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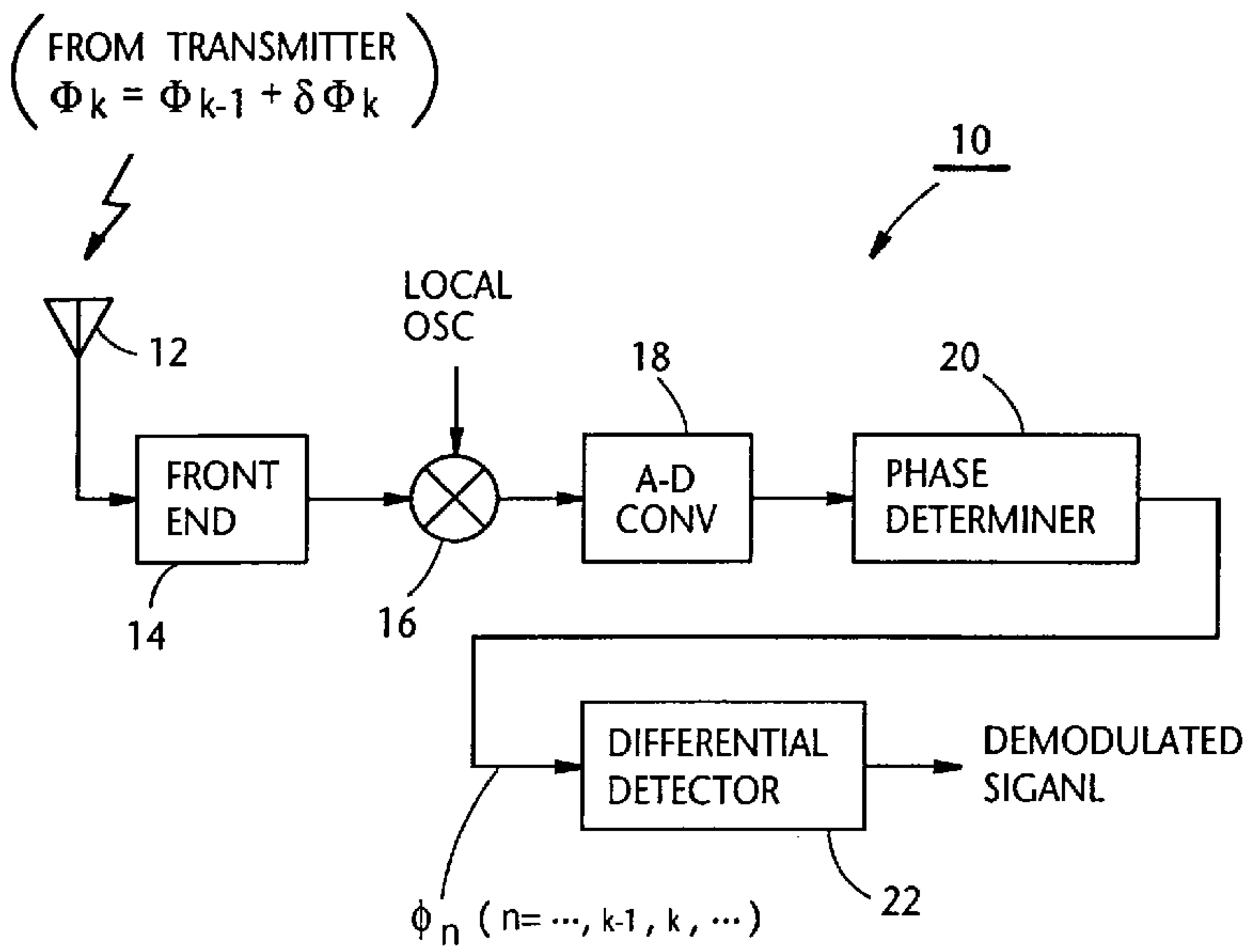
(54) **METHODE ET SYSTEME DE DETECTION DIFFEREE D'UN SIGNAL DE SAISIE A DECALAGE POLYPHASE UTILISANT UN CUMUL DE SYMBOLES DEJA DETERMINES**

(54) **METHOD AND ARRANGEMENT FOR DIFFERENTIALLY DETECTING AN MPSK SIGNAL USING A PLURALITY OF PAST SYMBOL DATA**



(57) In order to differentially detect a multiple-phase shift keying (MPSK) signal, a predetermined number of phase signals are stored at successive symbol time points. Thereafter, a plurality of phase differences between the phase signals stored in the above are calculated. Subsequently, a symbol value of the MPSK signal is decided or estimated at a current symbol time point using the phase differences obtained in the above and using symbol values already determined at a plurality of preceding symbol time points.

ABSTRACT OF THE DISCLOSURE

In order to differentially detect a multiple-phase shift keying (MPSK) signal, a predetermined number of phase signals are stored at successive symbol time points. Thereafter, a plurality of phase differences between the phase signals stored in the above are calculated. Subsequently, a symbol value of the MPSK signal is decided or estimated at a current symbol time point using the phase differences obtained in the above and using symbol values already determined at a plurality of preceding symbol time points.

TITLE OF THE INVENTION

Method And Arrangement For Differentially Detecting An MPSK Signal Using A Plurality Of Past Symbol Data

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to a differential detection technique for MPSK (multiple-phase shift keying), and more specifically to a method of implementing differential detection for MPSK using multiple-symbol observation interval. The instant invention is highly suited for use in a digital mobile communications system wherein signal transmission paths are susceptible to multipath phasing or the like.

