slice to slice, and multiples thereof represent the amount of lead or lag with respect to the reference vector.

FIG. **7** demonstrates that for an incoming signal frequency that does not perfectly match the reference frequency, the slice data becomes more and more out of phase (leads or lags) with the reference vector as the slice number increases. Even a very small initial angle Φ tends to grow such that the slices become significantly out of phase over time. The angle Φ is proportional to the ratio of freqDelta (the frequency difference between the incoming signal and the reference templates in the receiver) to the frequency of the reference templates, freqRef. The angle Φ is also proportional to the slice interval. According to one embodiment, the angle Φ in radians may be defined as

$$\Phi = 2\pi\left(\frac{freqDelta}{freqRef}\right)\cdot \text{cycles per slice}$$

where freqDelta is the difference between the frequency of the incoming signal (freqSignal) and the frequency of the reference signal (freqRef),

freqDelta=freqSignal−freqRef

For a signal with a constant frequency, the angular shift between slices is consistent across slices. As graphically seen in FIG. **7**, the amount of rotation for successive slices is not a constant angle with respect to the reference. Rather, the angle by which each successive slice is shifted, relative to the first slice is, in this illustrative example, an integer multiple of the angle Φ.

VECTOR ROTATION—The general form of a complex vector rotation by an angle θ can be represented in matrix form as:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

Where x and y are the original vector coordinates and θ is the rotation angle, with positive rotation in the counterclockwise direction. The resulting rotated vector coordinates are x' and y'. In algebraic form, the rotation operation can be expressed by two equations:

$$x'=x\cos\theta-y\sin\theta$$

$$y'=x\sin\theta+y\cos\theta$$

The operation may be represented informally as

rotated vector=VectorRotate(input vector,angle)

In slice notation, cos term plays the role of the x value, and sin term plays the role of the y value.

WARP FUNCTION—A complex representation allows slices to be displayed as vectors on a complex polar plane. Complex vector notation is a convenient way to illustrate warping operations in the following description of the so-called warp function (WF). Slices may be represented as complex pairs; namely, cos term+j·sin term. According to one embodiment, the manner in which slice data are operated upon may be characterized as vector rotation where the rotation angle is determined by a Warp Function (WF). Warping of a slice record may be the result of a complex vector rotation operation (say, VectorRotate), which takes two arguments: the input slice data record (denoted Input Slice below) and a rotation angle (determined by the output of a Warp Function) to which each slice in the slice data record is to be rotated. Stated more succinctly, the generalized warping operation may be described as:

$$\text{Warped Slice}(i)=\text{VectorRotate}(\text{Input Slice}(i),\text{WF}(\theta,i,\text{other arguments}))$$

Where i runs from 1 to the number of slices in the slice record. The rotation angle is derived from a warp function,

$$\text{angle}(i)=\text{WF}(\theta,i,\text{other arguments})$$

In various embodiments, the selection of the warp function WF and the angle θ in the equation determines the properties of the resulting warped slice record.

WARP FUNCTION EXAMPLES— This section describes a number of warp functions, from a simple case to a more complex case from which several useful definitions may be derived.

Beginning with a relatively simple example, the warp function may be defined as $\text{WF}(\,)=1\cdot\theta$. Applying this warp function to the slice record results in the entire slice record being shifted by a constant phase angle θ. In the polar coordinate diagram of FIG. **5**, this warp function corresponds to rotating all slice vectors by the same amount, θ. In the time domain, the constant phase shift advances or delays the incoming signal with respect to the receiver's reference templates, without otherwise altering the properties of the signal.

WARPING TO TUNE SLICES TO A NEW CENTER FREQUENCY—In one embodiment, the warp function may be defined as

$$\text{WF}(\,)=-i\cdot\Phi$$

where the canonical index i is the slice index number (not the complex root "i") and Φ is the angle between successive slices. Then

$$\text{Warped Slice}(i)=\text{VectorRotate}(\text{Input Slice}(i),-i\cdot\Phi)$$

The warp operation may be carried out on the original slice terms (cos term, sin term) to generate the warped slice record comprising warped slice terms (warped cos term, warped sin term):

$$\text{warped cos term}(i)=\text{cos term}(i)\cdot\cos(-i\cdot\Phi)-\text{sin term}(i)\cdot\sin(-i\cdot\Phi)$$

$$\text{warped sin term}(i)=\text{cos term}(i)\cdot\sin(-i\cdot\Phi)+\text{sin term}(i)\cdot\cos(-i\cdot\Phi)$$

The warp operation immediately above effectively re-tunes the receiver **104**, using the stored slices, to a new frequency (freqRef+freqDelta). According to embodiments, this re-tuning is achieved from the stored slice data and not from a re-acquisition of slice data at some other frequency (such as the new frequency) or a re-processing of the original ADC samples—which were may have been discarded or never even stored upon acquisition thereof. Moreover, such an operation is not a straightforward vector rotation, but rather a warping operation on slices, which has the resulting effect of tuning a slice record from one frequency (freqRef) to another (freqRef+freqDelta). As shown in FIG. **8**, slices 1, 2, 3 and 4, . . . N become aligned with each other. Performing a slice combining operation, as described earlier, on a set of warped slices produces a peak response at the warped frequency, freqRef+freqDelta. This corresponds to a filter tuned with this center frequency. FIG. **8** illustrates how slice combination (a vector addition), according to one embodiment, combines the aligned slice vectors resulting from the warp operation. If the incoming signal is a frequency equal to freqRef+freqDelta, slices in the warped slice record will be aligned with each other or substantially aligned with each other, and will combine to give the maximum possible filter response.

