

(51) International Patent Classification:

G06F 3/041 (2006.01) G06F 3/044 (2006.01)

(21) International Application Number:

PCT/US2024/022717

(22) International Filing Date:

03 April 2024 (03.04.2024)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

63/461,013 21 April 2023 (21.04.2023) US

18/429,684 01 February 2024 (01.02.2024) US

(71) Applicant: MICROCHIP TECHNOLOGY INCORPORATED [US/US]; 2355 West Chandler Blvd., Chandler, Arizona 85224-6199 (US).

(72) Inventor: HEIM, Axel; Westendstr. 154, 80339 Munich (DE).

(74) Agent: SLAYDEN, Bruce W., II et al.; Slayden Grubert Beard PLLC, 401 Congress Ave., Suite 1650, Austin, Texas 78701 (US).

(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, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(54) Title: DECODING TOUCH DATA BASED ON A CODE WORD PORTION

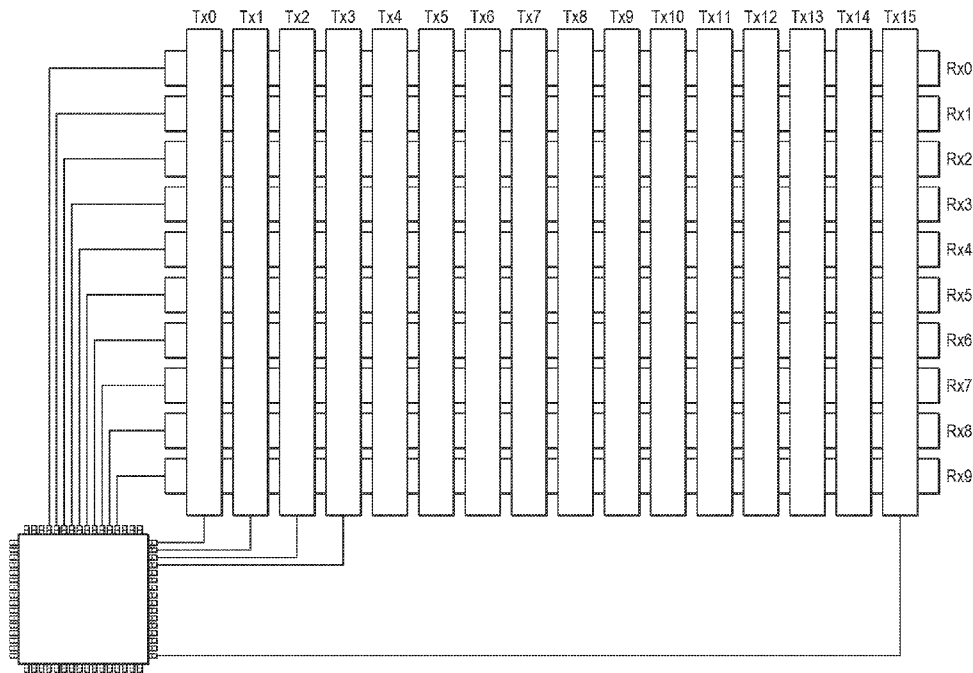


FIG. 1

(57) Abstract: Systems having a capacitive touch sensing system with transmit and receive electrodes positioned to have mutual capacitances at node intersections that deviate when a node is touched; a processor; and a machine readable storage medium with instructions to: assign complete code words to transmit electrodes; identify a subset of transmit electrodes based on a prior touch position estimate; generate a transmit signal for the transmit electrodes; receive a first portion of a receive signal for receive electrodes indicative of capacitances; decode the first portion of the receive signal of receive electrodes using the first portions of the code words; and compute touch position estimates for the subset of transmit electrodes based on the decoded first portions of the receive signals.

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

Published:

— *with international search report (Art. 21(3))*

DECODING TOUCH DATA BASED ON A CODE WORD PORTION

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional Patent Application No. 63/461,013, filed April 21, 2023, which is hereby incorporated by reference in its entirety as if fully set forth herein.

TECHNICAL FIELD

The present disclosure relates to code-division multiplexing in capacitive touch sensing devices, in particular, decoding code-division multiplexed receive data based on code word portions to estimate a touch position in a capacitive touch sensing device.

BACKGROUND

Code-Division Multiplexing (CDM) is a spread spectrum technique which allows multiple usage of the same channel. In spread spectrum implementations of capacitive touch sensing devices, a respective signal is given a code word. Signal data is available on a shared channel. A respective signal has a unique code word assigned to it called a chip sequence or orthogonal sequence, because the code words comprise symbols or “chips.” Knowing the code words, the receiver can distinguish the different signals. The code words are comprised of +1 or -1. Respective code words have L chips, where L also is the maximum number of orthogonal signals. Two code words are orthogonal when their dot product yields zero (0). The dot product of only the first elements of such two code words usually is non-zero. That is, code word portions often are non-orthogonal to each other.

For some applications, however, it is of interest to obtain an estimate (of the transmitted information, or the channel gain before a full code word is received and processed. Such applications, for example, include capacitive touch sensing applications, which have relatively fast output report rates.

In particular, human interface devices (HID) using capacitive touch sensing have relatively fast output report rates. Capacitive touch sensing devices comprise sensor electrodes functioning as antenna that are often formed in layers of conductive material, e.g. stripes of copper of printed circuit board layer (PCB). These electrodes are electrically connected to a touch detection unit, for example, on the same PCB to form a compact unit. The touch detection unit's measurement value, among others, depends on the position of a target object (finger/hand) in the sensor electrode's vicinity which influences the capacitive coupling

between electrode and target, yielding a target measurement signal depending on the distortion of the alternating electric field. Touch sensing technology for 2-dimensional touch detection often uses a signal deviation matrix over Tx-Rx nodes (i.e., in (x,y)) to identify positions being touched by a user's finger, for example. A touch screen may, for example, have a signal deviation 16X16 matrix of Tx-Rx nodes having Tx electrodes ($m = 0, 1, 2, \dots, 15$) and Rx electrodes ($n = 0, 1, 2, \dots, 15$). The code words of the Tx electrodes (m) are transmitted, receive signals of Rx electrodes (n) are received, and the information for electrode nodes (n,m) are decoded. When using CDM, decoding is possible only after receiving the receive signal in full, i.e., when containing information from the entire transmitted code words. For some touch screen applications, however, it is of interest to obtain an estimate (of the transmitted information, or complex channel gain) before the receive signals are received in full and processed.

There is a need for code-division multiplexing touch sensing schemes using a spread-spectrum technique that estimates the touch positions prior to receipt of the full receive signals.

SUMMARY OF THE INVENTION

According to aspects, there is provided a code-division multiplexing touch sensing scheme using a spread-spectrum technique that estimates touch positions prior to receipt of the full receive signals.

An aspect provides a method comprising: providing a capacitive touch sensing system comprising transmit electrodes and receive electrodes positioned to have mutual capacitances between transmit electrodes and receiver electrodes at electrode intersections called nodes, wherein the capacitance at respective ones of nodes deviates when touched; identifying a first and a second subset of transmit electrodes based on a prior touch position estimate; assigning code words from a first subset of code words to respective ones of transmit electrodes of the first set of transmit electrodes, wherein respective ones of code words are a complete code word having a first code word portion and a second code word portion; assigning code words from a second subset of code words to respective ones of transmit electrodes of the second set of transmit electrodes, wherein respective ones of code words are a complete code word having a first code word portion and a second code word portion; generating a transmit signal for respective ones of transmit electrodes according to its assigned code word; transmitting the transmit signals; receiving a first portion of a receive signal, for respective ones of receive electrodes, indicative of the respective capacitances between the receive electrode and

respective ones of transmit electrodes; decoding the first portion of the receive signal for respective ones of receive electrodes using the first portions of the first subset of code words; and computing touch position estimates for the first subset of transmit electrodes based on the decoded first portions of the receive signals.

5 An aspect provides a method as in the preceding paragraph, comprising: receiving a second portion of receive signal for respective ones of receive electrodes; decoding the complete receive signal for respective ones of receive electrodes using the complete code words; computing a touch position estimate for the set of transmit electrodes based on the decoded complete receive signals; and serially and alternately decoding the first portion of
10 the receive signal and decoding the complete receive signal.

 An aspect provides the method as in any one of the two preceding paragraphs, comprising default assigning respective ones of code words from the first subset of code words to respective ones of the first set of transmit electrodes and default assigning respective ones of code words from the second subset of code words to respective ones of the second set of
15 transmit electrodes, wherein code words comprise unique numbers, wherein transmit electrodes are numbered uniquely, and wherein the default assigning comprises assigning the code word with the lowest number to the lowest numbered transmit electrode, and assigning the code word with the second lowest number to the second lowest numbered transmit electrode.

20 An aspect provides the method as in any one of the three preceding paragraphs, comprising repeating the performing a touch position estimate.

 An aspect provides the method as in any one of the four preceding paragraphs, wherein assigning respective ones of code words from the first subset of code words to respective ones of the first set of transmit electrodes comprises: adaptive assigning respective ones of code
25 words from the first subset of code words to transmit electrodes identified as having been touched or identified as assumed to have been touched based on the prior touch position estimate, and wherein assigning respective ones of code words from the second subset of code words to respective ones of the second set of transmit electrodes comprises: adaptive assigning respective ones of code words from the second subset of code words to transmit electrodes
30 identified as having not been touched or identified as assumed to have not been touched based on the prior touch position estimate.

An aspect provides the method as in any one of the five preceding paragraphs, wherein assigning respective ones of code words from the second subset of code words to respective ones of the second set of transmit electrodes comprises: adaptive assigning respective ones of code words from the second subset of code words to transmit electrodes identified as having not been touched or identified as assumed to have not been touched based on the prior touch position estimate, and wherein assigning respective ones of code words from the first subset of code words to respective ones of the first set of transmit electrodes comprises: adaptive assigning respective ones of code words from the first subset of code words to remaining unassigned transmit electrodes.

An aspect provides the method as in any one of the six preceding paragraphs, wherein respective ones of the code words comprise binary sequences having $2 \cdot K$ chips of a Hadamard matrix where K is an integer, wherein the code word portions of respective ones of the code words comprise K chips.

According to an aspect, there is provided a system comprising: a capacitive touch sensing system comprising transmit electrodes and receive electrodes positioned to have mutual capacitances between transmit electrodes and receive electrodes at electrode intersections called nodes, wherein the capacitance at respective ones of nodes deviates when touched; a processor; and a machine readable storage medium storing instructions, which when executed by the processor, cause the system to: identify a first and a second subset of transmit electrodes based on a prior touch position estimate; assign code words from a first subset of code words to respective ones of transmit electrodes of the first set of transmit electrodes, wherein respective ones of code words are a complete code word having a first code word portion and a second code word portion; assign code words from a second subset of code words to respective ones of transmit electrodes of the second set of transmit electrodes, wherein respective ones of code words are a complete code word having a first code word portion and a second code word portion;; generate a transmit signal for respective ones of transmit electrodes of the first subset of transmit electrodes according to its assigned code word; transmit the transmit signals; receive a first portion of a receive signal, for respective ones of receive electrodes, indicative of the respective capacitances between the receive electrode and respective ones of transmit electrodes; decode the first portion of the receive signal for respective ones of receive electrodes using the first portions of the first subset of code words;

and compute touch position estimates for the first subset of transmit electrodes based on the decoded first portions of the receive signals.

An aspect provides the system as in the preceding paragraph, wherein the instructions, which when executed by the processor, cause the system to: receive a second portion of receive
5 signal for respective ones of receive electrodes; decode the complete receive signal for respective ones of receive electrodes using the complete code words; compute touch position estimates for the set of transmit electrodes based on the decoded complete receive signals; and serially and alternately decode the first portion of the receive signal and decode the complete receive signal.

10 An aspect provides the system as in any one of the two preceding paragraphs, wherein the instructions, which when executed by the processor, cause the system to default assign respective ones of code words from the first subset of code words to respective ones of the first set of transmit electrodes and default assign respective ones of code words from the second subset of code words to respective ones of the second set of transmit electrodes, wherein code
15 words comprise unique numbers, wherein transmit electrodes are numbered uniquely, and wherein the default assigning comprises assigning the code word with the lowest number to the lowest numbered transmit electrode, and assigning the code word with the second lowest number to the second lowest numbered transmit electrode.

20 An aspect provides the system as in any one of the three preceding paragraphs, wherein the instructions, which when executed by the processor, cause the system to repeatedly perform a touch position estimate.

25 An aspect provides the system as in any one of the four preceding paragraphs, wherein the instructions, which when executed by the processor, cause the system to: adaptively assign respective ones of code words to transmit electrodes identified as having been touched or identified as assumed to have been touched based on the prior touch position estimate, and adaptively assign respective ones of code words to transmit electrodes identified as having not been touched or identified as assumed to have not been touched based on the prior touch position estimate.