2. Description of the Related Art

It is known in the art that, in applications where signal transmission tends to be deteriorated due to multipath fading, differential detection is preferably used rather than coherent detection. One approach to improving error characteristics inherent in differential detection is to use multiple symbols. One example of such techniques is disclosed in a paper entitled "Multiple-Symbol Differential Detection of MPSK" by D. Divsalar, et al., IEEE Transactions on Communications, Vol. 38, March 1990.

According to this related art, a plurality of symbols are simultaneously detected using differential detection techniques. That is, the related art says that increasing the number of symbols simultaneously demodulated is able to improve detection characteristics.

However, the related art has suffered from the problem that the amount of calculation becomes extremely large and the hardware becomes extremely bulky.

SUMMARY OF THE INVENTION

It is therefore an object of the present to provide a method of implementing differential detection using multiple symbols without increase in the amount of calculation.

In brief, these objects are achieved by a technique wherein in order to differentially detect a multiple-phase shift keying (MPSK) signal, a predetermined number of phase signals are stored at successive symbol time points. Thereafter, a plurality of phase differences between the phase signals stored in the above are calculated. Subsequently, a symbol value of the MPSK signal is decided or estimated at a current symbol time point using the phase differences obtained in the above and using symbol values already determined at a plurality of preceding symbol time points.

BRIEF DESCRIPTION OF THE DRAWIINGS

The features and advantages of the present invention will become more clearly appreciated from the following description taken in conjunction with the accompanying drawings in which like elements are denoted by like reference numerals and in which:

Fig. 1 is a block diagram schematically showing part of a digital mobile radio receiver to which the present invention is applicable;

Fig. 2 is a diagram for describing operations in accordance with an embodiment of the present invention;

Fig. 3A is a sketch for describing phase difference data obtained from incoming phase information in accordance with the embodiment;

Fig. 3B shows equations representing relationships of phase differences obtained from Fig. 3A;

Figs. 4A and 4B are each diagram which shows combinations used to determine a transmitted symbol according to the embodiment; and

Fig. 5 is a block diagram for describing multiple-symbol differential detection of MPSK in accordance the embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

As is well known in the art, in order to implement differential detection at a receiver, input information applied to a transmitter must be differentially encoded before transmission over a channel. The differential encoding at the transmitter is represented by

$$\Phi_k = \Phi_{k-1} + \delta\,\Phi_k \qquad (1)$$

where Φ_k denotes a phase of a transmit signal at a symbol time point "k", Φ_{k-1}

denotes a phase of the transmit signal at a previous symbol time point "k-1", and $\delta \Phi_k$ denotes a phase difference between Φ_k and Φ_{k-1}.

For the sake of convenience of description, the instant invention will be discussed when applied to a QPSK (quaternary phase shift keying) demodulator. However, it should be understood that the present invention is in no way limited to such an application and applicable to binary PSK, 8-phase PSK or the like.

Before turning to a preferred embodiment of the present invention, it is deemed advantageous to briefly describe, with reference to Fig. 1, part of a receive section of a mobile communications unit to which the present invention is applicable.

As shown in Fig. 1, a mobile radio receiver 10 comprises an antenna 12 via which a code-modulated carrier conveying the phase information Φ_k (Equation (1)) is received. A front end (viz., radio section) 14 is provided for amplifying and demodulating a modulated carrier wave (viz., channel frequency) received by the antenna 12. Although not shown in Fig. 1, the front end 14 is comprised of a high frequency amplifier, a frequency converter, an IF (intermediate frequency) amplifier, and a discriminator. An IF signal, outputted from the front end 14, is converted to a base band signal at a mixer 16 to which a local oscillator (no numeral) is operatively coupled. The base band signal thus generated is digitized at an analog-to-digital (A-D) converter 18. The digital signal from the A-D converter is supplied to a phase determiner 20, which in turn generates successively phase signals ϕ_n (n=..., k, k-1, ...) at symbol time points based on the applied digital signal. The phase signals ϕ_n are successively applied to a differential detector 22 which is directly concerned with the present invention.

Fig. 2 is a diagram illustrating a plurality of functional blocks of the differential detector 22 (Fig. 1) whose operations will be described with reference to Figs. 3A to 5B.

As shown in Fig. 2, the differential detector 22 comprises a buffer 23 which temporarily stores four phase signals ϕ_{k-3}, ϕ_{k-2}, ϕ_{k-1} and ϕ_k in this particular case. It is understood that the four phase signals ϕ_{k-3}, ϕ_{k-2}, ϕ_{k-1} and ϕ_k involve or contain six phase difference data θ_1, θ_2, θ_3, θ_4, θ_5 and θ_6 as illustrated in Fig. 3A. More specifically, the phase difference data θ_1- θ_6 are given by

$$\theta_1 = \phi_k - \phi_{k-1} = \delta \phi_k$$

$\theta_2 = \phi_k - \phi_{k-2} = \delta\phi_k + \delta\phi_{k-1}$

$\theta_3 = \phi_k - \phi_{k-3} = \delta\phi_k + \delta\phi_{k-1} + \delta\phi_{k-2}$

$\theta_4 = \phi_{k-1} - \phi_{k-2} = \delta\phi_{k-1}$

$\theta_5 = \phi_{k-1} - \phi_{k-3} = \delta\phi_{k-1} + \delta\phi_{k-2}$

$\theta_6 = \phi_{k-2} - \phi_{k-3} = \delta\phi_{k-2}$

These relationships are also listed in Figs. 3B. The phase difference data θ_1, θ_2 and θ_3 are calculated at a phase difference calculator 24. These data θ_1, θ_2 and θ_3 are stored in a phase difference memory 26. The memory 26 has already stored the previous phase difference data θ_4, θ_5 and θ_6, which respectively correspond to θ_1, θ_2 and θ_3.