FINDING CARRIER BY WARPING AND SLICE COMBINATION—According to one embodiment, the warping and slice combining functions shown and described herein may be used to identify the incoming carrier during the initial phase of the detection process by searching for the transmitted carrier over a range of frequencies. As shown in FIG. **9**, freqRef is a reference frequency such as, for example, the frequency at which the transmitter was nominally designed to transmit. The actual carrier **904** may be unknown a priori to the receiver **104**, which may then search for the actual carrier, armed only with the knowledge of the reference frequency and perhaps some knowledge of the transmitter (for example, that the actual frequency at the receiver is unlikely to deviate from the reference frequency by more than some number of Hertz). According to one embodiment, to find the actual carrier **904** of the incoming signal, the incoming signal may be sampled and converted to digital form (optionally after some analog pre-processing) and converted to slice data (complex cosine, sine pairs). The received incoming data is, therefore, converted to slice data, indexed and stored (the sequential storing of the slice data starting from a known memory location may inherently operate to index the slice data) as the ADC **110** generates samples from the incoming pre-processed (e.g. filtered, amplified and/or normalized among other possible operations) analog data. The sampled incoming data (e.g. samples generated by the ADC **110**) need not be stored and if stored, may be discarded after the generation and storage of the slice data. The stored slices may then be combined over a selectable number of slices to achieve a filter **905** having a correspondingly selectable bandwidth. The bandwidth of the filter may be selected by combining fewer (resulting in a broader filter) or a greater number of slices (resulting in a narrower filter). A peak in the filtered slice data may be indicative of the actual carrier. If no peak is detected indicative of the presence of the actual carrier **904** within the pass-band of the filter, the warping function shown and described above may be used to warp the original slices (in exemplary FIG. **9**) to a next candidate frequency **906**, a shift of freqDelta Hz in FIG. **9**. The warped slices may again be combined to form a selectably narrow or broad filter at a new center frequency **907** and the presence of a peak **908** that is indicative of the actual carrier may be checked. This process may be repeated rapidly until the frequency of the actual carrier **904** is encompassed within the pass-band of the filter **909**. Increasingly good estimates of the frequency of the actual carrier **904** may then be made by constructing one or more filters having a narrower band-width (by combining a greater number of slices) and checking for the presence of the actual carrier **904**. Such narrower filters may aid the detection process, as a great deal of the noise may be attenuated, such that much of the energy within the pass-band of the filter originates from the carrier **904**. The carrier hunt strategy described above is one simple strategy for locating the actual carrier. Other strategies may be envisioned that use warping and slice combination functions to achieve the same end.

USING A SINGLE SLICE RECORD TO DETECT FSK—According to one embodiment, the warping function shown and described herein may be used for efficient detection of Frequency Shift Keying (FSK) modulation. It is to be noted that FSK detection may also be carried out by performing two parallel slice computations, one at freq0 and one at freq1. Referring now to FIG. **10**, the incoming data may be converted to slice data at one reference frequency (freqRef) **1001** that may be selected, according to one embodiment to be, for example, about mid-way between the known or nominal upper (freq1) **1002** and nominal lower (freq0) **1003** FSK frequencies. If not already, the slice data may then be indexed and stored as the ADC **110** generates digital samples from the incoming pre-processed analog data. The incoming data (e.g. samples from the ADC **110**) need not be stored and if stored, may be discarded after the acquisition and storage of the slice data. The stored slices may then be selectably warped over a selectable number of frequencies and combined to achieve a first relatively wide-band filter having a center frequency that is centered on one of the two nominal FSK frequencies, say freq0 **1004**. Effectively, this re-tunes the receiver **104** from a first frequency (freqRef in this example) to a second frequency freq0 away from the first frequency by an amount (in Hz) equal to the difference between freqRef and freq0. Similarly, the original stored slices may then be selectably warped over a selectable number of frequencies and combined to achieve a second relatively wide-band filter having a center frequency that is centered on the second of the nominal FSK frequencies, freq1 **1005** in this example. As was the case with the re-tuning of the receiver **104** to freq0, this effectively retunes the receiver **104** from the first frequency (freqRef in this example) to a second frequency freq1 away from the first frequency by an amount equal to the difference between freq1 and freqRef. When re-tuning the receiver **104** to freq0 and freq1, the pass-band of the first **1004** and second **1005** filters may be configured to be relatively wide (by combining relatively few slices) so as to increase the likelihood that, in each instance, the actual FSK frequencies (presumably in the vicinities of freq0 and freq1) will be located within the pass-band of the respective first and second filters. The warping function may be applied as needed to hunt or fine-tune for the actual FSK frequencies. The detection may be refined by constructing relatively narrower filters (by combining a relatively greater number of slices), which would increase the S/N of the output by attenuating a greater amount of noise.

Indeed, according to one embodiment and with reference to FIG. **11**, supposing that an indication of the actual first and second FSK frequencies (actualfreq0 at reference numeral **1104** and actualfreq1 at reference numeral **1110**) is detected within the pass-band of the wide-bandwidth filters generated from the slice data, the warping function may be used again for a precise identification of the two actual FSK frequencies actualfreq0 **1104** and actualfreq1 **1110**. As shown, freq0 **1102** and actualfreq0 **1104** differ by freqDelta0 Hz, as shown at reference numeral **1106**. Similarly, freq1 **1108** and actualfreq1 **1110** differ by freqDelta1 Hz, as shown at reference numeral **1112**. The two deltas, namely freqDelta0 **1106** and freqDelta1 **1112**, represent the amount of deviation of the two FSK frequencies away from the nominal FSK frequencies freq0 **1102** and freq1 **1108** at which the transmitter was designed to transmit. Such deviation may be caused by, for example, a calibration error caused by imperfect tuning of the transmitter at the factory, temperature effects, or other environmental effects such as local conductivity around the transmitter that influence the transmitted frequency. As such, freq0 **1102** and freq1 **1108** may be thought of as a first order approximation of the location of actualfreq0 **1104** and actualfreq1 **1110**, respectively. To fine tune the receiver **104** to the two actual FSK frequencies actualfreq0 **1104** and actualfreq1 **1110** and to reject unwanted signal(s) (if any), the warping function may be again applied to the already-warped slice data to iteratively (if required) create suitably narrow bandwidth filters at different center frequencies until strong peaks indicative of the presence of the actual frequencies at **1104** and **1110** appear in the pass-bands of the filters. This process may be iteratively carried out until the actual frequencies at **1104** and **1110** are sufficiently isolated and the frequencies (noise, generally) on either side of the thus-created narrowband filters are rejected to enable reliable detection and decoding.

