

(51) International Patent Classification:
H04W 64/00 (2009.01) *G01S 5/02* (2010.01)(21) International Application Number:
PCT/MY2009/000131(22) International Filing Date:
1 September 2009 (01.09.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

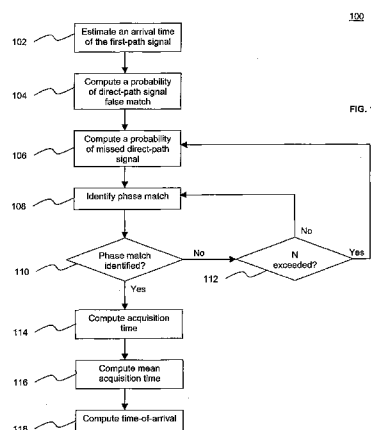
(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

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(54) Title: A METHOD OF TIME-OF-ARRIVAL ESTIMATION FOR DIRECT-PATH SIGNAL DETECTION IN AN ULTRA-WIDE BAND LOCALIZER



(57) Abstract: A method (100) of time-of-arrival estimation for direct-path signal detection in an ultra-wide band localizer using a maximum likelihood estimation algorithm to estimate an arrival time of a first-path signal (102), to compute a probability of direct-path signal false match (104) and to compute a probability of missed direct-path signal (106), wherein the method comprises steps of performing a search cycle with a value, N number of iterations to identify a phase match (108) of a direct-path signal; if the phase match of the direct-path signal is identified, an acquisition time is computed (114) and a mean acquisition time is computed (116), however if the phase match of the direct-path signal is not identified and the value, N has been exceeded, the probability of missed direct-path signal is re-computed (106) and performing the search cycle with the value, N number of iterations is repeated; and computing time-of-arrival (118) of the direct-path signal wherein time-of-arrival is a sum of the arrival time of the first-path signal and the mean acquisition time.



Published:

- *without international search report and to be republished
upon receipt of that report (Rule 48.2(g))*

A METHOD OF TIME-OF-ARRIVAL ESTIMATION FOR DIRECT-PATH SIGNAL DETECTION IN AN ULTRA-WIDE BAND LOCALIZER

FIELD OF INVENTION

The present invention relates to a method of time-of-arrival estimation for direct-path signal detection in an ultra-wide band localizer.

BACKGROUND ART

Ultra-wide band is a radio technology that transmits signals at a much wider bandwidth compared to conventional radio technologies and most ultra-wide band systems are designed for low power indoor applications. To complement further, the cost to implement ultra-wide band systems is substantially low.

The combination of wide bandwidth and low power provides a suitable platform for high speed or high data rates of information exchange capability and simultaneously reduces interference with other wireless applications. Additionally, the wide bandwidth of ultra-wide band signals results in signals with very high time resolution that enable high level of accuracy for location estimation applications.

With the development in position based applications, ultra-wide band technology has advanced as the preferred solution for indoor location systems over the more expensive Global Positioning System, suitable for outdoor location systems and the less accurate 802.11 wireless Local Area Networks and Bluetooth technology.

The implementation of ultra-wide band localizers in indoor location estimation applications poses some challenges during implementation of the same. Due to the nature of ultra-wide band technology itself, the first challenge, clock jitter, becomes an important factor in accuracy of distance measurement in location estimation since ultra-wide band signal pulses have very short, sub-nanosecond duration. Several synchronization schemes are employed to overcome clock jitter to enable high accuracy of location estimation.

The second challenge is, unlike outdoor environments where noise is the major external disturbance, indoor environments introduce aspects of multi-path propagation from reflection of the signals from walls and other objects as well as intermittent obstruction caused by walls and other objects resulting in non-line-of-sight or obstructed-line-of-sight. Hence, this poses difficulty and uncertainty of direct-path signal detection for distance measurement in location estimation. The detection of the direct-path signal has been optimized based on various time-of-arrival estimation algorithms and techniques.

Traditionally, in correlation based time-of-arrival estimation algorithms, correlations of the received signal with shifted versions of a template signal are considered. In a single path channel, the transmitted waveform can be used as the optimal template signal, and conventional correlation based estimation can be employed.