The differential detector 22 has received the newest phase signal ϕ_k which corresponds to the original phase signal Φ_k. Therefore, it is necessary for the detector 22 to specify (viz., estimate or determine) the value of a transmitted symbol (viz., original) symbol $\delta\Phi_k$. The instant embodiment is being described when applied to QPSK and accordingly, the transmitted symbol $\delta\Phi_k$ is chosen (viz., estimated) among the four values of $\pm\pi/4$ and $\pm 3\pi/4$. This estimation is carried out at a phase decision circuit 28 using the data θ_1 to θ_6 stored in the memory 26 and four phase difference data

$[\delta\phi_{k-2}^1]$, $[\delta\phi_{k-2}^2]$, $[\delta\phi_{k-1}^1]$, and $[\delta\phi_{k-1}^2]$

which are stored in a buffer 30.

The phase difference data $[\delta\phi_{k-2}^1]$ implies the most likely "transmitted symbol" already determined at the symbol point (k-2) and was outputted from the differential detector 22 as a modulated signal. On the other hand, the phase difference signal $[\delta\phi_{k-2}^2]$ is the second likely "transmitted symbol" already determined at the same symbol point (k-2). However, this signal $[\delta\phi_{k-2}^2]$ is not outputted as the differential detection result but stored or reserved to estimate the original symbol $\delta\Phi_k$. In a similar manner, the phase difference data $[\delta\phi_{k-1}^1]$ implies the most likely "transmitted symbol" already determined at the preceding symbol point (k-1) and was outputted from the differential detector 22 as a modulated signal, whilst the phase difference signal $[\delta\phi_{k-1}^2]$ is the second likely "transmitted symbol" already determined at the same symbol point (k-1). However, this signal $[\delta\phi_{k-1}^2]$ is not outputted as the differential detection result but stored or reserved to estimate the original symbol $\delta \Phi_k$.

Referring to Fig. 4, it is assumed that the above mentioned phase difference data $[\delta \phi_{k-2}^1]$ has been estimated or determined to assume the symbol (viz., value) of $\pi/4$, while the phase difference data $[\delta \phi_{k-2}^2]$ has been specified to assume the symbol of $3\pi/4$. Likewise, it is assumed that the aforesaid phase difference data $[\delta \phi_{k-1}^1]$ has been determined to assume the symbol of $3\pi/4$, while the phase difference data $[\delta \phi_{k-1}^2]$ has been specified to assume the symbol of $-\pi/4$.

In order to determine the most likely "transmitted symbol" in connection with $\delta \Phi_k'$ at the symbol point k, the following equation is used.

$$\begin{aligned} Q = &(\theta_1 - \delta \Phi_k')^2 \\ &+ (\theta_2 - (\delta \Phi_k' + [\delta \phi_{k-1}^M]))^2 \\ &+ (\theta_3 - (\delta \Phi_k' + [\delta \phi_{k-1}^M] + [\delta \phi_{k-2}^J]))^2 \\ &+ (\theta_4 - [\delta \phi_{k-1}^M])^2 \\ &+ (\theta_5 - ([\delta \phi_{k-1}^M] + [\delta \phi_{k-2}^J]))^2 \\ &+ (\theta_6 - [\delta \phi_{k-2}^J])^2 \end{aligned}$$

where J=1, 2, M=1, 2, and $\delta \Phi_k'$ assumes $\pm\pi/4$ and $\pm 3\pi/4$.

Each of J , M and $\delta \Phi_k'$ in the above equation takes its own values independently and thus, Q assumes 16 sums in total, the manner of which is shown in Figs. 5A and 5B. It is therefore understood that the symbol value of $\delta \Phi_k'$, which renders the value of Q minimum, is the most likely "transmitted symbol" of $\delta \Phi_k'$. On the other hand, the symbol value of $\delta \Phi_k'$, which causes the value of Q to be minimum, is the most likely "transmitted symbol" of $\delta \Phi_k'$. On the other hand, the symbol value of $\delta \Phi_k'$, which causes the value of Q to be second minimum, is the second likely "transmitted symbol" of $\delta \Phi_k'$.

As mentioned above, the most likely "transmitted symbol" of $\delta \Phi_k'$ is outputted as the modulated signal. The most and second likely "transmitted symbols" are stored in the buffer 30 and retrieved for use in determining the subsequent two symbols.

In the foregoing, the present invention has been described with reference to QPSK. However, it is to be noted that the present invention is in no way limited to QPSK. It is understood that the instant invention is applicable to BPSK (binary

PSK), 8-phase PSK, or the like.

It will be understood that the above disclosure is representative of only one possible embodiment of the present invention and that the concept on which the invention is based is not specifically limited thereto.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A method of differentially detecting a multiple-phase shift-keying (MPSK) signal, comprising the steps of:

(a) storing a predetermined number of phase signals applied at successive symbol time points;

(b) calculating a plurality of phase differences between the phase signals stored in step (a); and,

(c) deciding a symbol value of the MPSK signal at a current symbol time point using the phase differences obtained in step (b) and using symbol values already determined at a plurality of preceding symbol time points.

2. A method as in claim 1, wherein the symbol values, determined at one of said plurality of preceding symbol time points, consists of at least two symbol values, one of which is a most-likely value and the other of which is a second-most-likely value.