30 An aspect provides the system as in any one of the five preceding paragraphs, wherein assign respective ones of code words from the second subset of code words to respective ones of the second set of transmit electrodes comprises: adaptive assign respective ones of code words from the second subset of code words to transmit electrodes identified as having not

been touched or identified as assumed to have not been touched based on the prior touch position estimate.

An aspect provides the system as in the preceding paragraph, wherein assign respective ones of code words from the first subset of code words to respective ones of the first set of transmit electrodes comprises: adaptive assign respective ones of code words from the first subset of code words to remaining unassigned transmit electrodes.

An aspect provides the system as in any one of the seven preceding paragraphs, wherein respective ones of the code words comprise binary sequences having $2 \cdot K$ chips of a Hadamard matrix where K is an integer, wherein the code word portions of respective ones of the code words comprise K chips.

BRIEF DESCRIPTION OF THE DRAWINGS

The figures illustrate examples of systems and methods of capacitive touch sensing using code-division multiplexing.

FIGURE 1 shows a sensor layout with ten receive electrodes RX0, ... , Rx9 and sixteen transmit electrodes Tx0, ... , Tx15.

FIGURE 2A shows a touch surface and time axis, illustrating a single finger touch on the electrode crossing of Tx3, Rx3 with a constant position over time.

FIGURE 2B shows a default code-word-to-TX (S2T) mapping for the touch surface and single finger touch shown in FIGURE 2A.

FIGURE 2C shows the code-word-to-Tx mapping as shown in FIGURE 2B while illustrating the code words' chip values.

FIGURE 2D shows the code-word-to-Tx mapping and chip values as shown in FIGURE 2C highlighting the construction of a default code-word-to-Tx mapping matrix, wherein a Hadamard matrix consists of four quadrants with smaller Hadamard matrices.

FIGURE 3A shows a touch surface and time axis, illustrating a two-finger touch with constant finger positions over time.

FIGURE 3B shows the code-word-to-Tx mapping as shown in FIGURE 2B yielding ambiguous detection after eight chips for the touch surface shown in FIGURE 3A.

FIGURE 3C shows an adapted assignment or mapping of code words to the transmit electrodes of FIGURES 3A-3B.

FIGURE 4A shows a touch surface and time axis, illustrating a two-finger touch on Tx0-Tx7 with touch positions constant over time.

FIGURE 4B shows the code-word-to-Tx mapping as shown in FIGURE 2B yielding un-ambiguous detection after eight chips, for the touch surface shown in FIGURE 4A.

FIGURE 5A shows a touch surface and time axis, illustrating a three-finger touch with constant positions over time.

5 FIGURE 5B shows an adapted code-word-to-TX (S2T) mapping yielding un-ambiguous detection after eight chips for the touch surface shown in FIGURE 5A, wherein the adapted mapping is different than a default mapping and may be based on a prior touch estimation.

10 FIGURE 6 shows a timeline where alternatingly transmissions 100% and 50% of code-division multiple access data. The 50% of code-division multiple access data is based on code word portions or an incomplete set of code words to estimate a signal deviation matrix of a capacitive touch sensing system.

FIGURE 7 shows a block diagram of a system having a capacitive touch sensing system, a processor and a storage medium.

15 FIGURE 8 shows a method comprising assigning code words to transmit electrodes, decoding received signals with code words, and estimating a current touch position.

The reference number for any illustrated element that appears in multiple different figures has the same meaning across the multiple figures, and the mention or discussion herein of any illustrated element in the context of any particular figure also applies to each other
20 figure, if any, in which that same illustrated element is shown.

DESCRIPTION

Aspects provide code-division multiplexing (CDM) touch sensing schemes implementing a spread-spectrum technique to decode partial CDM receive data based on parts of code words to estimate touch positions before the receive signals for the entire multiplexed
25 code words are received and decoded with a complete code word or a complete set of code words. Code word portions of respective ones of the code words may be compiled into a Hadamard matrix, wherein respective ones of code word portions comprise respective ones of rows of the Hadamard matrix.

Where the approximate location or locations of a finger or fingers touching a capacitive
30 sensing system's touch surface are known, a subset of a set of orthogonal code words may be assigned to the touched Tx electrodes. The code words in the subset assigned to the touched Tx electrodes begin with sub-code words orthogonal to each other. At the receiver side, de-

spreading and unambiguous touch detection may happen after receiving data for the sub-code words orthogonal to each other in the subset assigned to the touched Tx electrodes, without waiting until the full code words of data has been received.

FIGURE 1 shows a schematic view of a mutual-capacitance touch detection system.

5 This touch detection system comprises a set of parallel transmit electrodes and a set of parallel receive electrodes positioned orthogonal to the set of parallel transmit electrodes in a two-dimensional (x,y) plane. A Tx-Rx electrode intersection, crossing, or 'node' is located at the intersection of a transmit electrode and a receive electrode. FIGURE 1 shows a mutual-capacitance touch detection system having a 16X10 array of Tx-Rx electrode nodes. In the
10 touch detection system, measurement values change for a node when a finger is touching a touch surface of this (x,y) plane at the node. The measurement value for a Tx-Rx electrode node is dominated by the mutual-capacitance between the respective electrodes, which is affected by a finger touching this node. When a finger touches the node, the measurement value change of the node is a signal deviation because the capacitance at the node changes when the
15 node is touched. The term touching, as used herein, is not meant to be limited to physical contact, and is meant to include proximity sufficient to cause significant change of the capacitance at the node which can be detected as a signal deviation.

A receive signal may be observed for respective ones of the receive electrodes, wherein the receive signal is indicative of the respective capacitances between the receive electrode and
20 respective ones of the transmit electrodes. Because a single receive electrode (for example, Rx2) receives transmit signals from multiple transmit electrodes (Tx0 through Tx15), the transmit signals may be independently deciphered by assigning a complete code word (for example, a 16 chip binary code word) to respective ones of the transmit electrodes. The assigned code words may be the rows of a size 16 Hadamard matrix. The receive signal may
25 be decoded to identify the transmit signal of respective ones of the transmit electrodes by its complete assigned code word. For the mutual-capacitance touch detection system shown in FIGURE 1, the receive signals of respective ones of the receive electrodes (Rx0 through Rx9) may be separately decoded to identify the transmit signal of respective ones of the transmit electrodes (Tx0 through Tx15) by its complete assigned code word so that all transmit signals
30 are deciphered to identify deviations of the transmit signals at nodes being "touched." A signal deviation matrix over the 16X10 array of Tx-Rx electrode nodes (i.e., in (x,y)) may be derived from the decoded receive signals. Touch positions of the two-dimensional (x,y) plane may then

be estimated for a point in time at which the receive signals are observed. U.S. Patent Number 9,927,933 discloses a system having a gesture detection device with a plurality of input channels and an output channel which uses an alternating electric near field generated through at least one transmission electrode coupled with the output channel, wherein some of the input channels are coupled with receiving electrodes of the gesture detection device. The entire disclosure of U.S. Patent Number 9,927,933 is incorporated herein by reference for all purposes.

Parts of a signal deviation matrix over the 16X10 array of Tx-Rx electrode nodes (i.e., in (x,y)), may also be derived in less time than it takes to transmit complete code words. For example, parts of a signal deviation matrix may be derived after receiving only eight chips of the receive signal, before receiving all sixteen chips of the receive signals containing complete code words. First, a subset, T_{subset} , of transmit electrodes are identified whose signals are affected by fingers touching at any receive electrode (signal deviation) at a previous point in time. Next, eight transmit electrodes, including those identified as being affected by fingers at the previous point in time, are assigned respective ones of the first eight rows of the size sixteen Hadamard matrix H_{16} in FIGURE 2C as respective code words, where Hadamard matrix H_{16} in FIGURE 2C is constructed from four Hadamard matrices H_8 as shown in FIGURE 2D and as explained further below. While FIGURES 2B-2D show a default assignment of code words, an adapted code-word-to-TX-electrode mapping may be based on the prior touch estimate so that the subset, T_{subset} , of transmit electrodes being touched may be reassigned the first eight code words (first eight rows of the size 16 Hadamard matrix H_{16}). Then, the remaining eight rows of the size 16 Hadamard matrix H_{16} are assigned to the remaining transmit electrodes outside the subset of transmit electrodes T_{subset} , i.e. the transmit electrodes not being touched. The transmission system is then run to transmit the transmit signals, i.e., code words, for all sixteen transmit electrodes. After reception of the first eight chips of the receive signal, the detection system performs the CDM de-spreading operation with the size eight Hadamard matrix H_8 to derive a partial signal deviation matrix over the 16X10 array of Tx-Rx electrode nodes (i.e., in (x,y)). This estimate may be called a 50% estimate because it is based on code word portions that are 50% of the complete code words (eight chips of the complete sixteen chips) in an H_8 Hadamard matrix, and the signal deviation matrix can only be computed and updated for the transmit electrodes in T_{subset} – the rest of the signal deviation matrix is assumed

to be unchanged compared to a previous, 100% (full) estimate. For a 100% (full) estimate, the receiving signal comprises both a first portion of the code words (first eight chips) and a second portion of the code words (second eight chips) so that complete code words (sixteen chips) are received, and the complete receive signal may be decoded for the receive electrodes using the complete code words.

FIGURES 2A-2D illustrate providing a capacitive touch sensing system comprising transmit electrodes and receive electrodes positioned to have mutual capacitances between transmit electrodes and receive electrodes at electrode intersections called nodes (see FIGURE 1), wherein the capacitance at respective ones of nodes deviates when touched; and performing a touch position estimate by: identifying a first and a second subset of transmit electrodes based on a prior touch position estimate; assigning code words (default or adapted) from a first subset of code words to respective ones of transmit electrodes of the first set of transmit electrodes, wherein respective ones of code words from the first subset of code words are a complete code word having a first code word portion and a second code word portion; assigning code words (default or adapted) from a second subset of code words to respective ones of transmit electrodes of the second set of transmit electrodes, wherein respective ones of code words from the second subset of code words are a complete code word having a first code word portion and a second code word portion; generating a transmit signal for respective ones of transmit electrodes according to its assigned code word; transmitting the transmit signals; receiving a first portion of a receive signal, for respective ones of receive electrodes, indicative of the respective capacitances between the receive electrode and respective ones of transmit electrodes; decoding the first portion of the receive signal for respective ones of receive electrodes using the first portions of the first subset of code words; and computing a touch position estimate for the first subset of transmit electrodes based on the decoded first portions of the receive signals.

A signal deviation matrix over the 16X10 array of Tx-Rx electrode nodes (i.e., in (x,y)), may further be derived after reception of all sixteen chips. The detection system performs the de-spreading operation with the full size sixteen Hadamard matrix H_{16} using the complete code words for all transmit electrodes. The signal deviation matrix thereby obtained may be an estimate with improved signal-to-noise ratio (SNR) compared to the 50% estimate. This second

estimate may be called a 100% estimate because it is based on the complete code words (sixteen chips) in a H_{16} Hadamard matrix.

Arrays of Tx-Rx electrode nodes may be of any size and any aspect ratio. Code words may take any form, in particular, they may be any spreading sequence. Chip values may take values other than +1 and -1, for example, +2 and -2. A Hadamard matrix or any other mathematical structure may be used to derive an estimated signal deviation matrix of an array of Tx-Rx electrode nodes.

A signal deviation matrix and detection system that makes alternating 50% and 100% report estimates may provide an increase of the report rate of the touch position estimates. As explained with reference to FIGURE 1, the report rate of the touch position estimates may be doubled by making estimates based on the first eight chips of the eight code words of the first group of transmit electrodes (50% estimate) in addition to making estimates based on the full sixteen chips of the sixteen code words of the combined first and second groups of transmit electrodes (100% estimate). Estimates in any communication/sensing system, including an estimate computed after 100% of the data are available, may be wrong because estimates are based on assumptions, and prone to measurement noise and other variables.

In some applications, report rates as high as 200Hz are desirable. By alternating between 50% estimates and 100% estimates, report rates as high as 200Hz may be obtained.

For use as a CDM sensing system, respective ones of the transmit electrodes are assigned a spreading sequence or code word from a set of orthogonal spreading sequences or code words. As used herein, default assigning or mapping means initial or original mapping of code words to transmit electrodes without using a prior touch estimate to inform the assignment or mapping. As used herein, adaptive assigning or mapping of code words means subsequently assigning or mapping code words to transmit electrodes based on a prior touch estimate. An adapted mapping may map a first set of code words to any transmit electrodes estimated to have been touched or assumed to have been touched by a prior touch estimate.