Referring again to FIG. **11**, after having detected the actual FSK signals around nominal frequencies freq0 **1102** and freq1 **1108**, the warping function may be applied to re-tune the receiver **104** (if not already re-tuned as a result of searching for the two actual FSK frequencies) from freq0 **1102** to actualfreq0 **1104**, by warping the filter by a few Hz, shown in FIG. **11** at freqDelta0 **1106**. Similarly, the warping function also may be applied to re-tune the receiver **104** from freq1 **1108** to actualfreq1 **1110**, by again warping the filter by a few Hz, shown in FIG. **11** at freqDelta1 **1112**. The result of this fine tuning, therefore, is a receiver **104** that utilizes slice data acquired at freqRef and that has been re-tuned to the first and second actual FSK frequencies; namely, freqwarp0 **1114** (equal to freq0−freqRef+freqDelta0) and freqwarp1 **1116** (equal to freq1−freqRef+freqDelta1). As the relationship between the two FSK frequencies is known a priori to the receiver (such as a known ratio relationship), such relationship may be exploited by the receiver as it tunes the two separate FSK frequencies.

According to one embodiment, therefore, an FSK receiver **104** may be configured to be tuned at a frequency freqRef that is neither the first FSK frequency freq0 nor the second FSK frequency freq1. The receiver **104** may then be re-tuned, using warp and slice combining functions, to each of the first and second FSK frequencies freq0 and freq1 and, thereafter, to the actual FSK frequencies through fine-tuning without, however, re-acquiring data at either of these frequencies; that is, without re-acquiring new raw ADC data at the re-tuned frequency or without reading previously stored sampled raw data from memory **114**. Moreover, such re-tuning according to embodiments may be carried out by processing vastly less data (by, e.g. orders of magnitude or more) than would otherwise be required had new ADC data been acquired or had the original data been maintained in memory **114** and re-processed to detect the freq0 and freq1 FSK frequencies. That is, according to one embodiment, the re-tuning of the receiver **104** may be effected solely by carrying out what are, for the most part, addition operations with some multiplication operations on a limited store of previously-acquired slice data.

WARPING TO REDUCE NOISE, ALIGN SLICES TO AN AXIS—Referring to FIG. **8**, the aligned slice vectors have a non-zero cosine component along the x-axis and a non-zero sine component along the y-axis. Each of these components may include some signal component and some noise. According to one embodiment, if the aligned slice vectors of FIG. **8** were forced to align with, for example, the x-axis (thereby driving the sine component thereof to zero), the sine components thereof would include zero signal and only noise. This noise may be safely ignored, as all of the energy of the slice (and thus of the signal) is now aligned with the x-axis. Accordingly, one embodiment changes the warping function WF in the detection to put all the slice energy into one of the two dimensions. For instance, if all slices were to be pointed along the real axis (cosine, x-axis), then no signal would be left in the imaginary (sine, y-axis) axis, leaving only noise therein. According to one embodiment, therefore, aligning the warped slices to either the x, or y axis may be carried out by adding a constant angle (Θ) to the warped slices:

$$WF(\Phi)=(i\cdot\Phi)+\Theta;$$

Accordingly, this implementation of the warping function adds a constant angle after scaling Φ by i, the slice index number. The addition of the constant angle, Θ (which may be positive or negative in sign) causes the output slices to be aligned in a selected (and preferred) direction, for example, aligned with the real axis (cosine component or x-axis) or the imaginary axis (sine component or y-axis). The warped slices, however, may be aligned by warping to any angle though judicious selection of the constant angle.

WARPING TO CORRECT FREQUENCY DEFECT—According to further embodiments, warping functions may be devised based on more sophisticated patterns or sequences of the slice index number. For example, the scaling factor need not be an integer. For example, if a transmitter transmits packets whose frequency falls (or rises) towards the end of a packet, the warping function may be adapted to track that falling frequency toward the end of the packet. For example, assuming the receiver has identified the starting slice index of a packet, the following warp function could be applied to the slice record for the purpose of aligning all slices in a packet.

$$\text{WF( )}=(\text{Scaling Factor}\cdot i\cdot\Phi)$$

where, for example, Scaling Factor=[1 1 1 1 1 1 1 1 0.9 0.9 0.8 0.8 0.7 0.6 0.5 0.3 etc.] The scaling factor may be an algebraic expression or may be read from a table stored in memory **114** with suitable values stored therein. The warping function, in this manner, may be configured to track any quantifiable change in the frequency profile of the received packets, thereby allowing for, for example, non-constant and/or non-integer sequential adjustments of warping angle Φ from slice to slice.

WARPING TO DETECT CHIRP—Warping, according to one embodiment, also may be applied to any incoming signal having a non-constant frequency, such an intentional chirp-type signal, or a transmitter with poor frequency control where the frequency of the transmitted signal increases or decreases as the transmitter battery depletes.