3. A method as in claim 1, wherein MPSK is a quadrature PSK.

4. A method of differentially detecting a quadrature PSK signal, comprising the steps of:

(a) storing four phase signals (ϕ_k, ϕ_{k-1}, ϕ_{k-2} and ϕ_{k-3}) applied at successive symbol time points (k, k-1, k-2 and k-3), wherein k indicates a current symbol time point;

(b) calculating three phase differences (θ_1, θ_2 and θ_3) between the phase signal (ϕ_k) and each of the phase signals (ϕ_{k-1}, ϕ_{k-2}, ϕ_{k-3});

(c) storing said three phase differences calculated at step (b) in a phase difference memory, said phase difference memory having already stored another three phase difference (θ_4, θ_5 and θ_6) between the phase signals ϕ_{k-1} and ϕ_{k-2}, ϕ_{k-1} and ϕ_{k-3}, and ϕ_{k-2} and ϕ_{k-3}; and,

(d) deciding a symbol value of the quadrature PSK signal at the current symbol time point using the phase differences stored in said phase difference memory and using symbol values already determined at the preceding symbol time points k-1 and k-2.

5. A method as in claim 4, wherein the symbol values, determined at each of the symbol time points k-1 and k-2, consist of two symbol values, one of which is a most-likely value and the other of which is a second-most-likely value.

6. A differential detector, provided in a receiver used in a digital communications system, for detecting a multiple-phase shift-keying (MPSK) signal, said differential detector comprising:

a first memory for temporarily storing a predetermined number of phase signals applied thereto at successive symbol time points;

a phase difference calculator coupled to calculate a plurality of phase differences between the phase signals stored in said first memory;

a second memory coupled to store said plurality of phase differences calculated at said phase difference calculator; and,

a phase decision determiner for deciding a symbol value of the MPSK signal at a current symbol time point using the phase differences stored in said second memory and using symbol values already determined at a plurality of preceding symbol time points.

7. A differential detector as in claim 6, wherein the symbol values, determined at one of said plurality of preceding symbol time points, consist of at least two symbol values, one of which is a most-likely value and the other of which is a second-most-likely value.

8. A differential detector, provided in a receiver used in a digital communications system, for detecting a quadrature PSK signal, said differential detector comprising:

a first memory for storing four phase signals (ϕ_k, ϕ_{k-1}, ϕ_{k-2} and ϕ_{k-3}) applied thereto at successive symbol time points (k, k-1, k-2 and k-3), wherein k indicates a current symbol time point;

a phase difference coupled to calculate three phase differences (θ_1, θ_2

and θ_3) between the phase signal (ϕ_k) and each of the phase signals (ϕ_{k-1}, ϕ_{k-2}, ϕ_{k-3});

a second memory coupled to store said three phase differences calculated at said phase difference calculator, said second memory having already stored another three phase differences (θ_4, θ_5 and θ_6) between the phase signals ϕ_{k-1} and ϕ_{k-2}, ϕ_{k-1} and ϕ_{k-3}, and ϕ_{k-2} and ϕ_{k-3}; and,

a phase decision determiner for deciding a symbol value of the quadrature PSK signal at the current symbol time point using the phase differences stored in said second memory and using symbol values already determined at the preceding symbol time points k-1 and k-2.

9. A differential detector as in claim 8, wherein the symbol values, determined at each of the symbol time points k-1 and k-2, consist of two symbol values, one of which is a most-likely value and the other of which is a second-most-likely value.