However, this approach is less effective for multi-path signals, as the optimal template signal is the received waveform instead of the transmitted waveform. The received waveform is a combination of the transmitted waveform and the channel impulse response. Therefore, the correlation of the received signal with the transmit waveform

template is suboptimal in a multi-path environment. If this suboptimal technique is employed in ultra-wide band indoor location systems, the correlation peak may not provide an accurate time-of-arrival since multiple replicas of the transmitted signal partially overlap due to multi-path propagation and the fact that the first multi-path component is often not the strongest signal or the signal with the highest energy level. For example, in the case of the hard non-line-of-sight situation, the first multi-path component is not the strongest signal, and in the case of accumulative time in multi-path signals, the selective rake fingers results in signals that are stronger than the direct-path signal.

To overcome this, time-of-arrival based techniques are employed in ultra-wide band localizers to accurately detect the direct-path signal. Nevertheless, the fundamental challenge in this technique is to reduce errors in direct-path signal delay estimation due to errors caused by multi-path propagation as well as intermittent obstruction.

SUMMARY OF INVENTION

In one embodiment of the present invention is a method of time-of-arrival estimation for direct-path signal detection in an ultra-wide band localizer using a maximum likelihood estimation algorithm to estimate an arrival time of a first-path signal, to compute a probability of direct-path signal false match and to compute a probability of missed direct-path signal, wherein the method comprises steps of performing a search cycle with a value, N number of iterations to identify a phase match of a direct-path signal; if the phase match of the direct-path signal is identified, an acquisition time is computed and a mean acquisition time is computed, however if the phase match of the direct-path signal is not identified and the value, N has been exceeded, the probability of missed direct-path signal is re-computed and performing the search cycle with the value, N number of iterations is repeated; and computing time-of-arrival of the direct-path signal wherein time-of-arrival is a sum of the arrival time of the first-path signal and the mean acquisition time.

The present invention consists of several novel features and a combination of parts hereinafter fully described and illustrated in the accompanying drawings, it being understood that various changes in the details may be made without departing from the scope of the invention or sacrificing any of the advantages of the present invention.

BRIEF DESCRIPTION OF THE ACCOMPANYING DRAWINGS

For the purpose of facilitating an understanding of the present invention, there is illustrated in the accompanying drawings, from an inspection of which, when considered in connection with the following description, the invention, its construction and operation and many of its advantages would be readily understood and appreciated.

FIG. 1 is a flowchart that illustrates the method of time-of-arrival estimation for direct-path signal detection in an ultra-wide band localizer.

FIG. 2A illustrates a time-domain representation of a doublet Gaussian pulse.

FIG. 2B illustrates a power spectral density for a second derivative Gaussian pulse.

FIG. 3 is a block diagram of a generic time-of-arrival estimation apparatus.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention relates to a method of time-of-arrival estimation for direct-path signal detection in an ultra-wide band localizer. Hereinafter, this specification will describe the present invention according to the preferred embodiments of the present invention. However, it is to be understood that limiting the description to the preferred embodiments of the invention is merely to facilitate discussion of the present invention and it is envisioned that those skilled in the art may devise various modifications and equivalents without departing from the scope of the appended claims.

The present invention describes a method of time-of-arrival estimation for direct-path signal detection in an ultra-wide band localizer using maximum likelihood estimation algorithm to identify the phase match of the direct-path signal and consequently compute time-of-arrival of the direct-path signal. The time-of-arrival estimation algorithm of the direct-path signal proposed herein is applied to multi-path, high time resolution ultra-wide band localizers. The time-of-arrival estimation algorithm uses maximum likelihood algorithm for time-of-arrival estimation of the direct-path signal that utilizes mean acquisition time and further enhanced with a synchronization scheme. The algorithm is implemented in a receiver and the receiver operating characteristics are configured accordingly.

Reference is first being made to FIG. 1. FIG. 1 is a flowchart that illustrates the method of time-of-arrival estimation for direct-path signal detection in an ultra-wide band localizer. The method (100) of time-of-arrival estimation for direct-path signal detection in an ultra-wide band localizer of the present invention describes the method using a

maximum likelihood estimation algorithm to estimate an arrival time of the first-path signal (102), to compute a probability of direct-path signal false match (104) and to compute a probability of missed direct-path signal (106), wherein the method comprises steps of performing a search cycle with a value, N number of iterations to identify a phase match (108) of a direct-path signal and computing time-of-arrival (118) of the direct-path signal as a sum of the arrival time of the first-path signal and the mean acquisition time.

The time-of-arrival estimation algorithm of the present invention assumes a first-path detection algorithm wherein the arrival time of the earliest ultra-wide band signal at the receiver is assumed as the arrival time that will be utilized to compute the time-of-arrival of the direct-path signal. Thus, at the instance the straight-line path from transmitter to receiver is in fact a viable propagation path, time-of-arrival estimation of the direct-path signal is useful for location estimation. The time-of-arrival estimation algorithm does not assume that the direct-path is the strongest signal or the signal with the highest energy level.