For example, if the incoming signal is a rising chirp, the slice data may be warped by an angle that increases faster than the integer pattern shown and described relative to FIGS. **7** and **8**. For example, the first slice may be warped by 1·ϕ, the second slice may be warped by 2.2·Φ, the third slice may be warped by 3.3·Φ, and so on. According to embodiments, therefore, the computation of the warping angle may comprise any function that reflects the frequency structure of the expected incoming signal. The use of slices, according to embodiments, enables efficient use of resources, in that a high degree of data compression may be achieved by converting the raw sample stream from the ADC **110** to slice data and discarding (or failing to store) the raw sample data. This is significant not only in terms of the size of the memory **114** required, but also in terms of the amount of calculations to be carried out later in the detection and decoding processes. The use of slices, warping functions, and slice combining functions, according to embodiments, also affords the receiver **104** a high degree of flexibility at multiple places in the detection algorithm. Because the original slices can be designed to have a relatively wide bandwidth, they can be re-tuned/warped over great number of Hz in either direction. For example, a slice with a 5000 Hz bandwidth, according to embodiments, may be warped 1000-2000 Hertz or more, up or down, without significant loss of signal strength. SLICE CORRELATION: FINDING A KNOWN PATTERN—According to one embodiment, a detection procedure may be carried out, to determine the presence of one or more data packets in the slice record. According to one embodiment, it is not the original raw ADC sampled data stream that is analyzed (which may have been previously discarded anyway), but the indexed and stored slice data. According to one embodiment, a function (for example, a real or complex correlation function) may be applied to the slice data, to compare the slice data with one or more pre-stored slice patterns corresponding to a known slice pattern in the signal. According to one embodiment, the data packets sought to be detected (and framed, to determine the boundaries thereof) may comprise a preamble of known length and configuration, followed by a payload of known length from which useful information may be extracted by a decoding process. For example, each data packet sought to be detected may comprise a preamble comprising 11 bits. For example, the preamble may comprise a known sequence such as, for example, a sequence of 7 zeros, followed by 1010 (00000001010). To determine the presence of a packet, therefore, a real or complex correlation function may be applied, according to one embodiment, to cross-correlate slice data to a slice pattern corresponding to the known preamble. To the extent that the slice data encodes data corresponding to one or more preambles of one or more data packets, the correlation function will return higher results when the preamble(s) of the input slice data and that of the template are aligned with one another, correspondingly lower results as the preambles in the input slice data and the template are only partially aligned with one another and lowest results when the preambles in the input slice data and the template are not aligned with one another or the input slices do not comprise any packets. This cross-correlation operation represents a very narrow-band filter, with bandwidth proportional to the reciprocal of the number of slices in the known preamble.

In one embodiment, slice correlation and warping may be used together to provide a fair estimate of the actual carrier frequency of the received signal, as the receiver **104** is iteratively re-tuned through warping and the resultant warped slices correlated with, for example, the expected slice pattern used to determine the presence and boundaries of the preamble. In this manner, a high correlation value may be associated with the actual carrier frequency of the received signal.

SLICE CORRELATION: FINDING EVIDENCE OF A PACKET—According to one embodiment, a detection procedure may be carried out to determine the presence of one or more data packets in the slice record prior to determining the frequency(ies) of the carrier(s). As in the discussion of cross-correlation with a pre-stored template above, only the indexed and stored slice data need be analyzed. According to one embodiment, a function (for example, a real or complex correlation function) may be applied to the slice data, to compare the slice data with itself (auto-correlation). Often, it is useful to perform correlation calculations at just a few different lags. For example, is the energy for an entire slice record, A, can be estimated by slice correlation with lag=0:

$$\text{Corr}(0)=\sum_{n=1}^{N}A_n\times A_n$$

AutoCorr(0) represents the baseline energy level for the slice record, against which other autocorrelations can be compared.

For a slice record containing no packets, slice auto-correlation with lag=1:

$$\mathrm{Corr}(1) = \sum_{n=1}^{N-1} A_n \times A_{n+1}$$

According to one embodiment, prior to determining the frequency(ies) of the carrier(s), an autocorrelation may be performed on the slice record A to determine if a packet is present therein. For a case where the slice record contains one or more packets, Corr(1) will have a higher value relative to Corr(0). This is an indication that a packet exists somewhere in the slice record. For a slice record containing no packets, slice auto-correlation with lag=1 will have a very low value relative to AutoCorr(0) if the slice record contains only uncorrelated noise. According to one embodiment, a packet may be considered to have been detected when the autocorrelation term Corr(1)/Corr(0) is determined to be above a predetermined threshold.

Confirmatory evidence for the presence of a packet can be developed if multiple packets exist in the slice record at a known packet separation m (measured in slices). Correlating the slice record with a lag=m (lag equal to the packet spacing) produces a high correlation result if packets are present at the anticipated spacing:

$$\mathrm{Corr}(m) = \sum_{n=1}^{N-m} A_n \times A_{n+m}$$

According to one embodiment, a packet may be considered to have been detected when the correlation terms computed multiple times over a range of anticipated packet separations, Corr(m±range), are determined to be above a predetermined threshold relative to Corr(0). The expected range of packet separations arises due to variations in the as-yet to be determined packet frequency. In this manner, using slice data, packet detection may be carried out by correlating a delayed version of the slice record A with the slice record A and monitoring the magnitude of the resulting correlation terms.

OVERLAPPING PACKETS—According to one embodiment, the greater the number of packets in a slice data record, the better the auto-correlation results may be. Slices representing multiple suspected packets may be added to one another, to increase the likelihood of correct packet detection. Moreover, the packet boundaries may be determined by adding two or more suspected packets with one another. The result of the addition will be highest when the respective packets are perfectly aligned. The suspected packets may be shifted by one or more slices (according to one embodiment, by the number of slices between packets) and the addition operation may be applied to the shifted packets in this manner to determine the boundaries of the packets. It is to be understood, however, that there is more than one method of packet detection and framing. All such methods are understood to be encompassed by the present embodiments. It is also to be understood that, having identified the boundaries of packets, the signal to noise ratio is increased when only the packet is observed, as the only noise present is that within the packet and as all noise outside of the packet boundaries may be excluded or greatly attenuated.