For the mutual-capacitance touch detection system shown in FIGURE 1, there are sixteen transmit (Tx) electrodes Tx0, Tx1, ..., Tx15. FIGURE 2D shows a default code-word-to-TX (S2T) mapping of code words to the transmit electrodes, wherein the transmit electrodes are numbered Tx0 through Tx15 from top to bottom. The set of sequences or code words may be the rows of the size 16 Hadamard matrix

$$H_{16} = \begin{bmatrix} H_8 & H_8 \\ H_8 & -H_8 \end{bmatrix}$$

which can be recursively computed by

$$H_{2^k} = \begin{bmatrix} H_{2^{k-1}} & H_{2^{k-1}} \\ H_{2^{k-1}} & -H_{2^{k-1}} \end{bmatrix}$$

with $H_{16} = 1$ using Sylvester's construction. Row q of H_{16} , $q \in \{0,1, \dots, 15\}$, denoted
 5 by $c_q^{(16)}$, is assigned to Tx m , $m \in \{0,1, \dots, 15\}$. Generally, the decoding ('de-spreading') of a
 receive sequence or code word when employing code words of length sixteen chips, is
 completed after having received all sixteen chips of the code word. However, according to an
 aspect providing a special construction of the size 16 Hadamard matrix H_{16} , the first eight
 received chips may be decoded using the size 8 Hadamard matrix H_8 , which may yield an
 10 ambiguous result because the same encoding size 8 Hadamard matrix H_8 is used for both the
 first subset T_{subset} of transmit electrodes (Tx0 – Tx7) and the remaining transmit electrodes
 outside the subset T_{subset} (Tx8 – Tx15). Ambiguous results are described more fully below.

FIGURE 2A shows a touch surface and time axis, illustrating a single finger touch
 (shown by a circle on the plane representing a touch surface) on the electrode crossing of Tx3,
 15 Rx3 with constant position over time (shown by a cylinder extending from the plane
 representing a touch surface). FIGURE 2B shows a default code-word-to-TX (S2T) mapping
 for the touch surface and single finger touch shown in FIGURE 2A, wherein code words c_0
 through c_{15} are assigned to transmit electrodes Tx0 through Tx15, respectively, and respective
 ones of the code words has sixteen chips. In this example, a single finger is touching the touch
 20 surface on Tx3. There is no finger touching any of the other electrodes, particularly not the Tx
 electrodes TX8 – Tx15. Consequently, as there is no change in the position of the touch, and
 neither a new touch, there is no influence from a finger touching Tx electrodes Tx8 - Tx15 on
 the signal deviation, such that there is no ambiguity in the signal deviation. Touches on TX8 –
 Tx15 may result in receive data ambiguous with receive data upon touches on Tx0-Tx7 after
 25 receipt of the first eight chips, because portions $C_0^{(8)}$ - $C_7^{(8)}$ of code words $C_0 - C_7$ are the same
 as portions $C_0^{(8)} - C_7^{(8)}$ of code words $C_8 - C_{15}$. As used herein, the term "ambiguous" means
 a detection system is unable to definitively determine a touch position between two or more
 possible positions because there are two or more code word portions that are identical. As
 shown in FIGURES 2C-2D, the first eight chips of code words assigned to transmit electrodes
 30 Tx0-Tx7 are identical to the first eight chips of code words assigned to transmit electrodes Tx8-

Tx15, so that the touch position is ambiguous based on encoding data solely of transmit electrodes Tx0-Tx7, because the touch position could be at either transmit electrodes Tx0-Tx7 or transmit electrodes Tx8-Tx15. Because CDM is based on a set of orthogonal code words, for this example, the rows of Hadamard matrix are of size sixteen. Two code words are orthogonal when their dot product is zero (0). Two code words are substantially orthogonal when the code words comprise a dot product less than 0.1 times the code word length. Orthogonality means that touching Tx m does not affect measurement values for other Tx $\tilde{m}$, where $\tilde{m} \neq m$.

$$H_{16} = \begin{bmatrix} c_0 \\ c_1 \\ c_2 \\ \vdots \\ c_{15} \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ & & & & & & & \vdots & & & & & & & & \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 & 1 & -1 & -1 & 1 \end{bmatrix}$$

A respective Tx is assigned a code word c_i , for example, a binary sequence from H16, where for the scalar product of two code words holds

$$c_i \cdot c_j^T = \begin{cases} 16 & : i = j \\ 0 & : i \neq j \end{cases}$$

The transmit vector of Tx electrode m is:

$$s^{(m)} = c_m, \quad m = 0, 1, \dots, 15$$

On the Rx side, respective receive signal $r^{(n)}$ of receive electrode n is a weighted sum of the sixteen transmit signals, where the weight for a TX changes upon finger touch on this Tx. The received vector of Rx electrode n is:

$$r^{(n)} = \sum_{m=0}^{15} w^{(n,m)} \cdot s^{(m)}, \quad n \in \{0, 1, \dots\}$$

The decoding of electrode node (n, m) is:

$$y^{(n,m)} = r^{(n)} \cdot (s^{(m)})^T, \quad n \in \{0, 1, \dots\}$$

$$= 16 \cdot w^{(n,m)}$$

For the first eight chips, the code words for Tx8-Tx15 are identical to code words for Tx0-Tx7, which makes an ambiguity. The ambiguity may be resolved by decoding

after receiving all sixteen chips, because the full code words of length sixteen chips are orthogonal to each other. An ambiguity may be avoided by assuming that at most Tx electrodes of the first set of Tx electrodes are being touched and the remaining TX electrodes outside the first set are not being touched, wherein this assumption may be based on a 100% estimate prior to the 50% estimate. A single touch may cover more than one transmit electrode.

FIGURE 2D shows a diagram of the code words as shown in FIGURE 2C, wherein the set of orthogonal code words has rows of Hadamard matrix of size sixteen. FIGURE 2D is highlighting the construction of a default code-word-to-Tx mapping matrix, wherein a Hadamard matrix consists of four quadrants with smaller Hadamard matrices.

$$H_{16} = \begin{bmatrix} c_0 \\ c_1 \\ c_2 \\ \vdots \\ c_{N-1} \end{bmatrix} = \begin{bmatrix} H_8 & H_8 \\ H_8 & -H_8 \end{bmatrix}$$

As noted, there is an ambiguity for the first eight chips, because the first eight chips of the code words for Tx8-Tx15 are identical to the first eight chips of the code words for Tx0-Tx7. In particular, there is an ambiguity because a touch on Tx11 is indistinguishable from a touch on Tx3 when only given the receive signal values for the first eight chips. An ambiguity/interference may occur when touches are both on Tx0-Tx7 and Tx8-Tx15. When it is assumed, based on information from a previous point in time, that there is no touch on Tx8-Tx15, an interference can be excluded and an unambiguous measurement may be taken on Tx0-Tx7.

FIGURE 2D shows a construction method for Hadamard matrices, wherein the size sixteen Hadamard matrix H_{16} is recursively constructed, in four quadrants of the size sixteen Hadamard matrix, containing four copies of a size eight Hadamard matrix H_8 , one in the bottom right quadrant being sign inverted, where the size eight Hadamard matrix H_8 is a set of orthogonal rows eight chips long. There are repeating patterns in this matrix because of the special construction method, namely the size sixteen Hadamard matrix H_{16} is constructed from four copies of the size eight Hadamard matrix H_8 . The size eight Hadamard matrix H_8 , has orthogonal rows.

After eight Rx chips are received, there is ambiguity between touches on Tx #0-#7 and #8-#15 because the partial code words of Tx #0-#7 and #8-#15 are identical. For example, a

touch on Tx #11 yields the same Rx signals as a touch on Tx #3. This ambiguity exists when there is a chance that there is a touch both on Tx #0-#7 *and* #8-#15. However, if it can be assumed there is *no* touch on Tx #8-#15, then a touch on Tx #0-#7 can be resolved unambiguously, or vice versa, even after receipt of only the first eight chips of the original code word's sixteen chips.

FIGURE 3A shows a touch surface and time axis, illustrating a two-finger touch—one touch on Tx electrode #3 (Tx3) and another touch on Tx electrode # 11 (Tx11). FIGURE 3B shows a code-word-to-TX (S2T) mapping for the touch surface shown in FIGURE 3A. In this example, a single finger is touching the touch surface on Tx3 and another single finger is touching the touch surface on Tx11. There is no finger touching any of the other electrodes. Consequently, in the event that there is no change in the position of touch, there will be an influence from a finger touching Tx electrodes Tx8-Tx15 on the signal deviation, such that there may be ambiguity in the signal deviation. Code words of Tx8 – Tx15 may be ambiguous with code words of Tx0-Tx7 after receipt of the first eight chips, because the first eight chips of code words C₀-C₇ are identical to the first eight chips of code words C₈-C₁₅, see Figure 2D. The ambiguity of FIGURE 3B may be resolved by decoding after receiving all sixteen chips, because the second eight chips of code words are not identical. Alternatively, FIGURE 3C shows an adapted assignment or mapping of code words to transmit electrodes, which may preclude an ambiguity of the code words when decoding after receipt of the first eight chips. Via the adapted assignment, code words C₀-C₃ are assigned to transmit electrodes Tx2-Tx5, respectively, and code words C₄-C₇ are assigned to transmit electrodes Tx10-Tx13, respectively. There is no ambiguity with this adapted assignment because the touched transmit electrodes (Tx2-Tx5 and Tx10-Tx13) are assigned code words C₀-C₇ and the remaining untouched transmit electrodes (Tx0-Tx1, Tx6-Tx9, and Tx14-Tx15) are assigned code words C₈-C₁₅.

FIGURE 4A shows a touch surface and time axis, illustrating a two-finger touch on Tx0-Tx7—one touch on Tx electrode #2 (Tx2) and another touch on Tx electrode # 5 (Tx5). FIGURE 4B shows a code-word-to-TX (S2T) mapping for the touch surface and single finger touch at the previous point in time shown in FIGURE 4A. There is no finger touching any of the other electrodes, particularly not the Tx electrodes Tx8 - Tx15. Consequently, in the event that there is no change in the position of touch, there will be no influence from a finger touching Tx electrodes Tx8 - Tx15 on the signal deviation, such that there is no ambiguity in the signal

deviation. In this example, two-finger touches can be unambiguously resolved/detected after only eight receive chips when they are both located on Tx electrodes Tx0 - Tx7. Any number of touches on the area of Tx electrodes Tx0 - Tx7 can be resolved provided it is assumed that there is no touch on Tx electrodes Tx8 to Tx15. Code words for Tx8 – Tx15 may be ambiguous with code words for Tx0-Tx7 after receipt of the first eight chips because these code word portions are identical. If it has been previously estimated that there are no touches on Tx8 – Tx15, then the detection system may assume estimated touches, if any, will be on Tx0 - Tx7, i.e. not on Tx8 – Tx15.

FIGURE 5A shows a touch surface and time axis, illustrating two fingers covering Tx electrodes Tx2 to Tx6, and one finger covering Tx electrodes Tx9 to Tx11. FIGURE 5B shows an adapted code-word-to-TX (S2T) mapping, wherein code words are mapped as follows: C0→Tx2; C1→Tx3; C2→Tx4; C3→Tx5; C4→Tx6; C5→Tx9; C6→Tx10; and C7→Tx11. This adaptive mapping may yield un-ambiguous detection after eight chips for the touch surface and finger touch positions shown in FIGURE 5A. One way to avoid an ambiguity is to confirm by a prior touch estimate that all of the touches are on transmit electrodes Tx0 – Tx7, so the current, touching finger(s) may be assumed to be located on transmit electrodes Tx0 - Tx7. However, in this example of FIGURES 5A-5B, the ambiguity problem may be solved for finger touches on any Tx electrodes, provided that sufficiently many Tx electrodes remain untouched or, more precisely, the respective Tx-Rx channels may be assumed to yield zero signal deviation. The first eight spreading sequences or code words in H_{16} are adaptively assigned to the touched Tx electrodes. In particular, the two fingers covering Tx electrodes Tx2 to Tx6 and one finger covering Tx electrodes Tx9 to Tx11 shown in FIGURES 5A, are adaptively assigned, respectively, to code words $c_0^{(16)}$ to $c_4^{(16)}$ and $c_5^{(16)}$ to $c_7^{(16)}$, as shown in FIGURE 5B. This is an adapted code-word-to-TX (S2T) assignment or mapping. This assignment can be represented by multiplication of the code word matrix with a code-word-to-Tx mapping matrix Γ . For the example in FIGURES 5A-5B, multiplication of the code word matrix with a code-word-to-Tx mapping matrix Γ , is $\Gamma \cdot H_{16}$ with

$$\mathbf{F} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

The sequences or code words may be spread by Sylvester's construction. For Hadamard matrices computed with Sylvester's recursive construction with

$$H_{2^k} = \begin{bmatrix} H_{2^{k-1}} & H_{2^{k-1}} \\ H_{2^{k-1}} & -H_{2^{k-1}} \end{bmatrix}$$

5 and $H_1 = [1]$, latency may be further reduced.