The ultra-wide band signal received can be expressed as the sum of the first-path signal, other multi-path components, and noise. The ultra-wide band signal received is given by:

$$r(t) = \alpha_1 p(t - \tau_1) + \sum_{l=2}^L \alpha_l p(t - \tau_l) + n(t) + \sigma_b^2$$

where $\tau_1 < \tau_2 < \dots < \tau_L$. The parameters τ_1 and α_1 are the arrival time and strength of the first-path signal, respectively, and τ_l and α_l are those of the l th reflected multi-path component. L is the number of multi-paths, where L is an unknown. The noise, $n(t)$ is assumed to be additive white Gaussian.

Dense multi-path propagation as well as intermittent obstruction may cause amongst others, present line-of-sight signals to appear undetectable and channel impulse response to be completely absent due to severe obstructions. This adversely affects the estimation of distance measurement in localizers as these situations cause errors. The errors are classified into two main types, the first being direct-path false match error and the second being direct-path missed error. Direct-path false match error occurs when a false detection in the noise only portion of the signal is regarded as the direct-path signal. Direct-path missed error occurs when the actual direct-path signal is lost and a multi-path signal is detected as the direct-path signal. The maximum likelihood algorithm enhanced by synchronization scheme is applied to estimate and minimize these two errors.

The probability of direct-path false match, P_{FM} is computed by applying the random process crossing probability given by:

$$P_{FM} = \int_{\theta_{\tilde{\tau}_1}}^{\theta_{\tilde{\tau}_1}} Pr \left\{ \sup_{\tilde{\tau}_1 \in [-\theta_{\tilde{\tau}_1}, -\tilde{\tau}_1 - T_p]} \frac{|\tilde{\mathbf{w}}' \mathbf{p}_{\tilde{\tau}_1}|}{\|\mathbf{p}_0\|^2} > \theta_{\tilde{\alpha}_1} \sqrt{\frac{E_b/N_0}{\beta}} \right\} \cdot f_{\tilde{\tau}_1}(\tilde{\tau}_1 | \tilde{\tau}_1 \neq 0) d\tilde{\tau}_1 \cdot (1 - P_0) +$$

$$Pr \left\{ \sup_{\tilde{\tau}_1 \in [-\theta_{\tilde{\tau}_1}, -T_p]} \frac{|\tilde{\mathbf{w}}' \mathbf{p}_{\tilde{\tau}_1}|}{\|\mathbf{p}_0\|^2} > \theta_{\tilde{\alpha}_1} \sqrt{\frac{E_b/N_0}{\beta}} \right\} \cdot P_0$$

where β , the ratio of B/R_b is related to the duty cycle of the pulse and can be thought of as the pulse processing gain. R_b is the data source rate and B is the signal bandwidth.

The probability of direct-path missed error, P_M is also computed by applying the random process crossing probability given by:

$$P_M = 1 - P_0 - (1 - P_0) \int_{\theta_{\tilde{\alpha}_1}}^1 \int_0^{\theta_{\tilde{\tau}_1}} f_{\tilde{\tau}_1}(\tilde{\tau}_1 | \tilde{\tau}_1 \neq 0) \cdot f_{\tilde{\alpha}_1}(\tilde{\alpha}_1 | \tilde{\alpha}_1 \neq 1)$$

where $f_{\tilde{\tau}_1}(\tilde{\tau}_1 | \tilde{\tau}_1 \neq 0)$ and $f_{\tilde{\alpha}_1}(\tilde{\alpha}_1 | \tilde{\alpha}_1 \neq 1)$ are Gaussian distributions and P_0 is the probability that the direct-path signal is the strongest signal.

Reference is being made to FIG. 2A. FIG. 2A illustrates a time-domain representation of a doublet Gaussian pulse. In the Gaussian distribution, the Gaussian doublet, is a pair of separated narrow second derivative Gaussian pulse is applied. The pair of separated narrow second derivative Gaussian pulse is described as a positive pulse followed by a negative pulse. This Gaussian doublet offers two degrees of freedom, time separation between the two pulses in the doublet, and time separation between doublets. The Gaussian doublet may be designed by regulating the position of the second Gaussian pulse, for example the first pulse, $P_0(t)$ begins at $t = 0$, the second pulse, $P_1(t)$ begins at a predetermined time, $t = T_n$. Reference is being made to FIG. 2B. FIG. 2B illustrates a power spectral density for the second derivative Gaussian pulse.