MODULATION SCHEME: BPSK—The packet need not be encoded and decoded using FSK modulation. According to one embodiment, another forms of digital modulation may be used such as, for example, binary phase shift keying (BPSK). In such an encoding scheme, the symbol 0 may be encoded using a sine waveform of a certain number of cycles and the symbol 1 may be encoded using a −sine waveform out of phase by π radians of the same number of cycles. For example, a packet encoded using BPSK may comprise a preamble and a payload. The preamble may comprise, for example, seven 0s, followed by 1, 0, 1 and 0, in the form (000000001010). Real or complex correlation methods may be utilized, as described above, to determine the presence of one or more packets by comparing the slice record to a predetermined slice pattern representing the preamble. This operation serves to identify the presence of a packet and to synchronize the receiver **104** with the starting bit of the preamble. As noted above, the correlation function may additionally provide an estimate of the actual carrier frequency of the signal.

ITERATIVE DECODING—According to one embodiment, the bits of the packet payload may be decoded in the receiver one at a time in succession. To determine whether a bit is a logic zero or a logic one, successive correlations against a "zero template" and a "one template" may be used, with the larger of the two correlation results indicating the value of the bit. Such a method may, according to one embodiment, be used to decode the payload of a packet that appears after the preamble thereof, as the bit sequence in the payload is most often unknown a-priori by the receiver.

ARCTANGENT—According to one embodiment, in cases in which the signal to noise ratio is reasonable (e.g. around 0 dB or above), taking the arctangent of slices containing suspected packets may be revealing, and may identify the presence or absence of a packet.

CARRIER HUNT STRATEGY—According to one embodiment, once the presence of one or more packets in the slice data is determined, to determine the frequency(ies) with which the packets were modulated, whether encoded using FSK or PSK (for example) or however encoded, if a rough estimate of the actual frequency of the signal is known (say within 20 Hz, for example for an exemplary 20 kHz signal), the magnitudes of the correlations of the preamble, for example, may be determined at each of 20 different frequencies, at 1 Hz (or less) increments. According to one embodiment, the rough estimate of the carrier frequency(ies) may be the nominal frequency(ies) with which the transmitter is designed to transmit. Some knowledge of the communication channel may enable such an educated guess as to the frequency range within which the actual signal is likely to be found. In such a case, after having computed the correlation for each frequency within the frequency range, the frequency associated with the largest correlation magnitude may be safely assumed to be the (or one of the) carrier frequencies.

FIX DETECTION BY FLATTENING PHASE—It is to be understood that other methods of determining the frequency of a detected packet may be employed, without departing from the scope of the embodiments described in the present disclosure. For example, for each bit of a packet, the phase angles of the bit's constituent slices may be determined. The phase angles may, according to one embodiment, be determined by taking the arctangent (the ratio of the sine component of the slice to the cosine component) of each slice. Such a method may be best implemented when the signal to noise ratio is above a predetermined threshold such as, for example, about 0 dB. For BPSK modulation, such a phase angle, may swing between 0 and 2π, in a saw-tooth like fashion. The presence of such a saw-tooth pattern is suggestive that the constituent slices making up the bits being examined are, using the polar representation of FIG. **7**, misaligned, as are slices 1, 2, 3 and 4 in that figure. With reference to FIG. **8**, when the frequency being tested results in warping angles that form more or less a straight line (as opposed to a saw-tooth pattern), that frequency may be the or close to the actual frequency of the signal of interest. For PSK, for example, the warping angles will shift from one warping angle to another warping angle that is indicative of the PSK frequency at which the data was encoded. The resultant pattern may then resemble a square wave, from which the data may be readily apparent.

MODULATION SCHEME: MSK—Using methods similar to those previously described, data encoded using other modulation formats may be detected and decoded using only the stored slices and the warping function described herein. For example, the data in the slices may have been encoded using, for example, Multiple Shift Keying (MSK) using, for example, 4 frequencies or, for example, 16 frequencies to represent different symbols. In this case, each symbol may comprise information bits encoded with one or more frequencies (e.g. one or two) out of a plurality (e.g. 16) of frequencies, with each symbol potentially representing more than one bit. Other modulation formats that encode data may be decoded using only the slice information (and not the original data from the ADC **110**, which has since been discarded) and the warping and slice combining functions described herein. Moreover, data encoded using combinations of modulation formats also may be detected and decoded, again using only slice information, warping, and slice combination. For example, data encoded with a combination of MSK and PSK may be decoded from the retained slice data.

In each case, the computational load on the controller **112** portion of the receiver **104** is lighter than it otherwise would be if the controller **112** were obliged to re-process the original raw data stream. For similar reasons, the memory requirements of the receiver's controller **112** are orders of magnitude less than would be the case had it been necessary to store the original raw incoming data in order to operate thereon later, during detection and decoding.

ONE-BIT ADC—For situations exhibiting an especially low signal to noise ratio, it may be advantageous for the receiver **104** to use an analog comparator or a 1-bit ADC to quantize the signal as being above or below a predetermined threshold (encoded as two values: +1 and −1). In this manner, the amount of data that is stored in the slice construct, according to embodiments, greatly decreases compared to storing multi-bit representations of the signal. A comparator or a 1-bit ADC may be used to good advantage in situations exhibiting low signal to noise ratio, as it enables samples to be gathered at a very high sample rate while still computing slices in a fast real-time loop on an ordinary processor. Inside the real-time loop, multiply operations are greatly simplified because one of the operands is either +1 or −1.