According to one aspect, the Hadamard matrix H_{16} may be expressed as

$$H_{16} = \begin{bmatrix} H_8 & H_8 \\ H_8 & -H_8 \end{bmatrix} = \begin{bmatrix} \begin{bmatrix} H_4 & H_4 \\ H_4 & -H_4 \end{bmatrix} & \begin{bmatrix} H_4 & H_4 \\ H_4 & -H_4 \end{bmatrix} \\ \begin{bmatrix} H_4 & H_4 \\ H_4 & -H_4 \end{bmatrix} & -\begin{bmatrix} H_4 & H_4 \\ H_4 & -H_4 \end{bmatrix} \end{bmatrix}$$

which implies that if at most four Tx electrodes are being touched, the first four rows of H_{16} may be adaptively assigned to the Tx electrodes being touched, so that the signal may be effectively decoded after having received the first four chips. In other words, when there are finger touches only on Tx electrodes to which the first four rows of H_{16} are assigned as code words, then the finger positioning can take place already after having received data for the first four chips. This process can be played down to a single touched electrode. Because the first eight spreading sequences or code words in H_{16} are adaptively assigned to the touched Tx electrodes, there is no ambiguity.

FIGURE 6 shows a graph with an example of the measurement and finger position estimate update over time. In this example, at ten millisecond intervals, the system has alternately received 50% and 100% of the chips, for 50% and 100% estimates, respectively. At 0 milliseconds, no previous information is given about finger positions on the touch sensor. Therefore, a default assignment or mapping of code words to Tx electrodes is applied, which is why the data bar is shown as an outline rather than a solid bar. At 10 milliseconds, the graph

shows that the system received data for the first eight chips. If there would have been prior touch information at time 0ms, and if the code word to Tx mapping could have been applied such that to all touched Tx electrodes were assigned code words from the first eight rows of the Hadamard matrix H16, then a position estimate update could be computed for the respective Tx electrodes. However, as there was no prior touch information available at time 0ms, a sensible position estimate update could not be computed at this 0ms time. At 20 milliseconds, the graph shows that the system received 100% of the transmitted code words, implying that position estimate updates were computed for 100% of the transmit electrodes ("100% Tx") by de-spreading the receive data with the code words from a full-sized Hadamard matrix, which also implies signal deviation estimates with improved SNR compared to the 50% Tx estimates where only the first halves of the full code words are employed. Also at 20 milliseconds, because there was information about finger touches available, an adapted code-word-to-Tx mapping is applied for the next measurement cycle, ensuring that all touched Tx electrodes have mapped code words from the set {c0, c1, ..., c7}. At 30ms with the next 50% Tx estimate, touch position estimate updates are computed for the Tx electrodes associated with code words c0, ..., c7 using the receive data for the first eight transmitted chips and code words from the rows of Hadamard matrix H8. At 40ms after receiving data for all sixteen transmitted chips, touch position updates are computed for all sixteen Tx electrodes, and a new adapted code word to Tx map is prepared for the next measurement cycle. The graph shows these steps are repeated at 50 and 60 milliseconds, and again at 70 and 80 milliseconds. Report estimates may be provided by serially and alternately decoding the first portion of the receive signal (50%) and decoding the complete receive signal (100%). Thus, signal deviation matrices providing estimates of touch position(s) may be reported at more frequent time intervals.

A detection system that makes alternating 50% and 100% report estimates may provide an increase of the report rate of the touch position estimates. In this case, an estimate of the touch position is decoded by the detection system on 10 millisecond intervals. Whereas, if 100% estimates are exclusively decoded, the detection system may estimate the touch position on 20 millisecond intervals. By making estimates based on the first eight chips of the eight code words of the first subset of transmit electrodes (50% estimate), wherein code words are adaptively mapped based on information from previous estimates, in addition to making estimates based on the full sixteen chips of the sixteen code words of the combined first and second subsets of transmit electrodes (100% estimate), the detection system may make

estimates at 10 millisecond intervals. Detections systems may make estimates of touch position(s) at 10 millisecond intervals, 5 millisecond intervals, 1 millisecond intervals, or any time interval greater than or equal to 1 millisecond. Detection systems may report estimates of touch position(s) at 50Hz, 100 Hz, 150 Hz, 200 Hz, or any report rate faster than or equal to 50 Hz. Signal deviation matrices providing estimates of touch position(s) may be reported at time intervals.

A first set of data may be transmitted to provide a 50% estimate, a second set of data may be transmitted to provide a 100% estimate, a third set of data may be transmitted to provide another 50% estimate, and so forth. Subsequent estimates may be based on prior assumptions about the number of touching fingers and their positions. An estimate at a point in time may be based on transmission of code word portions comprising 50% or more of the code words, respectively, for example the first eight chips of sixteen chip code words or any number of chips between eight and sixteen. An estimate at another point in time may be based on transmission of code word portions comprising 50% or less of the code words, respectively, for example the first eight chips of sixteen chip code words or any number of chips between one and eight.

FIGURE 7 shows a block diagram of a system having a capacitive touch sensing system 702, a processor 704, and a storage medium 706. The capacitive touch sensing system 702 may comprise transmit electrodes and receive electrodes positioned to have mutual capacitances between transmit electrodes and receive electrodes at their intersections called nodes, wherein the capacitance at respective ones of nodes deviates when a node is touched. The processor 704 may be a microcontroller. The machine readable storage medium 706 storing instructions, which when executed by the processor, may cause the system to: assign a code word to respective ones of transmit electrodes of the set of transmit electrodes, wherein respective ones of code words is a complete code word having a first code word portion and a second code word portion; identify a first subset of transmit electrodes and their assigned code words based on a prior touch position estimate; identify a second subset of transmit electrodes and their assigned code words; generate a transmit signal for respective ones of transmit electrodes of the first subset of transmit electrodes according to its assigned code word; transmit the transmit signals; receive a first portion of a receive signal, for respective ones of receive electrodes, indicative of the respective capacitances between the receive electrode and respective ones of the transmit electrodes of the first subset of transmit electrodes; decode the first portion of the

receive signal for respective ones of receive electrodes using the first portions of the first subset of code words; and compute touch position estimates for the first subset of transmit electrodes based on the decoded first portions of the receive signals.

FIGURE 8 shows a flow chart of method. A capacitive touch sensing system is provided 5 802 comprising transmit electrodes and receive electrodes positioned to have mutual capacitances between transmit electrodes and receiver electrodes at node intersections, wherein the capacitance at respective ones of nodes deviates when touched. A code word is assigned 804 to respective ones of transmit electrodes of the set of transmit electrodes, wherein respective ones of code words is a complete code word having a first code word portion and a 10 second code word portion. A first subset of transmit electrodes and their assigned code words is identified 806 based on a prior touch position estimate. A second subset of transmit electrodes and their assigned code words are identified 808. A transmit signal is generated 810 for respective ones of transmit electrodes of the first subset of transmit electrodes according to its assigned code word; and the transmit signal is transmitted 812. A first portion of a receive 15 signal is received 814, for respective ones of receive electrodes, indicative of the respective capacitances between the receive electrode and respective ones of transmit electrodes of the first subset of transmit electrodes. The first portion of the receive signal is decoded 816 for respective ones of receive electrodes using the first portions of the first subset of code words. Touch position estimates are computed 818 for the first subset of transmit electrodes based on 20 the decoded first portions of the receive signals.

Aspects may also apply to other sets of code words, and also when employing code words with near-zero cross-correlation also for non-zero time-shifts between two code words in the correlation function.

According to an aspect, there is provided the spreading gain, i.e., the signal-to-noise 25 ratio (SNR) gain due to CDM vs. Time-Division Multiplexing (TDM, where only one transmit electrode has a non-zero stimulus at a time) after receiving half the number of chips of the code words is half of what it is after receiving the full number of chips of the code words. For example, the SNR of a 100% estimate may be twice the SNR of a 50% estimate, because of the so-called spreading gain.

30 Although examples have been described above, other variations and examples may be made from this disclosure without departing from the spirit and scope of these disclosed examples.

CLAIMS

1. A method comprising:

providing a capacitive touch sensing system comprising transmit electrodes and receive electrodes positioned to have mutual capacitances between transmit electrodes and receive electrodes at electrode intersections called nodes, wherein the capacitance at respective ones of nodes deviates when touched; and

performing a touch position estimate by:

identifying a first and a second subset of transmit electrodes based on a prior touch position estimate;

assigning code words from a first subset of code words to respective ones of transmit electrodes of the first set of transmit electrodes, wherein respective ones of code words from the first subset of code words are a complete code word having a first code word portion and a second code word portion;

assigning code words from a second subset of code words to respective ones of transmit electrodes of the second set of transmit electrodes, wherein respective ones of code words from the second subset of code words are a complete code word having a first code word portion and a second code word portion;

generating a transmit signal for respective ones of transmit electrodes according to its assigned code word;

transmitting the transmit signals;

receiving a first portion of a receive signal, for respective ones of receive electrodes, indicative of the respective capacitances between the receive electrode and respective ones of transmit electrodes;

decoding the first portion of the receive signal for respective ones of receive electrodes using the first portions of the first subset of code words; and computing a touch position estimate for the first subset of transmit electrodes based on the decoded first portions of the receive signals.

2. The method as in claim 1, comprising:

receiving a second portion of receive signal for respective ones of receive electrodes;
decoding the complete receive signal for respective ones of receive electrodes using the
complete code words;

5 computing a touch position estimate for the set of transmit electrodes based on the
decoded complete receive signals; and

serially and alternatingly decoding the first portion of the receive signal and decoding
the complete receive signal.

10 3. The method as in any one of claims 1 to 2, comprising default assigning respective ones of
code words from the first subset of code words to respective ones of the first set of transmit
electrodes and default assigning respective ones of code words from the second subset of code
words to respective ones of the second set of transmit electrodes, wherein code words comprise
unique numbers, wherein transmit electrodes are numbered uniquely, and wherein the default
assigning comprises assigning the code word with the lowest number to the lowest numbered
15 transmit electrode, and assigning the code word with the second lowest number to the second
lowest numbered transmit electrode.

4. The method as in any one of claims 1 to 3, comprising repeating the performing a touch
position estimate.

20

5. The method as in any one of claims 1 to 4, wherein assigning respective ones of code words
from the first subset of code words to respective ones of the first set of transmit electrodes
comprises: adaptive assigning respective ones of code words from the first subset of code
words to transmit electrodes identified as having been touched or identified as assumed to have
25 been touched based on the prior touch position estimate, and wherein assigning respective ones
of code words from the second subset of code words to respective ones of the second set of
transmit electrodes comprises: adaptive assigning respective ones of code words from the
second subset of code words to transmit electrodes identified as having not been touched or
identified as assumed to have not been touched based on the prior touch position estimate.

30

6. The method as in any one of claims 1 to 5, wherein assigning respective ones of code words
from the second subset of code words to respective ones of the second set of transmit electrodes

comprises: adaptive assigning respective ones of code words from the second subset of code words to transmit electrodes identified as having not been touched or identified as assumed to have not been touched based on the prior touch position estimate, and wherein assigning respective ones of code words from the first subset of code words to respective ones of the first set of transmit electrodes comprises: adaptive assigning respective ones of code words from the first subset of code words to remaining unassigned transmit electrodes.

7. The method as in any one of claims 1 to 6, wherein respective ones of the code words comprise binary sequences having $2 \cdot K$ chips of a Hadamard matrix where K is an integer, wherein the code word portions of respective ones of the code words comprise K chips.

8. A system comprising:

a capacitive touch sensing system comprising transmit electrodes and receive electrodes positioned to have mutual capacitances between transmit electrodes and receive electrodes at electrode intersections called nodes, wherein the capacitance at respective ones of nodes deviates when touched;

a processor; and

a machine readable storage medium storing instructions, which when executed by the processor, cause the system to:

identify a first and a second subset of transmit electrodes based on a prior touch position estimate;

assign code words from a first subset of code words to respective ones of transmit electrodes of the first set of transmit electrodes, wherein respective ones of code words from the first set of code words are a complete code word having a first code word portion and a second code word portion;

assign code words from a second subset of code words to respective ones of transmit electrodes of the second set of transmit electrodes, wherein respective ones of code words from the second set of code words are a complete code word having a first code word portion and a second code word portion;

generate a transmit signal for respective ones of transmit electrodes according to its assigned code word;

transmit the transmit signals;

receive a first portion of a receive signal, for respective ones of receive electrodes, indicative of the respective capacitances between the receive electrode and respective ones of transmit electrodes;

decode the first portion of the receive signal for respective ones of receive electrodes using the first portions of the first subset of code words; and

compute touch position estimates for the first subset of transmit electrodes based on the decoded first portions of the receive signals,

whereby a touch estimate is performed.

9. The system as in claim 8, wherein the instructions, which when executed by the processor, cause the system to:

receive a second portion of receive signal for respective ones of receive electrodes;

decode the complete receive signal for respective ones of receive electrodes using the complete code words;

compute touch position estimates for the set of transmit electrodes based on the decoded complete receive signals; and

serially and alternatingly decode the first portion of the receive signal and decode the complete receive signal.

10. The system as in any one of claims 8 to 9, wherein the instructions, which when executed by the processor, cause the system to default assign respective ones of code words from the first subset of code words to respective ones of the first set of transmit electrodes and default assign respective ones of code words from the second subset of code words to respective ones of the second set of transmit electrodes, wherein code words comprise unique numbers, wherein transmit electrodes are numbered uniquely, and wherein the default assigning comprises assigning the code word with the lowest number to the lowest numbered transmit electrode, and assigning the code word with the second lowest number to the second lowest numbered transmit electrode.