To estimate and minimize the direct-path false match error and direct-path missed error, time-of-arrival of the direct-path signal is computed as a sum of the arrival time of the first-path signal and the mean acquisition time. To determine the mean acquisition time, a search cycle is performed with a value, N number of iterations to identify the phase match (108) of the direct-path signal. The value, N is predetermined based on the receiver operating characteristics to be any of the values 16, 32, 64 or 128 and it represents the different hypothesized phases in each search cycle.

During the search cycle, if a phase match of the direct-path signal is identified, an acquisition time is computed (114) and the corresponding mean acquisition time is computed (116). The acquisition time is computed using a penalty time, T_{FM} and a dwell time, T_d . Penalty time, T_{FM} is associated with the time for direct-path signal false match and is given by NT_d . Dwell time, T_d is the time required to evaluate a single phase of the direct-path signal.

If the phase match of the direct-path signal is identified at the n^{th} hypothesized position, and there are j misses and k false matches, the overall acquisition time is given by:

$$T_{acq}(n, j, k) = nT_d + jNT_d + kT_{FM}$$

Hence the number of iterations performed is given by $n + jN$, number of correct phases encountered is given by $j + 1$, and number of incorrect phases encountered is given by $n + jN - j - 1 \triangleq K$.

The mean acquisition time is given by:

$$\sum_{n=1}^N \sum_{j=0}^{\infty} \sum_{k=0}^K T_{acq}(n, j, k) P(n, j, k)$$

where $P(n, j, k) = P(k | n, j) P(j | n) P(n)$, $P(n) = \frac{1}{N}$, $P(j | n) = (1 - P_{DET})^j P_{DET}$,

$$P_{DET} = 1 - P_M \text{ and } P(k | n, j) = \binom{K}{k} P_{FM}^k (1 - P_{FM})^{K-k}.$$

As a result, the mean acquisition time is computed as

$$\bar{T}_{acq} = (N - 1)(T_d + P_{FM}T_{FM})\left(\frac{1}{P_{DET}} - 0.5\right) + \frac{T_d}{P_{DET}}$$

where N, representing the number of iterations performed is referred to as the total number of phases in each search cycle hypothesized until the phase match of the direct-path signal is identified.

Upon computation of the mean acquisition time, time-of-arrival is computed (118), wherein time-of-arrival of the direct-path signal is computed as a sum of the arrival time of the first-path signal and the mean acquisition time.

If the phase match of the direct-path signal is not identified and the value, N has been exceeded, the probability of missed direct-path signal is re-computed (106) and the search cycle with the value, N number of iterations is repeated.

Reference is being made to FIG. 3. FIG. 3 is a block diagram of a generic time-of-arrival estimation apparatus. The generic time-of-arrival estimation apparatus may be applied in an ultra-wide band localizer for time-of-arrival estimation for direct-path signal detection using maximum likelihood estimation algorithm to identify the phase match of the direct-path signal and consequently compute time-of-arrival of the direct-path signal.

CLAIMS

1. A method (100) of time-of-arrival estimation for direct-path signal detection in an ultra-wide band localizer using a maximum likelihood estimation algorithm to estimate an arrival time of a first-path signal (102), to compute a probability of direct-path signal false match (104) and to compute a probability of missed direct-path signal (106), wherein the method comprises steps of:
 - (a) performing a search cycle with a value, N number of iterations to identify a phase match (108) of a direct-path signal;
 - if the phase match of the direct-path signal is identified, an acquisition time is computed (114) and a mean acquisition time is computed (116);
 - if the phase match of the direct-path signal is not identified and the value, N has been exceeded, the probability of missed direct-path signal is re-computed (106) and performing the search cycle with the value, N number of iterations is repeated;
 - (b) computing time-of-arrival (118) of the direct-path signal wherein time-of-arrival is a sum of the arrival time of the first-path signal and the mean acquisition time.
2. A method according to claim 1, wherein the first-path signal is an earliest arrival ultra-wide band signal.
3. A method according to claim 1, wherein the probability of missed direct-path signal is computed based on a Gaussian distribution.

4. A method according to claim 2, wherein the Gaussian distribution applies a Gaussian doublet.
5. A method according to claim 1, wherein the value, N is predetermined based on a receiver operating characteristics.
6. A method according to claim 1, wherein the acquisition time is computed using a penalty time, time for direct-path signal false match and a dwell time, time to evaluate a single phase of the direct-path signal.
7. A method according to claim 1, wherein the mean acquisition time is computed using the acquisition time, the probability of missed direct-path signal and the probability of direct-path signal false match.