FIG. **12** is a logic flow of a method according to one embodiment. As shown therein, at B121 a signal that encodes one or more data packets is received. At B122, the received signal then may be sampled in an ADC to generate sampled values. At B123, a slice then may be generated and stored in memory, where each slice comprises a pair of values representing a selected slice interval of time. At B124, data packets are detected and decoded from the stored slices using various combinations of warp and slice combination operations.

FIG. **13** is a logic flow of a method according to one embodiment. As shown therein, at B131, a signal may be received that encodes a data packet at a first frequency. The received signal, as shown at B132, may then be sampled in an ADC to generate sampled values. The sampled values, as called for at B133, may then be correlated with first and second templates of values obtained at a second frequency that may be different from the first frequency to generate slices at the second frequency. According to one embodiment and as described and shown herein, the first template may be generated using a first reference function and the second template may be generated using a second reference function that is in quadrature with the first reference function. Some or all of the slices at the second frequency may be transformed (also denoted as "warped" herein) to slices at the second frequency (also denoted as "freqRef" herein), plus or minus an offset (denoted as "freqDelta" herein), as shown at B134. As shown at B135, a filter having a center frequency at the second frequency plus or minus the offset may be generated by combining the transformed (warped) slices.

According to one embodiment, a determination may then be made, as suggested at B136, whether the first frequency (the frequency of interest at which the data packet(s) is/are encoded) is within the pass-band of the generated filter. If the first frequency is indeed within the pass-band of the thus-generated filter, further steps may be carried out such as, for example, detection and decoding steps, as detailed herein. If the first frequency is not present within the pass-band of the generated filter, the slice transforming (warping) and filter generating (slice combining) steps may be iteratively repeated using respectively different offsets until the first frequency is indeed within the pass-band of the filter, as indicated by the NO branch of B136.

While certain embodiments of the disclosure have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the disclosure. Indeed, the novel methods, devices and systems described herein may be embodied in a variety of other forms. Furthermore, various omissions, substitutions and changes in the form of the methods and systems described herein may be made without departing from the spirit of the disclosure. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the disclosure. For example, those skilled in the art will appreciate that in various embodiments, the actual physical and logical structures may differ from those shown in the figures. Depending on the embodiment, certain steps described in the example above may be removed, others may be added. Also, the features and attributes of the specific embodiments disclosed above may be combined in different ways to form additional embodiments, all of which fall within the scope of the present disclosure. Although the present disclosure provides certain preferred embodiments and applications, other embodiments that are apparent to those of ordinary skill in the art, including embodiments which do not provide all of the features and advantages set forth herein, are also within the scope of this disclosure. Accordingly, the scope of the present disclosure is intended to be defined only by reference to the appended claims.

Embodiments of the present invention have been described above. Further embodiments of the present invention can also be realized by systems or apparatuses that read out and execute programs recorded on a memory device to perform the functions of the above-described embodiment(s), and by a method, the steps of which are performed by, for example, reading out and executing a program recorded on a memory device to perform the functions of the above-described embodiment(s). For this purpose, the program may be provided to the system or apparatus (e.g. receiver), for example via a network or from a recording medium of various types serving as the memory device (e.g. computer-readable medium).

The present invention may be defined by way of the following clauses. It will be understood that the features recited are interchangeable defined by the following clauses and their dependencies. That is, the features of the clauses may be combined to define the present invention.

Clauses

1. A method, comprising:

receiving a signal, the signal encoding a data packet;

sampling the received signal;

generating and storing a plurality of slices comprising pairs of values for each of a selected number of samples of the signal; and

detecting a presence of and decoding the data packet from the stored slices.

2. The method of clause 1, wherein generating each of the plurality of slices comprises:

correlating samples of the signal with a first reference template;

generating a first value of the pair of values;

correlating the selected number of samples of the signal with a second reference template; and

generating a second value of the pair of values.

3. The method of clause 2, wherein the first reference template comprises a cosine function at a reference frequency and the second reference template comprises a sine function at the reference frequency.

4. The method of any of clauses 1 to 3, further comprising forming a filter by combining a number of the plurality of slices.

5. The method of any of clauses 1 to 4, wherein detecting the presence of the packet comprises detecting a carrier frequency within a pass-band of a filter formed by the plurality of slices.

6. The method of any of clauses 1 to 4, wherein detecting the presence of the packet comprises detecting a carrier frequency within a pass-band of a filter formed by combining slices.

7. The method of any of clauses 4 to 6, wherein detecting further comprises re-tuning a center frequency of the filter from a first center frequency to a second center frequency that is different from the first center frequency using the stored slices.

8. The method of clause 7, wherein re-tuning the center frequency of the filter comprises warping the slices from which the filter was formed by rotating the respective pairs of values thereof by a quantity.

9. The method of clause 8, wherein the quantity comprises a rotation angle, a scaling factor and indices associated with the slices from which the filter was formed.

10. The method of clause 8, wherein the quantity comprises a sum of a phase angle from a reference frequency and a product of a rotation angle and a slice index.

11. A signal receiver, comprising:

analog-to-digital converter means (ADC) configured to sample a received signal;

memory means;

controller means coupled to the memory means and configured to:

generate and store, in the memory means, a slice comprising a pair of values for each of a selected number of samples of the signal; and

detect a presence of and decode the data packet from the stored slices.

12. The signal receiver of clause 11, wherein the memory means is configured to store at least a first reference template and a second reference template and wherein the controller means is further configured to correlate the selected number of cycles of the sampled signal with the first reference template to generate a first value of the pair of values and to correlate the selected number of samples of the signal with the second reference template to generate a second value of the pair of values.

13. The signal receiver of clause 11 or clause 12, wherein the controller means is further configured to combine a number of slices to form a filter.