11. The system as in any one of claims 8 to 10, wherein the instructions, which when executed by the processor, cause the system to repeatedly perform a touch position estimate.

12. The system as in any one of claims 8 to 11, wherein the instructions, which when executed by the processor, cause the system to:

adaptively assign respective ones of code words to transmit electrodes identified as having been touched or identified as assumed to have been touched based on the prior touch position estimate, and

adaptively assign respective ones of code words to transmit electrodes identified as having not been touched or identified as assumed to have not been touched based on the prior touch position estimate.

13. The system as in any one of claims 8 to 12, wherein assign respective ones of code words from the second subset of code words to respective ones of the second set of transmit electrodes comprises: adaptive assign respective ones of code words from the second subset of code words to transmit electrodes identified as having not been touched or identified as assumed to have not been touched based on the prior touch position estimate.

14. The system as in claim 13, wherein assign respective ones of code words from the first subset of code words to respective ones of the first set of transmit electrodes comprises: adaptive assign respective ones of code words from the first subset of code words to remaining unassigned transmit electrodes.

15. The system as in any one of claims 8 to 14, wherein respective ones of the code words comprise binary sequences having $2 \cdot K$ chips of a Hadamard matrix where K is an integer, wherein the code word portions of respective ones of the code words comprise K chips.

1/14

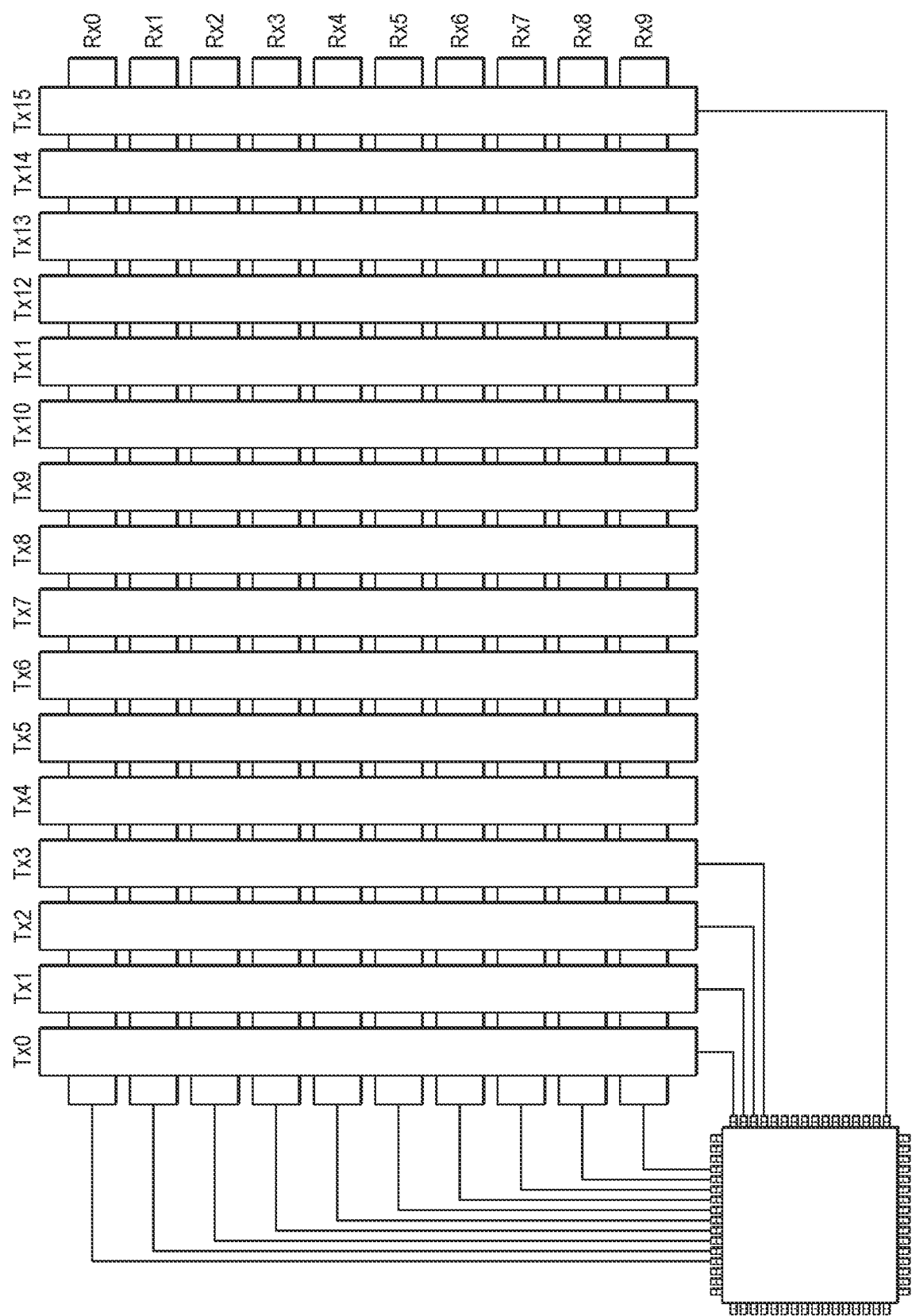


FIG. 1

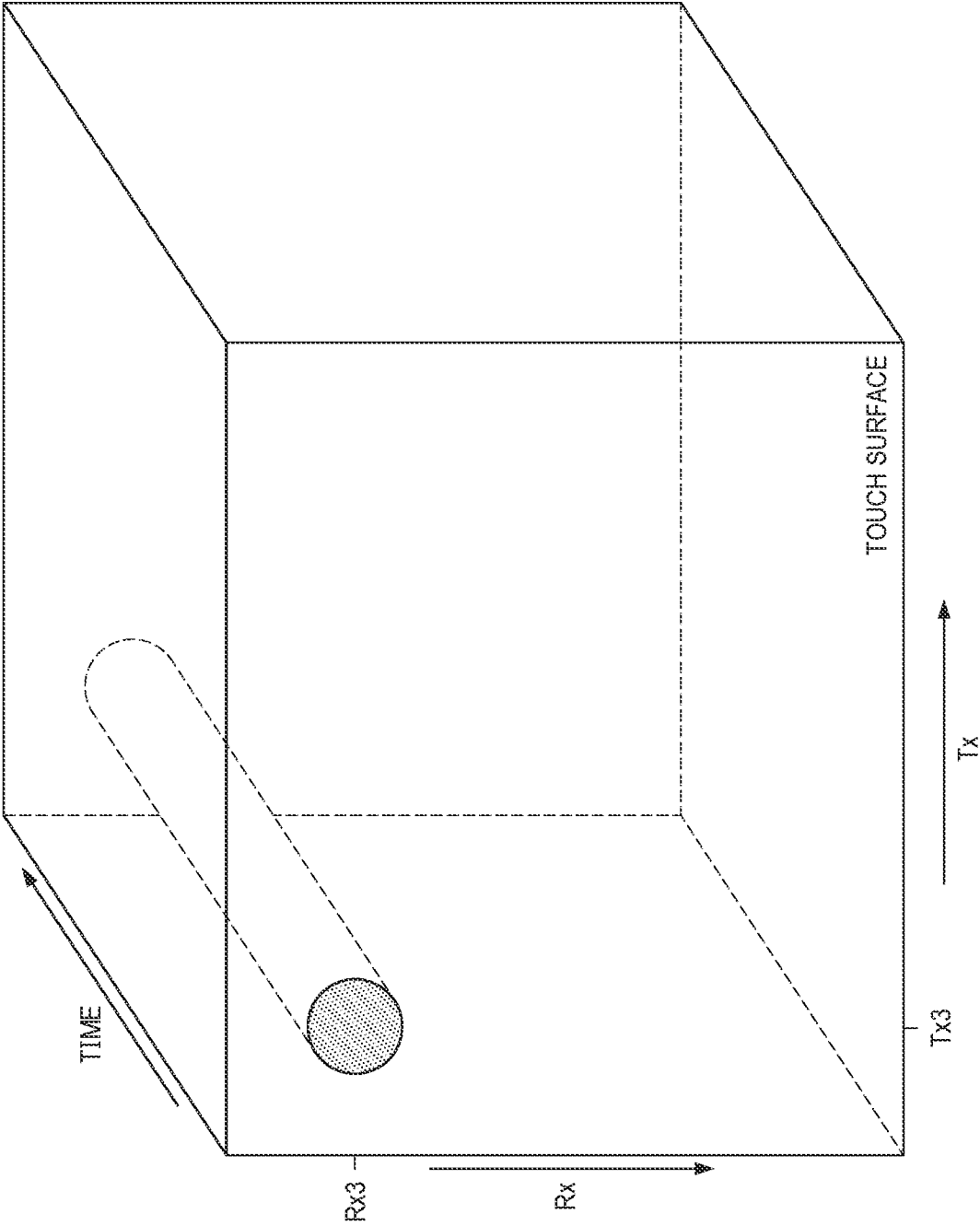


FIG. 2A

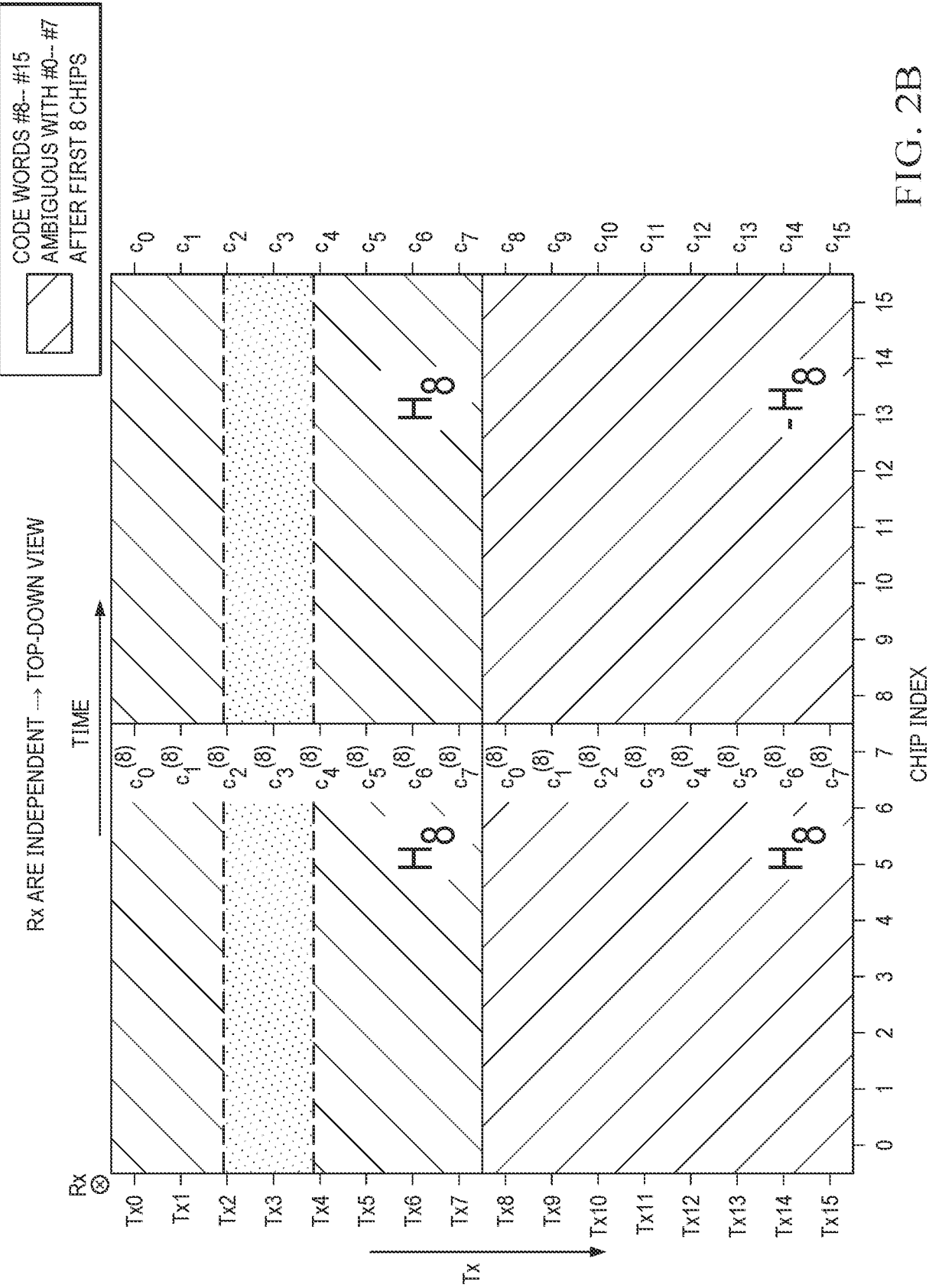


FIG. 2B

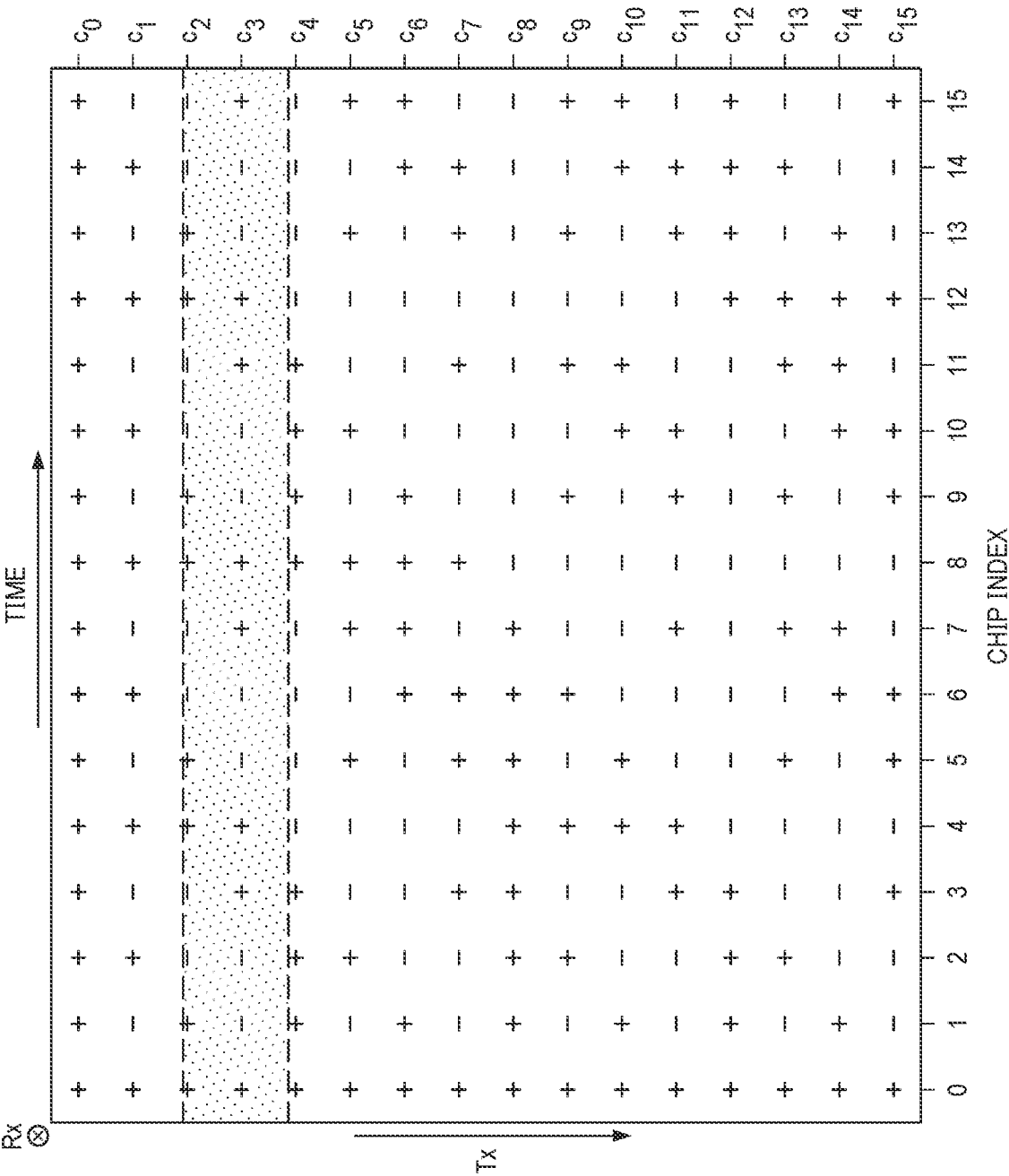
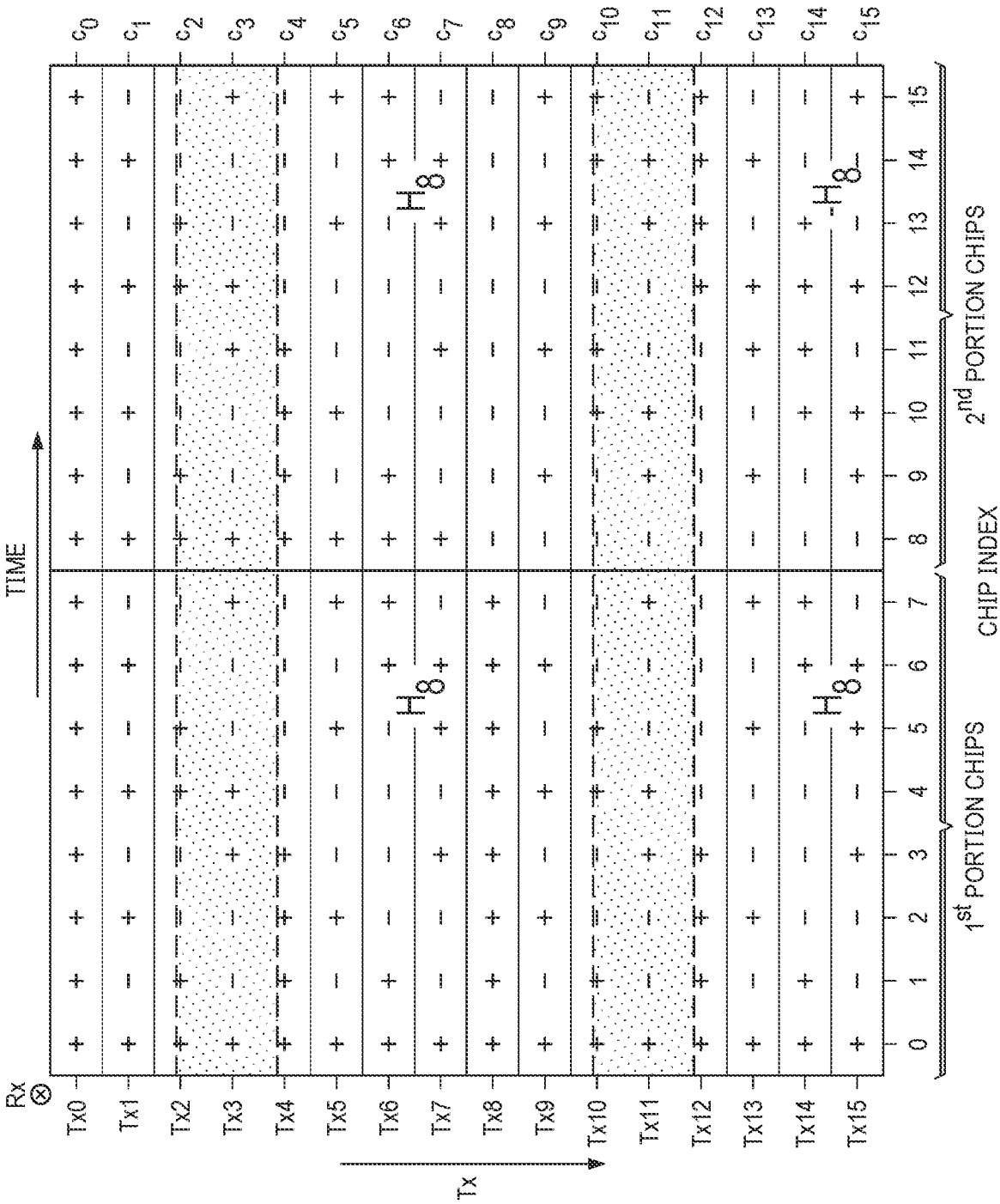