FIG. 1

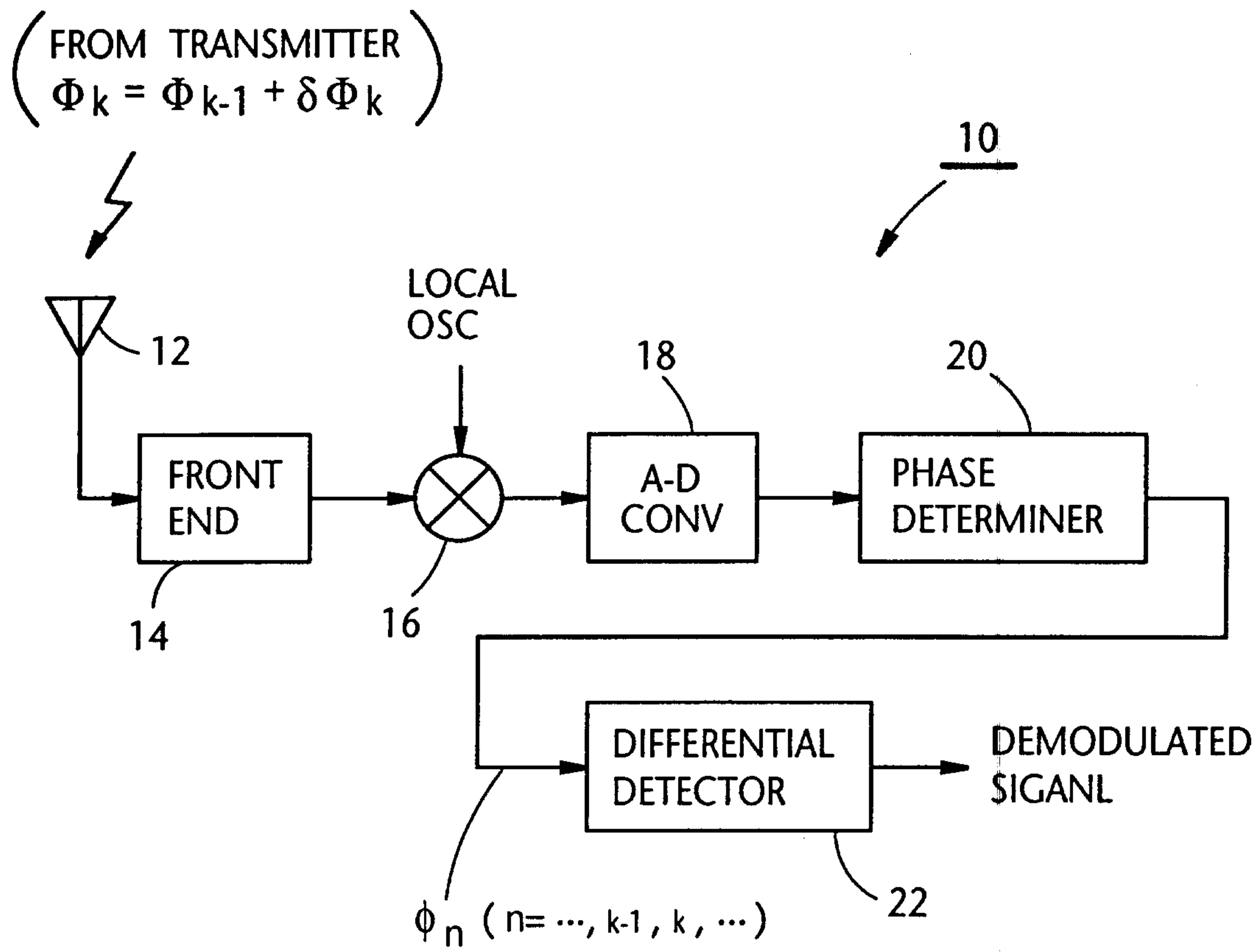

FROM TRANSMITTER
$\Phi_k = \Phi_{k-1} + \delta\Phi_k$
10
12
LOCAL
OSC
18
20
FRONT
END
A-D
CONV
PHASE
DETERMINER
14
16
DIFFERENTIAL
DETECTOR
DEMODULATED
SIGANL
22
ϕ_n (n= ···, k-1 , k , ···)

FIG. 2

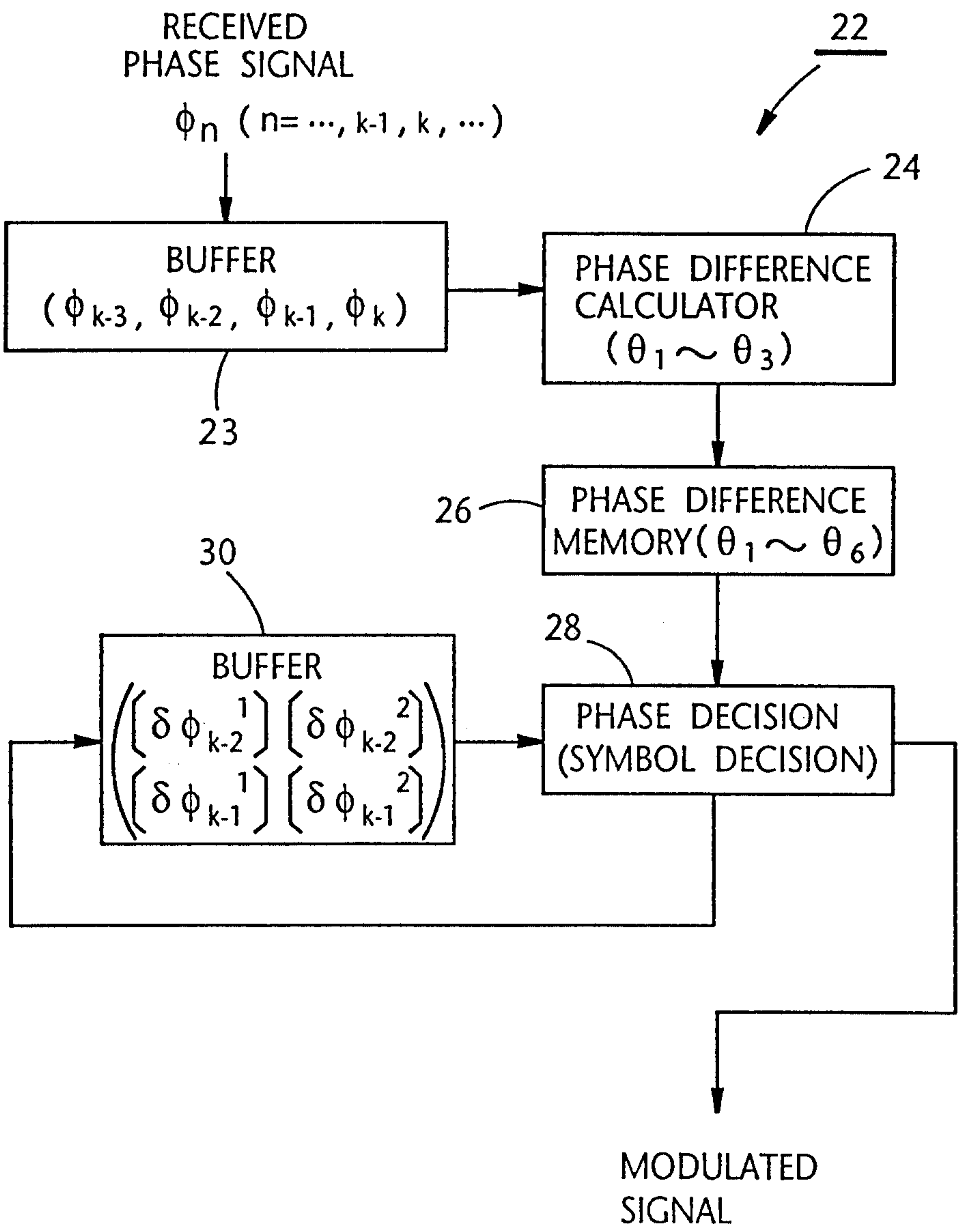

RECEIVED
PHASE SIGNAL
ϕn (n= ···, k-1 , k , ···)
22
24
BUFFER
(ϕ k-3 , ϕ k-2 , ϕ k-1 , ϕ k)
23
PHASE DIFFERENCE
CALCULATOR
(θ1 ∼ θ3)
26
PHASE DIFFERENCE
MEMORY(θ1 ∼ θ6)
30
28
BUFFER
δϕ k-2 1, δϕ k-2 2, δϕ k-1 1, δϕ k-1 2
PHASE DECISION
(SYMBOL DECISION)
MODULATED
SIGNAL