14. The signal receiver of clause 13, wherein a bandwidth of the filter is related to the number of combined slices.

15. The signal receiver of any of clauses 11 to 14, wherein the controller means is further configured to detect the presence of the packet by detecting a carrier frequency within a pass-band of a filter formed by combining the slices.

16. The signal receiver of any of clauses 13 to 15, wherein the controller means is further configured to re-tune, using the stored slices, a center frequency of the filter from a first center frequency to a second center frequency that is different from the first center frequency.

17. The signal receiver of any of clauses 11 to 16, wherein the signal encodes data packets at a first frequency and wherein controller means is further configured to:

correlate the samples with first and second templates of values obtained at a second frequency that is different from the first frequency to generate a plurality of slices that each comprise a pair of values;

transform at least some of the plurality of slices at the second frequency to slices at the second frequency plus or minus an offset, and

generate a filter having a center frequency at the second frequency plus or minus the offset by combining the transformed slices.

18. A method, comprising:

receiving a signal, the signal encoding a data packet at a first frequency;

sampling the signal to generate sampled values;

correlating the sampled values with first and second templates of values obtained at a second frequency that is different from the first frequency to generate a plurality of slices at the second frequency, each of the slices comprising a pair of values;

transforming at least some of the plurality of slices at the second frequency to slices at the second frequency plus or minus an offset, and

generating a filter having a center frequency at the second frequency plus or minus the offset by combining the transformed slices.

19. The method of clause 18, further comprising determining whether the first frequency is within a pass-band of the generated filter

20. The method of clause 19, further comprising iteratively transforming, generating and determining using respectively different offsets until the first frequency is within the pass-band of the filter.

21. A method, comprising:

receiving a signal, the signal encoding a data packet;

sampling the signal to generate sampled values;

generating a slice record comprising a plurality of slices by correlating the sampled values with first and second reference templates, the first reference template comprising a first reference function and the second reference template comprising a second reference function in quadrature with the first reference function;

auto-correlating a portion of the slice record with a delayed version of the portion of the slice record to generate auto-correlation terms; and determining when magnitudes of auto-correlation terms exceed a predetermined threshold for a predetermined number of auto-correlation terms.

22. The method of clause 21, further comprising determining a carrier frequency of the received signal.

23. The method of clause 22, wherein determining comprises:

warping at least some of the plurality of slices by a frequency offset, and

generating a filter from the warped slices and,

determining whether the carrier frequency is within a passband of the generated filter.

24. A method, comprising:

receiving a signal, the signal encoding a data packet;

sampling the signal to generate sampled values;

generating a slice record comprising a plurality of slices from the sampled values by correlating the sampled values with first and second reference templates, the first reference template comprising a first reference function and the second reference template comprising a second reference function in quadrature with the first reference function;

cross-correlating the slice record with a stored template to generate cross-correlation terms; and

determining when a magnitude of the cross-correlation terms exceeds a predetermined threshold for a width of the stored template.

25. The method of clause 24, wherein the first reference template comprises a cosine function and wherein the second template function comprises a sine function.

26. The method of clause 24, further comprising determining a carrier frequency of the received signal.

27. A method, comprising:

receiving a signal;

sampling the signal to generate sampled values;

correlating the sampled values with predetermined first and second templates of values obtained at a first frequency to generate a plurality of slices at the first frequency;

transforming at least some of the generated plurality of slices at the first frequency to slices at a second frequency that is different from the first frequency;

generating a first filter having from the slices at the second frequency;

transforming at least some of the generated plurality of slices at the first frequency to slices at a third frequency that is different from the first and second frequencies, and

generating a second filter from the slices at the third frequency.

28. The method of clause 27, further comprising discarding the generated sampled values of the received signal after generating the plurality of slices at the first frequency.

29. The method of clause 27 or clause 28, further comprising detecting a first carrier frequency within a pass-band of the first filter and detecting a second carrier frequency within a pass-band of the second filter.

30. A method, comprising:

receiving a signal, the signal encoding data packets;

sampling the signal to generate sampled values;

generating a slice record comprising a plurality of slices from the sampled values by correlating the sampled values with first and second reference templates, the first reference template comprising a first reference function and the second reference template comprising a second reference function in quadrature with the first reference function;

auto-correlating a portion of the slice record spanning at least two preambles of the encoded data packets with a delayed version thereof to generate auto-correlation terms; and

determining when magnitudes of auto-correlation terms exceed a predetermined threshold for a predetermined number of auto-correlation terms.

31. The method of clause 30, further comprising determining boundaries of the data packets from magnitudes of the auto-correlation terms.

32. The method of clause 30 or clause 31, wherein the carrier frequency of the signal is detected when successive phase angles, across bits of the data packet, least resemble a first predetermined pattern and most resemble a second predetermined pattern.

33. A program, which when executed by a computer, causes the computer to carry out the method of any of clauses 1 to 10 and 18 to 32.

34. A program which, when executed by a computer, causes the computer to function as the signal receiver of any of clauses 11 to 17.

35. A storage medium storing the program according to clause 33 or clause 34.

Accordingly, the preceding merely illustrates the principles of the invention. It will be appreciated that those skilled in the art will be able to devise various arrangements which, although not explicitly described or shown herein, embody the principles of the invention and are included within its spirit and scope. Furthermore, all examples and conditional language recited herein are principally intended to aid the reader in understanding the principles of the invention and the concepts contributed by the inventors to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions. Moreover, all statements herein reciting principles, aspects, and aspects of the invention as well as specific examples thereof, are intended to encompass both structural and functional equivalents thereof. Additionally, it is intended that such equivalents include both currently known equivalents and equivalents developed in the future, i.e., any elements developed that perform the same function, regardless of structure. The scope of the present invention, therefore, is not intended to be limited to the exemplary aspects shown and described herein. Rather, the scope and spirit of present invention is embodied by the appended claims.