FIG. 2C



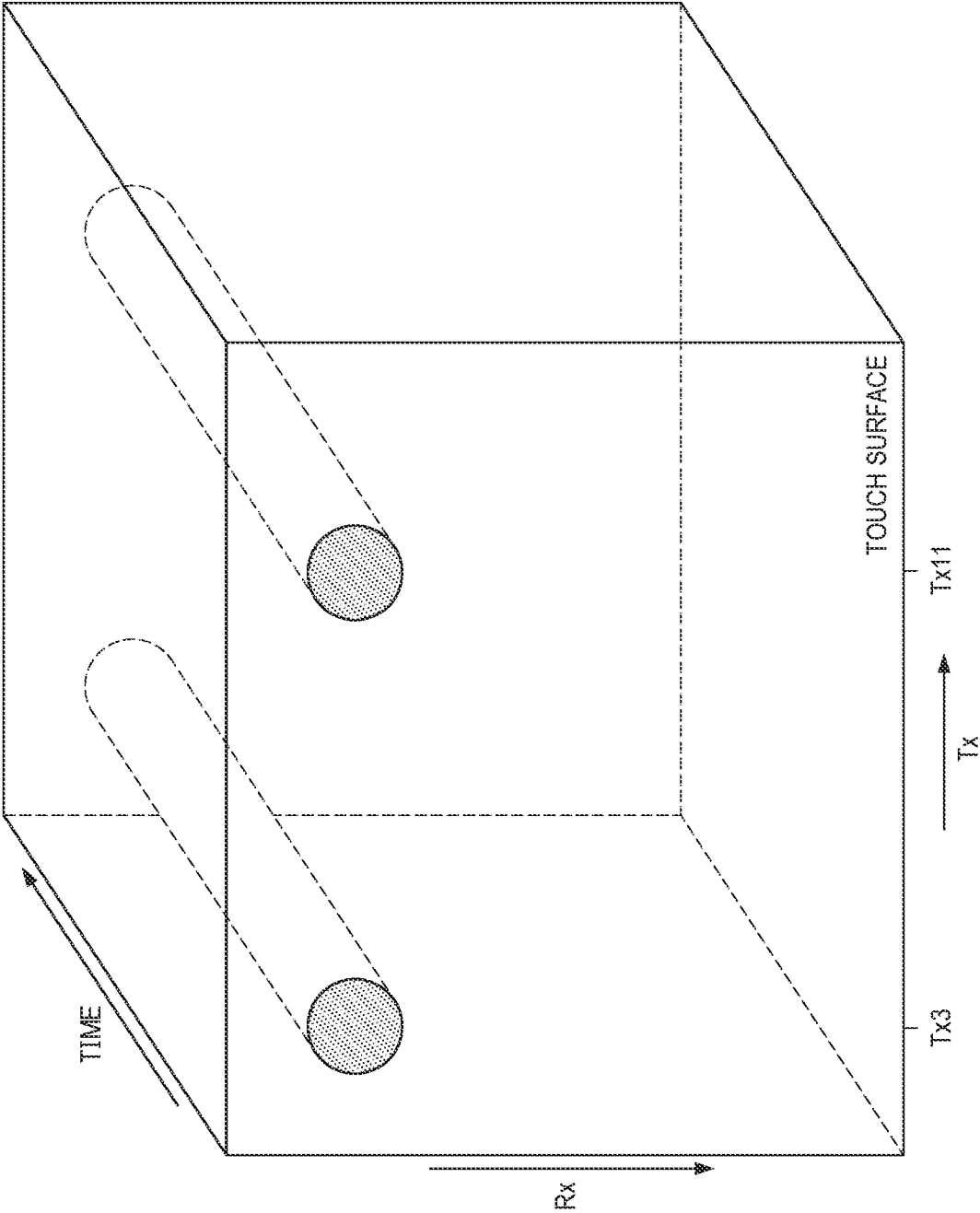
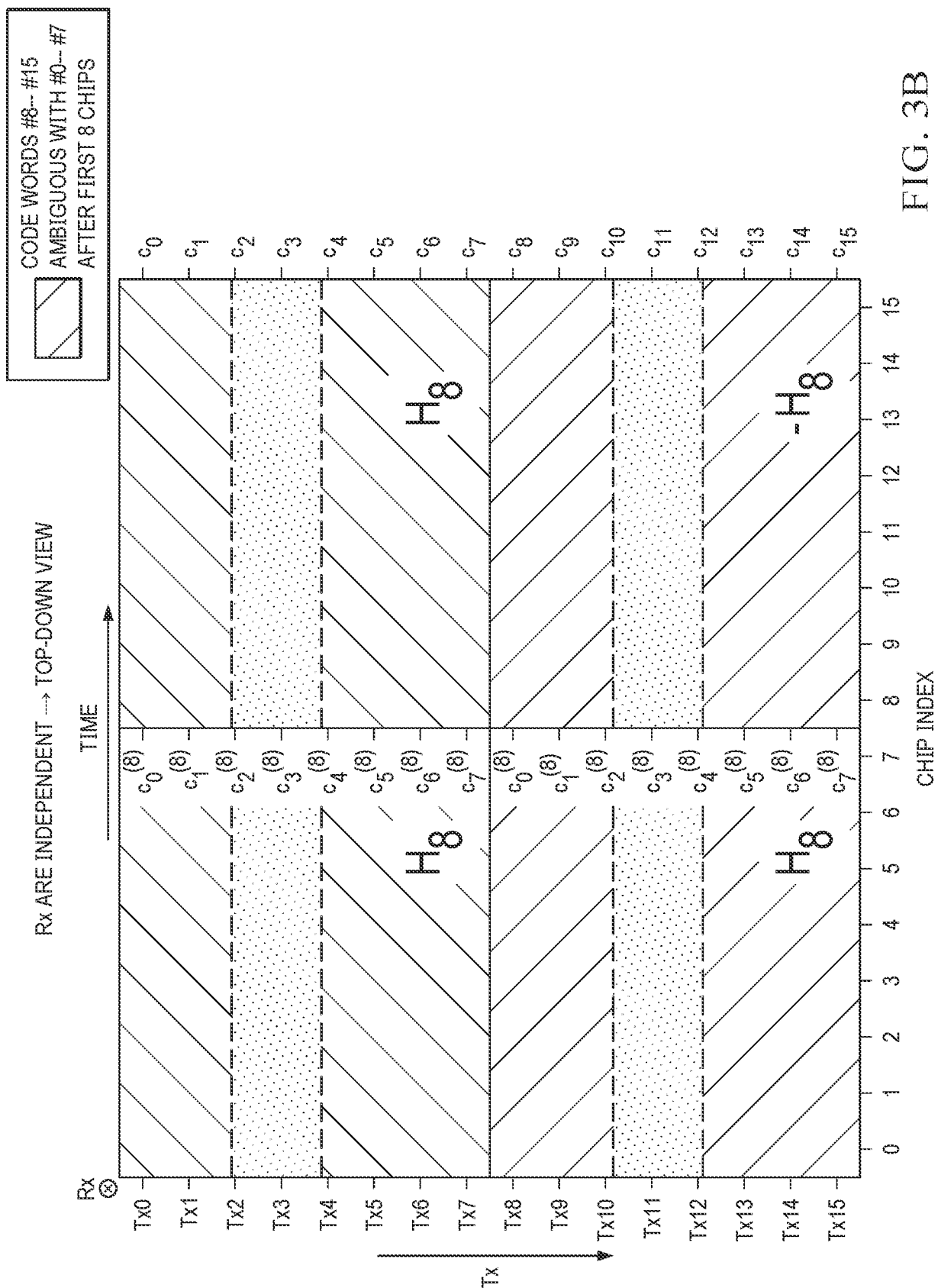
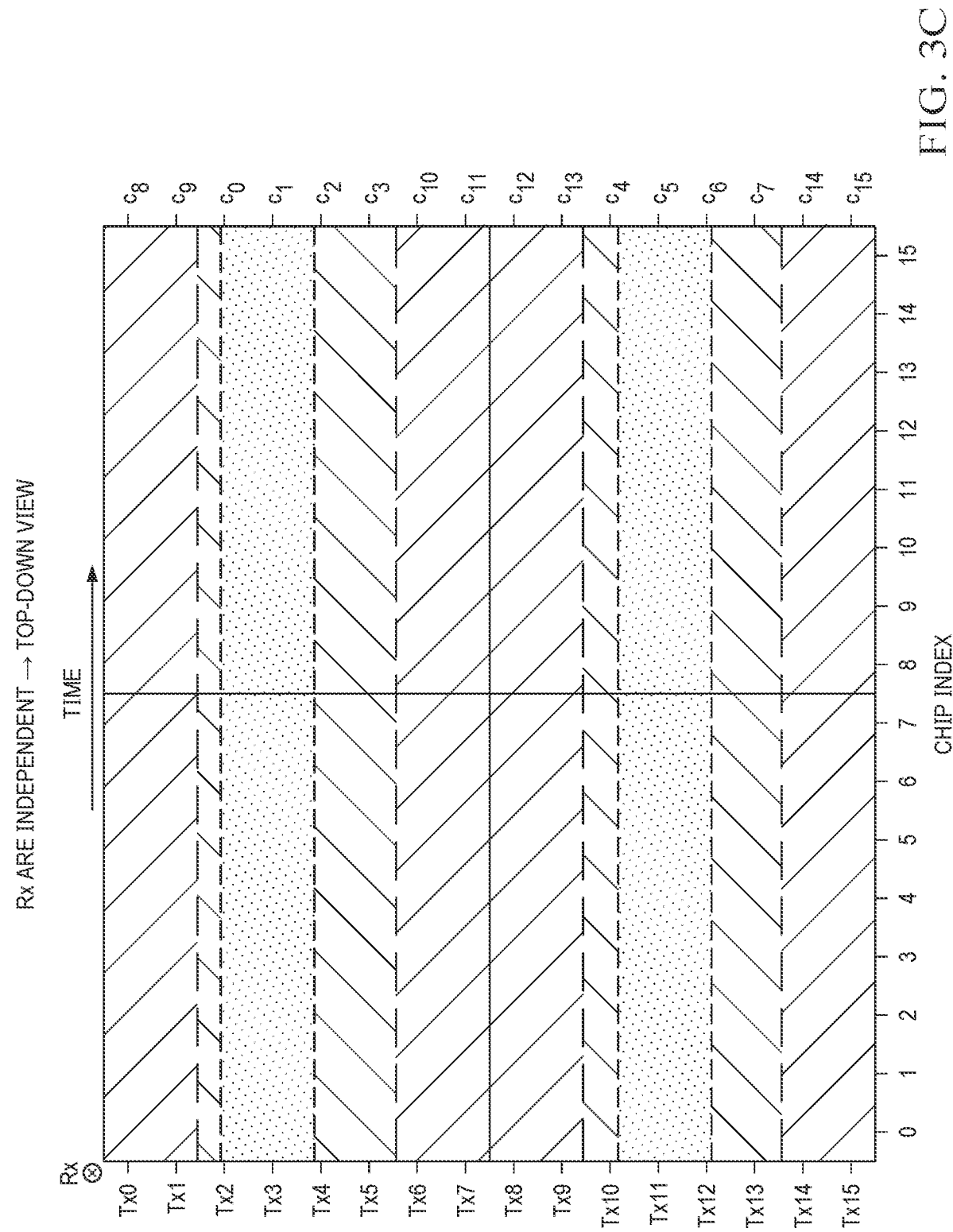