FIG. 3A

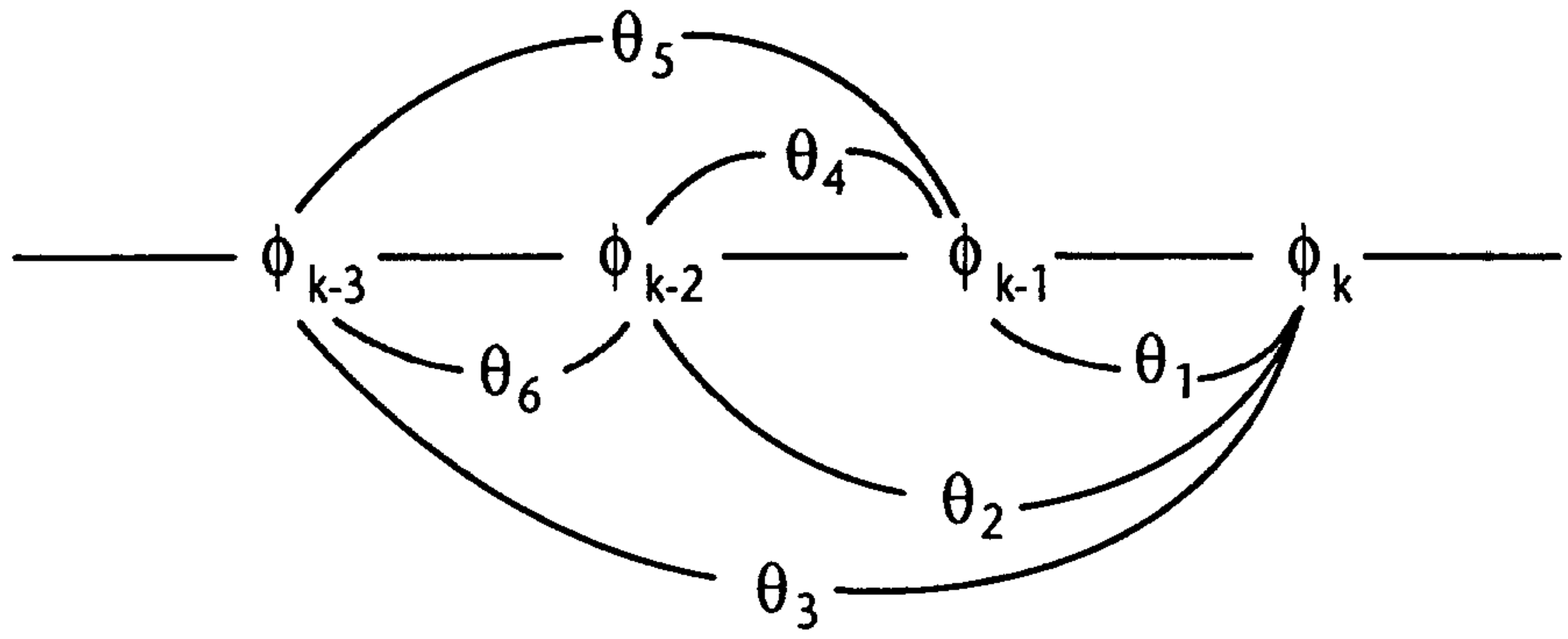


FIG. 3B

$$\begin{cases} \theta_1 = \phi_k - \phi_{k-1} = \delta\phi_k \\ \theta_2 = \phi_k - \phi_{k-2} = \delta\phi_k + \delta\phi_{k-1} \\ \theta_3 = \phi_k - \phi_{k-3} = \delta\phi_k + \delta\phi_{k-1} + \delta\phi_{k-2} \end{cases}$$

$$\begin{cases} \theta_4 = \phi_{k-1} - \phi_{k-2} = \delta\phi_{k-1} \\ \theta_5 = \phi_{k-1} - \phi_{k-3} = \delta\phi_{k-1} + \delta\phi_{k-2} \\ \theta_6 = \phi_{k-2} - \phi_{k-3} = \delta\phi_{k-2} \end{cases}$$