We claim:

1. A method, comprising:

receiving a signal, by an analog front-end of a receiver, the signal encoding a data packet;

sampling, by and analog-to-digital converter, the received signal;

generating, by a controller, and storing, by the controller in a memory coupled to the controller, a plurality of slices comprising pairs of values for each of a selected number of samples of the signal;

detecting, by the controller, a presence of and decoding, by the controller, the data packet from the stored slices;

forming, by the controller, a filter having a predetermined pass-band by combining, by the controller, a number of the plurality of slices; and

re-tuning, by the controller, a center frequency of the filter from a first center frequency to a second center frequency that is different from the first center frequency using the stored slices by warping the stored slices from which the filter was formed by rotating the respective pairs of values by a quantity.

2. The method of claim **1**, wherein generating and storing, by the controller, are carried out as the received signal is sampled.

3. The method of claim 1, further comprising discarding, by the controller, the sampled signal as the slice is generated and stored.

4. The method of claim 1, wherein generating and storing, by the controller, are carried out with constituent values of each of the slices being generated using a first reference function and a second reference function that is in quadrature with the first reference function.

5. The method of claim 1, wherein generating, by the controller, each of the plurality of slices comprises:

Correlating, by the controller, samples of the signal with a first reference template;

generating, by the controller, a first value of the pair of values;

correlating, by the controller, the selected number of samples of the signal with a second reference template; and

generating, by the controller, a second value of the pair of values.

6. The method of claim 5, wherein the first reference template comprises a cosine function at a reference frequency and the second reference template comprises a sine function at the reference frequency.

7. The method of claim 6, wherein the first value of the pair of values of the slice comprises a dot product of the sampled signal and the cosine function at the reference frequency and the second value of the pair of values of the slice comprises a dot products of the sampled signal and the sine function at the reference frequency.

8. The method of claim 1, wherein a bandwidth of the filter is related to the number of combined slices.

9. The method of claim 8, wherein when a first number of slices are combined, the filter has a first bandwidth and wherein when a second number, greater than the first number, of slices are combined, the filter has a second bandwidth that is narrower than the first bandwidth.

10. The method of claim 1, wherein detecting, by the controller, the presence of the data packet comprises detecting, by the controller, a carrier frequency within the predetermined pass-band of the filter formed by the plurality of slices.

11. The method of claim 1, wherein detecting, by the controller, further comprises re-tuning, by the controller, the center frequency of the filter from a first center frequency to a second center frequency that is different from the first center frequency using the stored slices.

12. The method of claim 1, wherein the quantity comprises a rotation angle, a scaling factor and indices associated with the slices from which the filter was formed.

13. The method of claim 1, wherein the quantity comprises a sum of a phase angle from a reference frequency and a product of a rotation angle and a slice index.

14. A signal receiver, comprising:

an analog front-end configured to receive a signal, the signal encoding a data packet;

an analog-to-digital converter (ADC) configured to sample a received signal;

a memory;

a controller coupled to the memory and configured to:

generate and store, in the memory, a slice comprising a pair of values for each of a selected number of samples of the signal;

detect a presence of and decode the data packet from the stored slices;

combine a number of the slices to form a filter having a predetermined pass-band; and

re-tune a center frequency of the filter by warping the slices from which the filter was formed by rotating the respective pairs of values by a quantity.

15. The signal receiver of claim 14, wherein the controller is configured to generate and store the slices as the ADC samples the received signal.

16. The signal receiver of claim 14, wherein the controller is further configured to discard the sampled signal as the slices are generated and stored.

17. The signal receiver of claim 14, wherein the controller is further configured to generate each of the slices such that constituent values thereof are generated using a first reference function and a second reference function that is in quadrature with the first reference function.

18. The signal receiver of claim 14, wherein the memory is configured to store at least a first reference template and a second reference template and wherein the controller is further configured to correlate the selected number of cycles of the sampled signal with the first reference template to generate a first value of the pair of values and to correlate the selected number of samples of the signal with the second reference template to generate a second value of the pair of values.

19. The signal receiver of claim 18, wherein the first reference template comprises a first reference function at a reference frequency and the second reference template comprises a second reference function at the reference frequency.

20. The signal receiver of claim 19, wherein the first reference function is in quadrature with the second reference function.

21. The signal receiver of claim 20, wherein the first reference function comprises a cosine function and the second reference function comprises a sine function.

22. The signal receiver of claim 21, wherein the first value of the pair of values of the slice comprises a dot product of the sampled signal and the cosine function at the reference frequency and the second value of the pair of values of the slice comprises a dot product of the sampled signal and the sine function at the reference frequency.

23. The signal receiver of claim 14, wherein a bandwidth of the filter is related to the number of combined slices.

24. The signal receiver of claim 23, wherein when a first number of slices are combined, the filter has a first bandwidth and wherein when a second number, greater than the first number, of slices are combined, the filter has a second bandwidth that is narrower than the first bandwidth.

25. The signal receiver of claim 14, wherein the controller is further configured to detect the presence of the data packet by detecting a carrier frequency within the pass-band of the filter formed by combining the slices.

26. The signal receiver of claim 14, wherein the controller is further configured to re-tune, using the stored slices, a center frequency of the filter from a first center frequency to a second center frequency that is different from the first center frequency.

27. The signal receiver of claim 14, wherein the quantity comprises a rotation angle, a scaling a factor and respective slice indices associated with the slices from which the filter was formed.

28. The signal receiver of claim 27, wherein the scaling factor is an integer.

29. The signal receiver of claim 27, wherein the scaling factor comprises an algebraic expression.

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