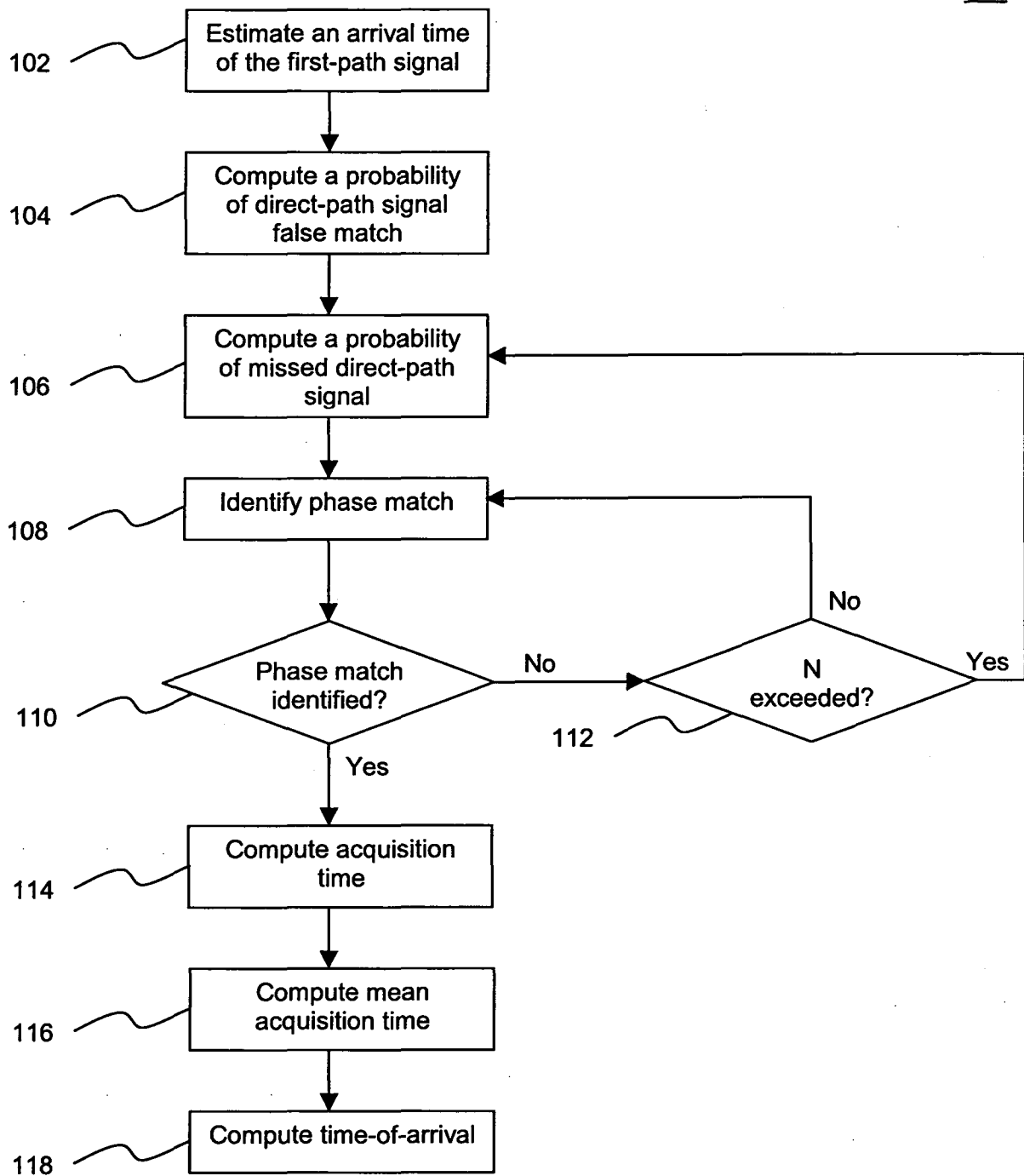


FIG. 1

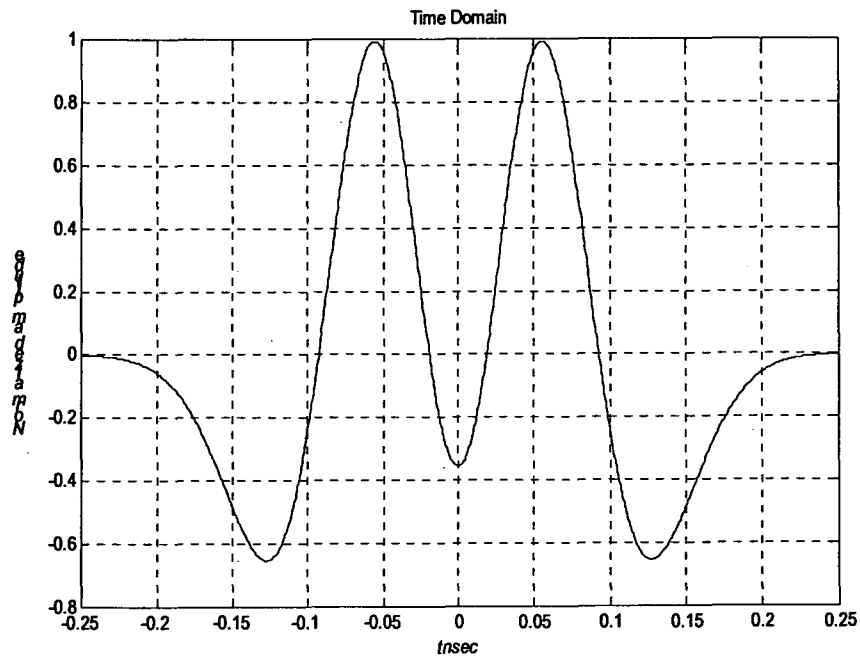


FIG. 2A