FIG. 4

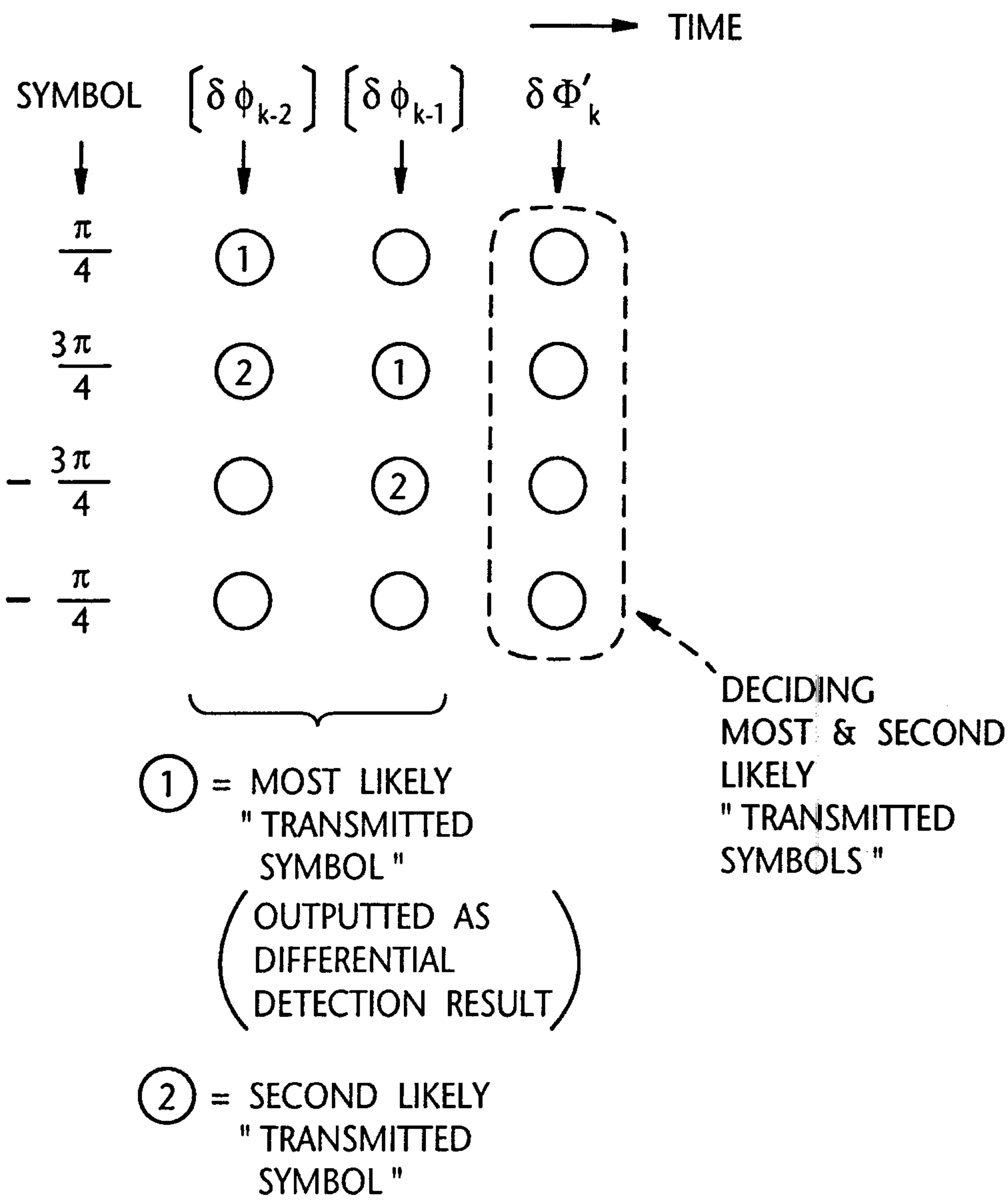

TIME
SYMBOL
[δ φk-2]
[δ φk-1]
δ Φ'k
π/4
3π/4
− 3π/4
− π/4
1
2
1
2
DECIDING MOST & SECOND LIKELY " TRANSMITTED SYMBOLS "
1 = MOST LIKELY " TRANSMITTED SYMBOL " (OUTPUTTED AS DIFFERENTIAL DETECTION RESULT)
2 = SECOND LIKELY " TRANSMITTED SYMBOL "

FIG. 5A

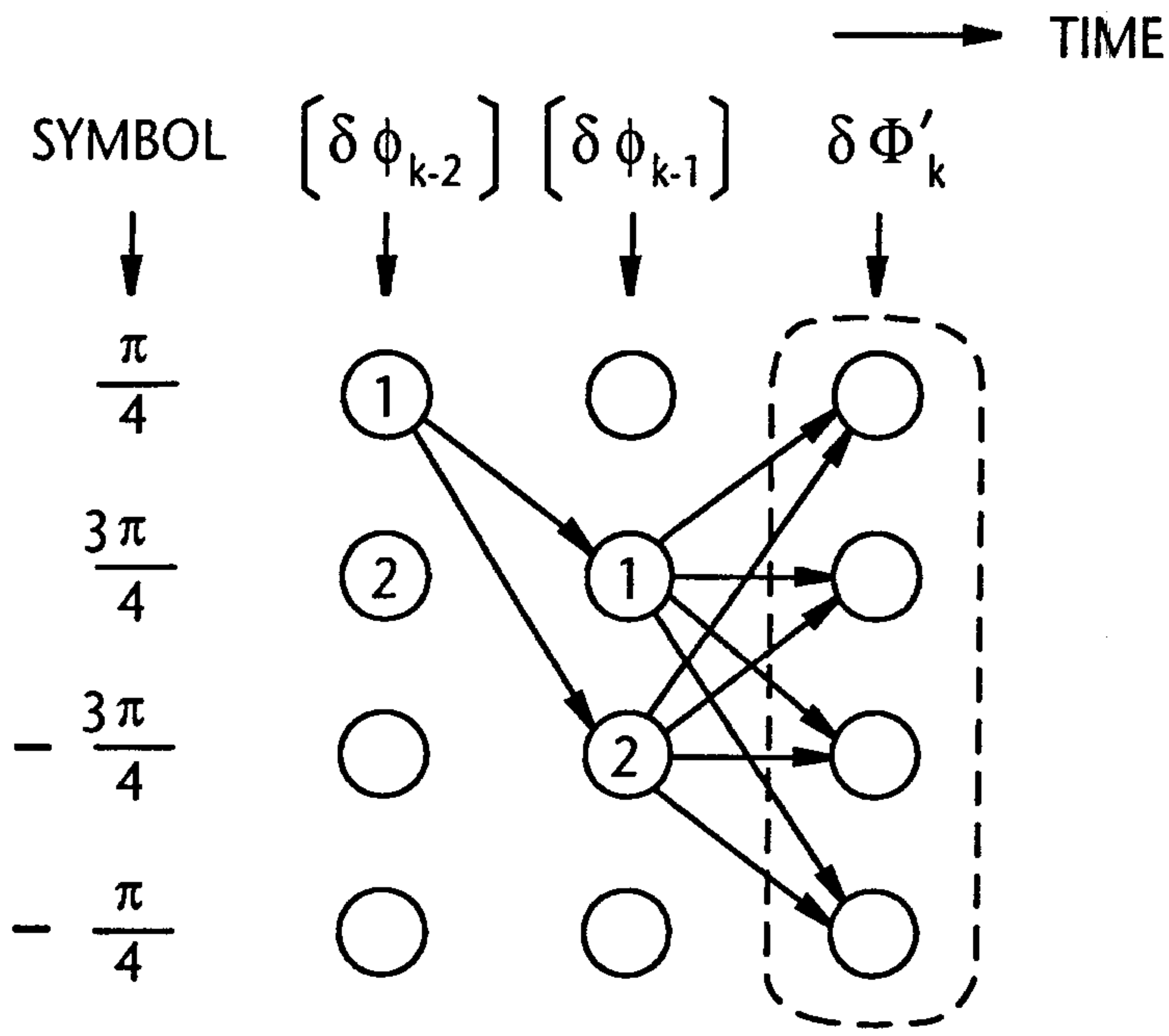
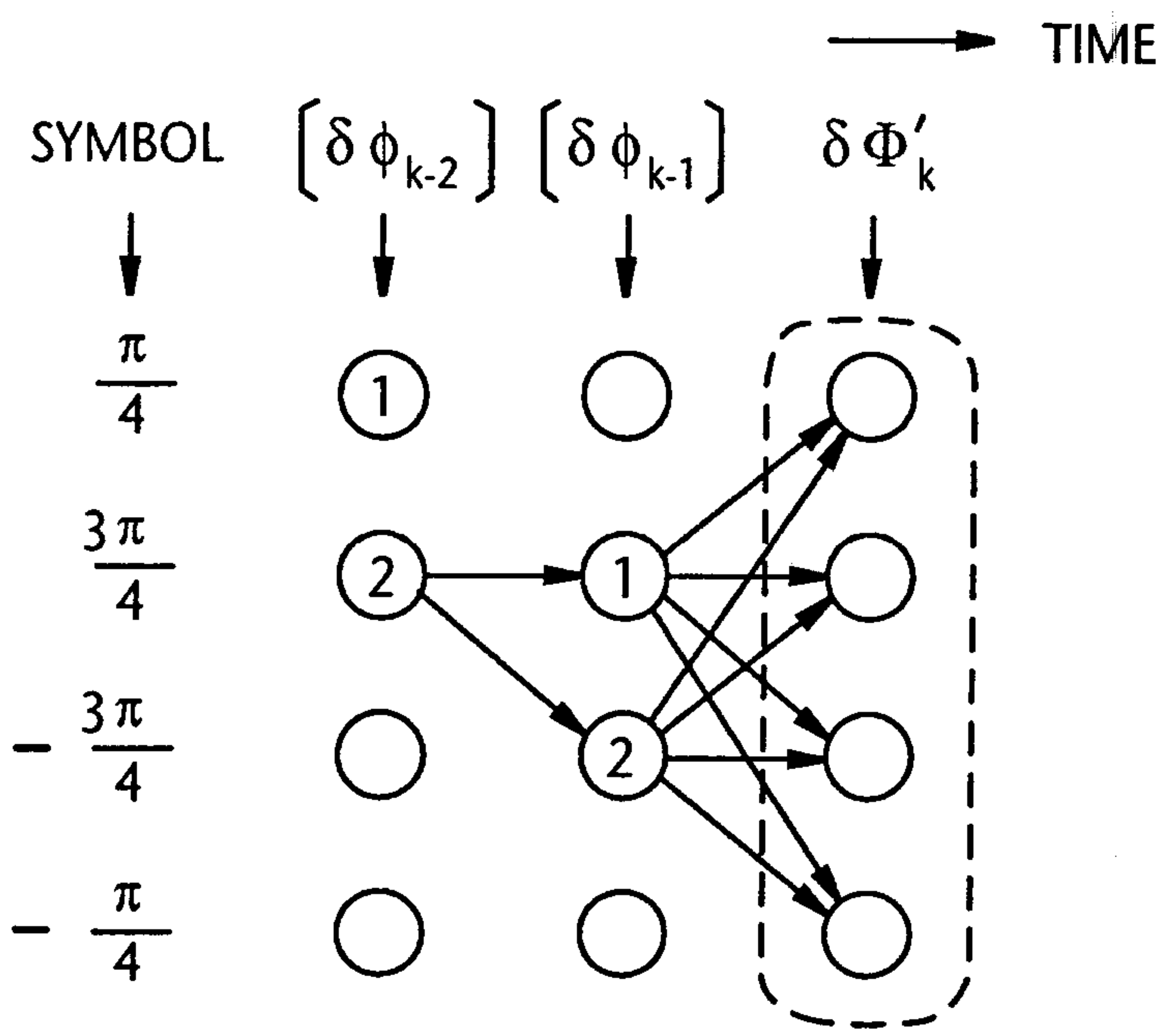

TIME
SYMBOL
[δφ_{k-2}]
[δφ_{k-1}]
δΦ'_k
π/4
3π/4
− 3π/4
− π/4
1
2
1
2

FIG. 5B


TIME
SYMBOL
[δφ_{k-2}]
[δφ_{k-1}]
δΦ'_k
π/4
3π/4
− 3π/4
− π/4
1
2
1
2