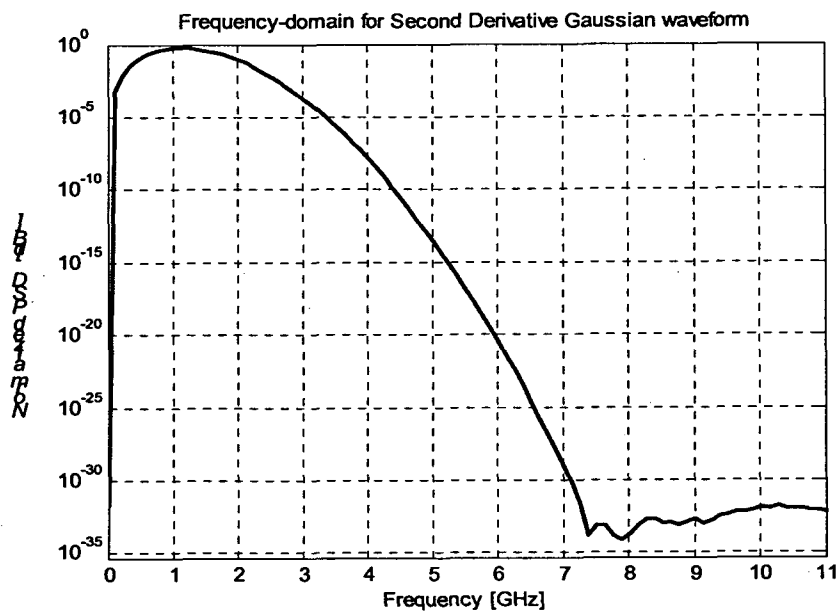


FIG. 2B

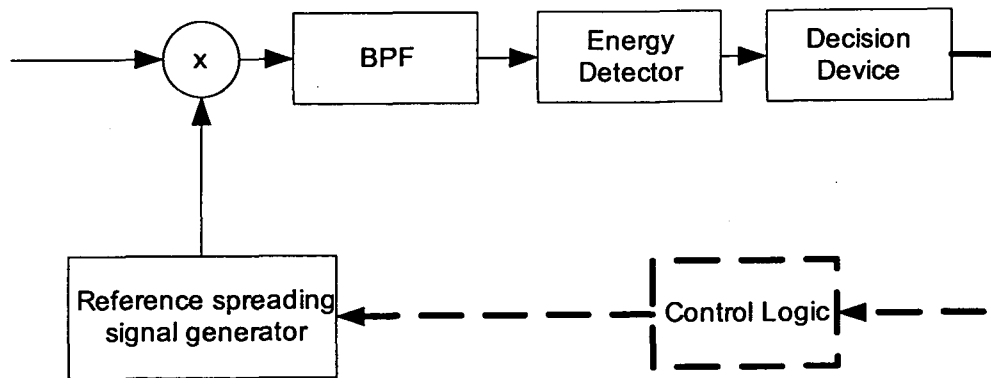


FIG. 3