FIG. 3A





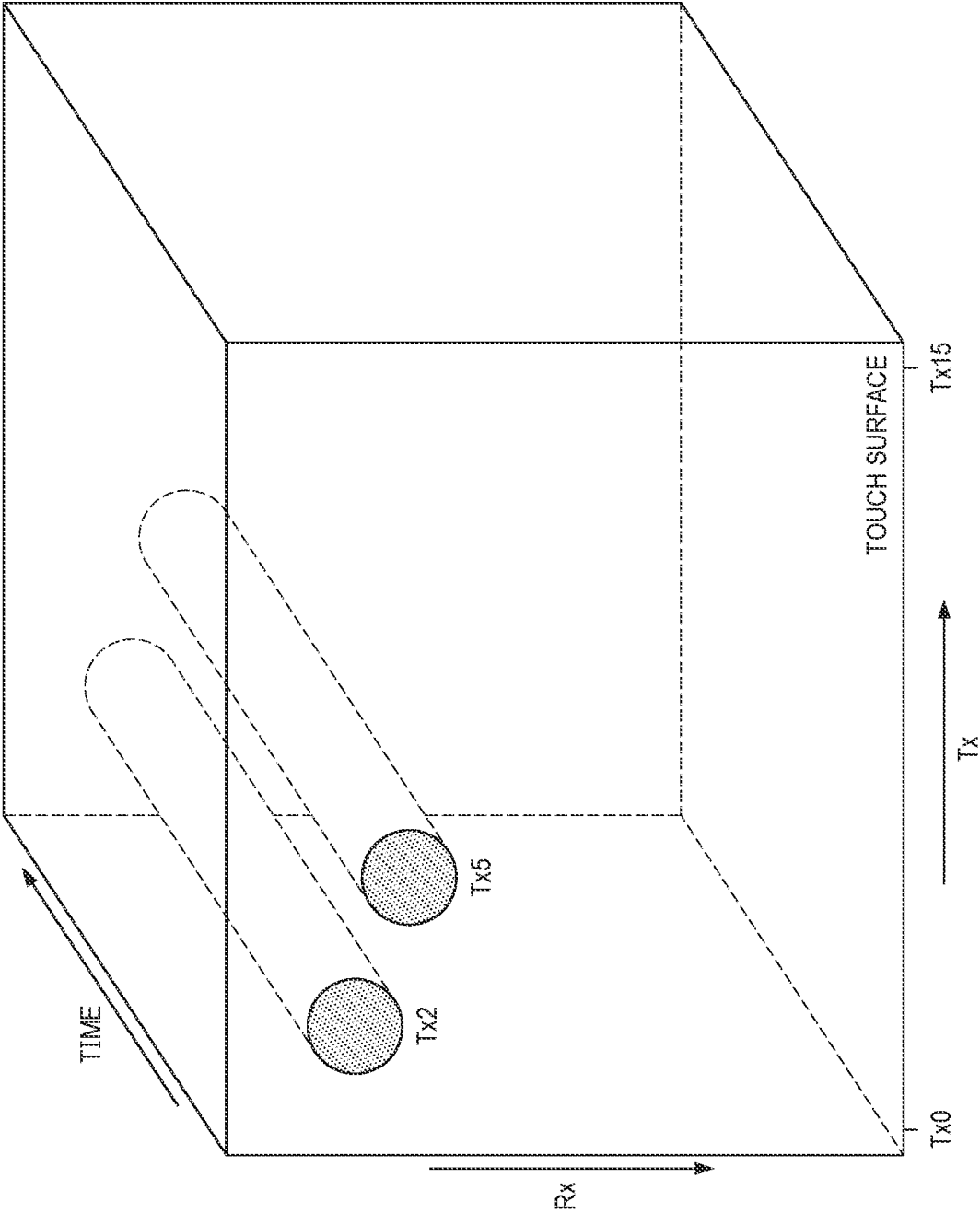


FIG. 4A

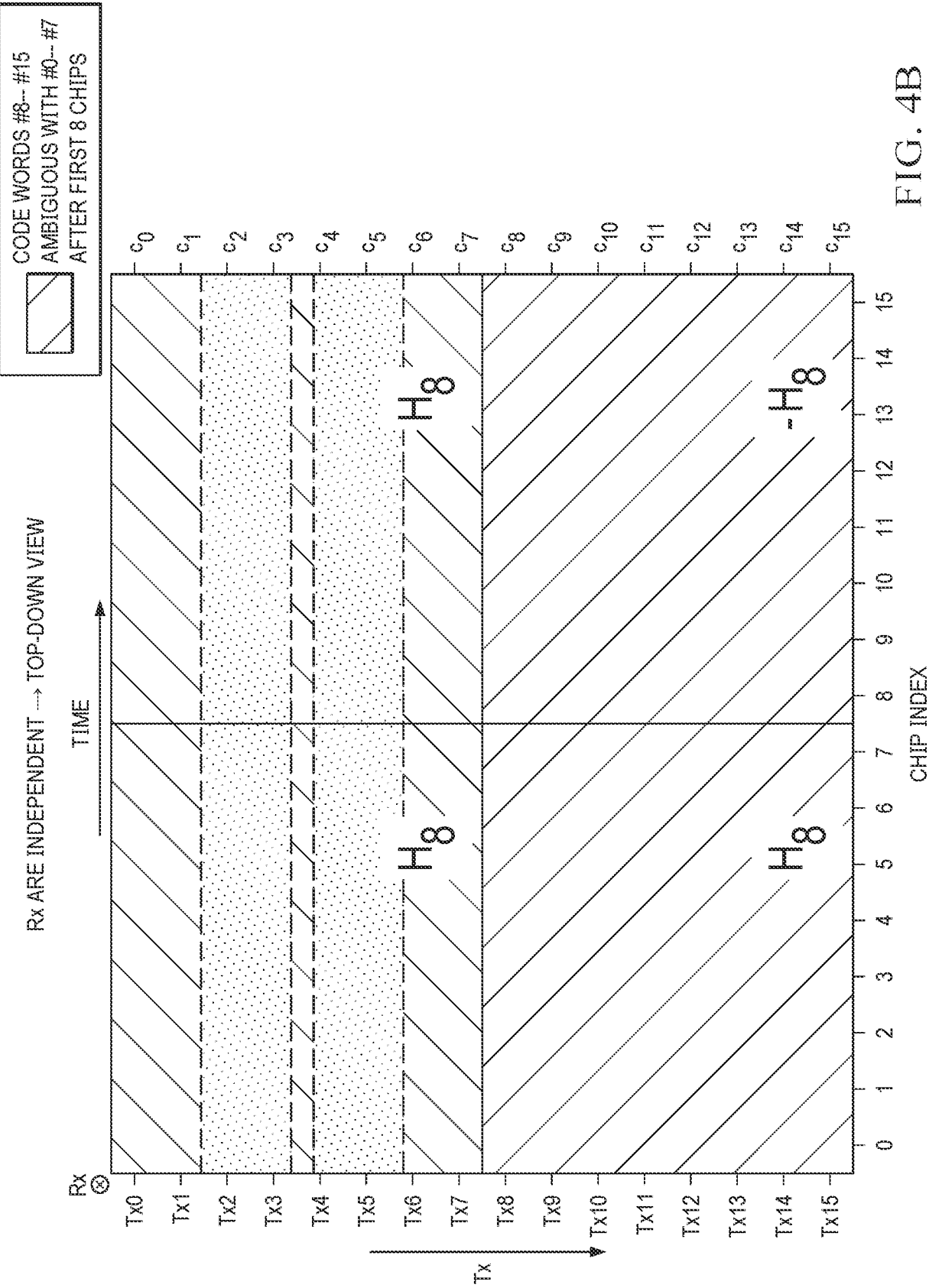


FIG. 4B

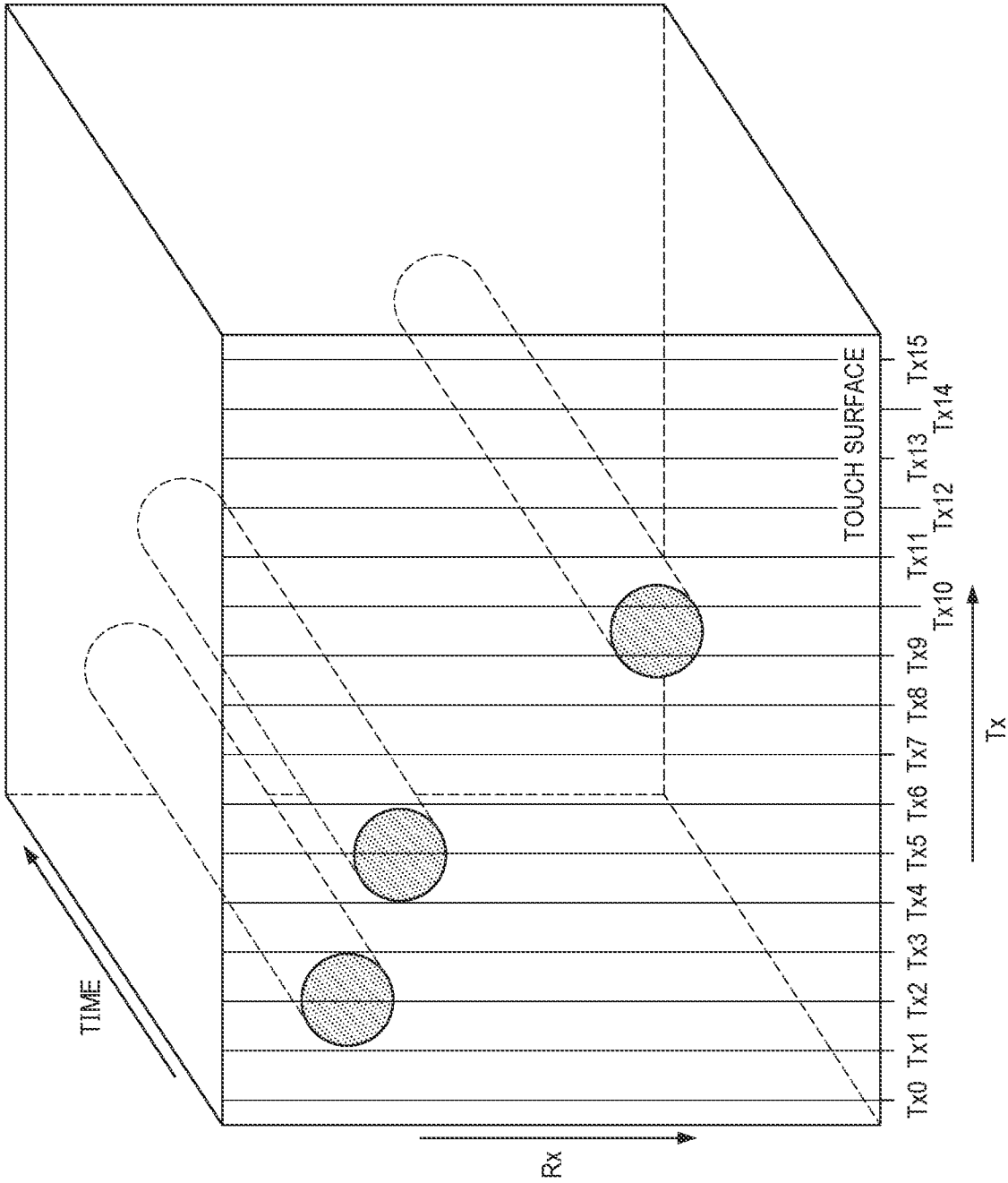
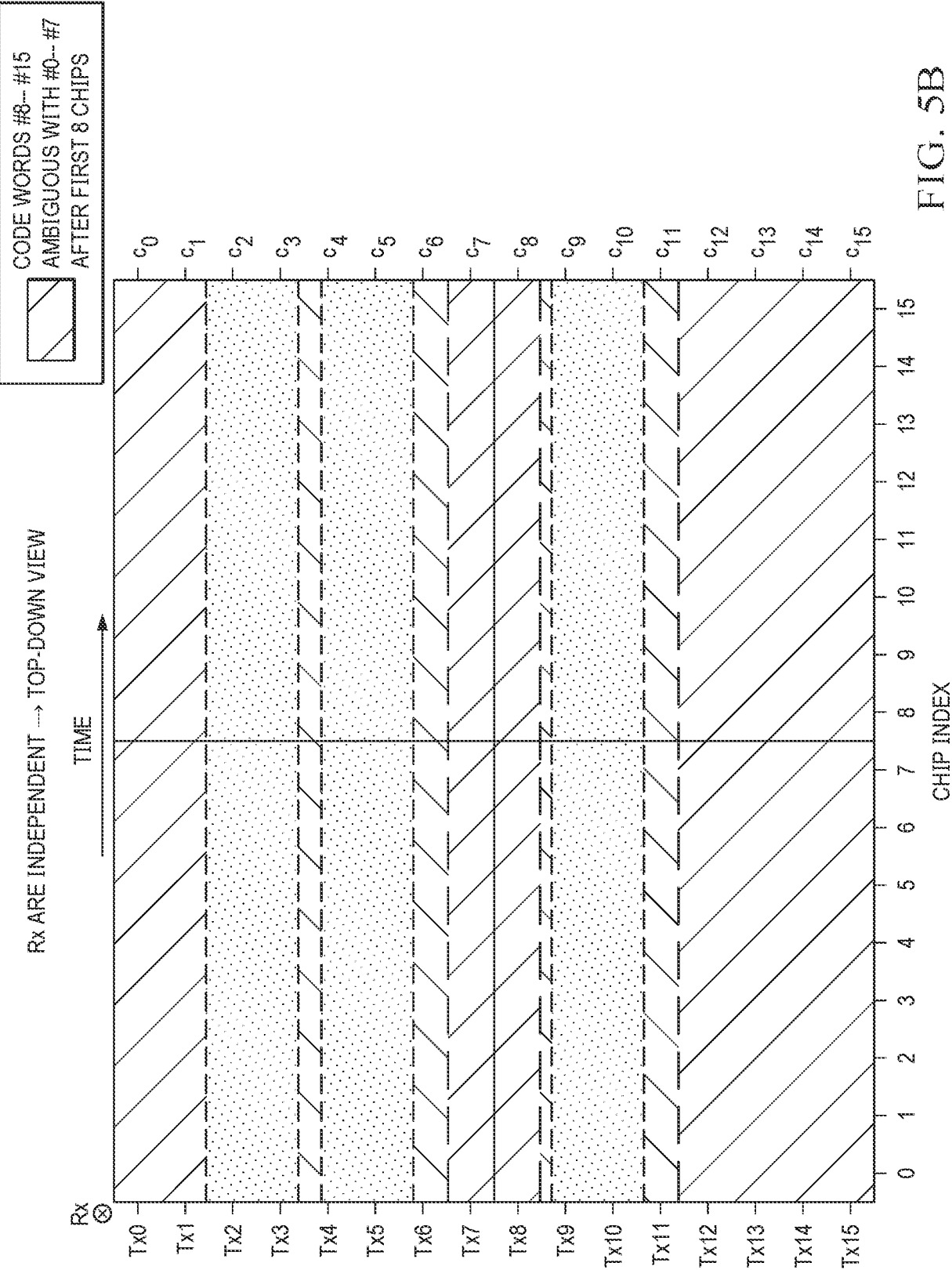


FIG. 5A



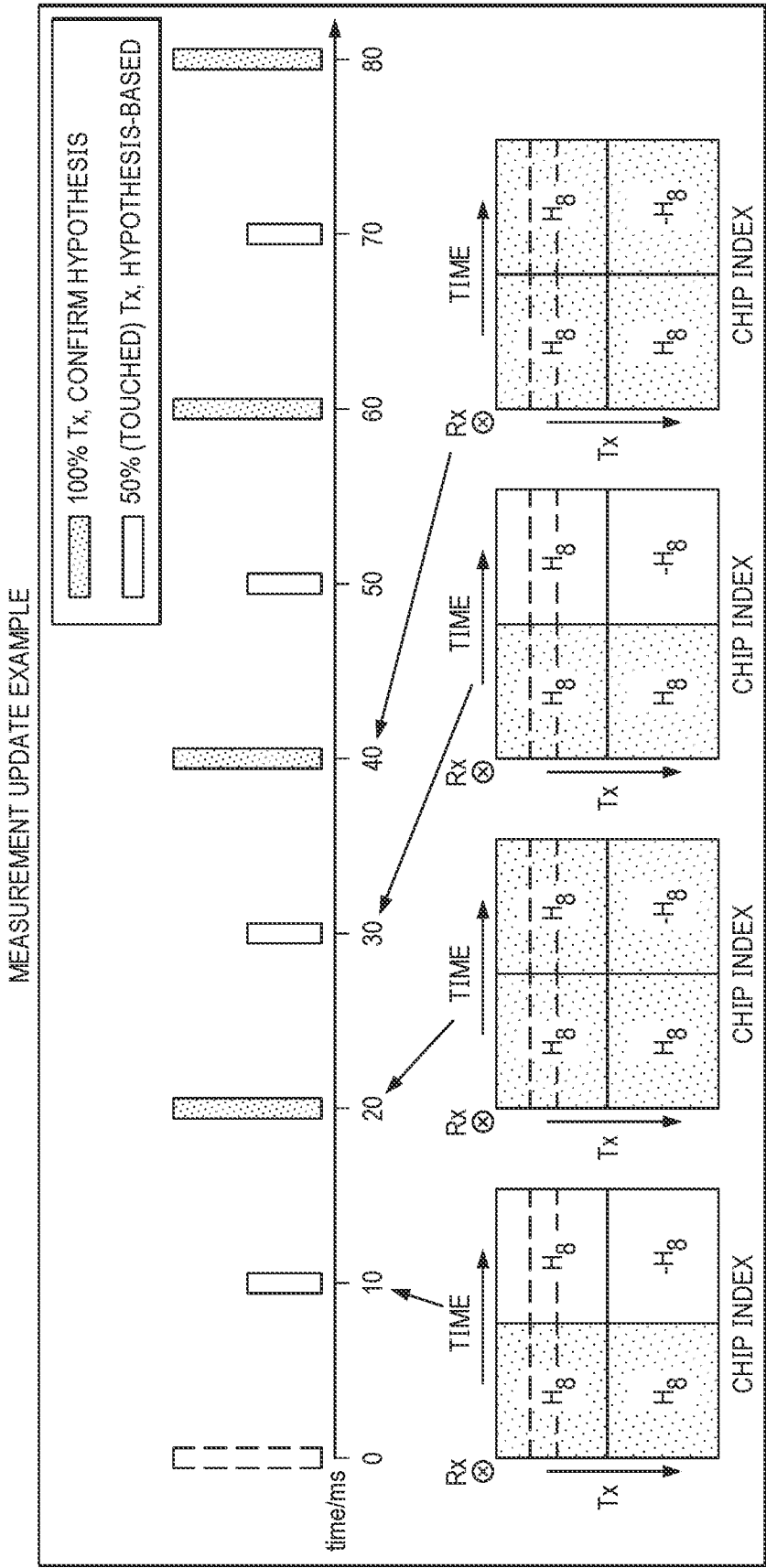


FIG. 6

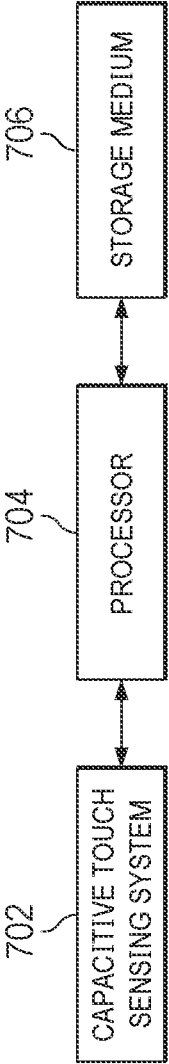


FIG. 7

14/14

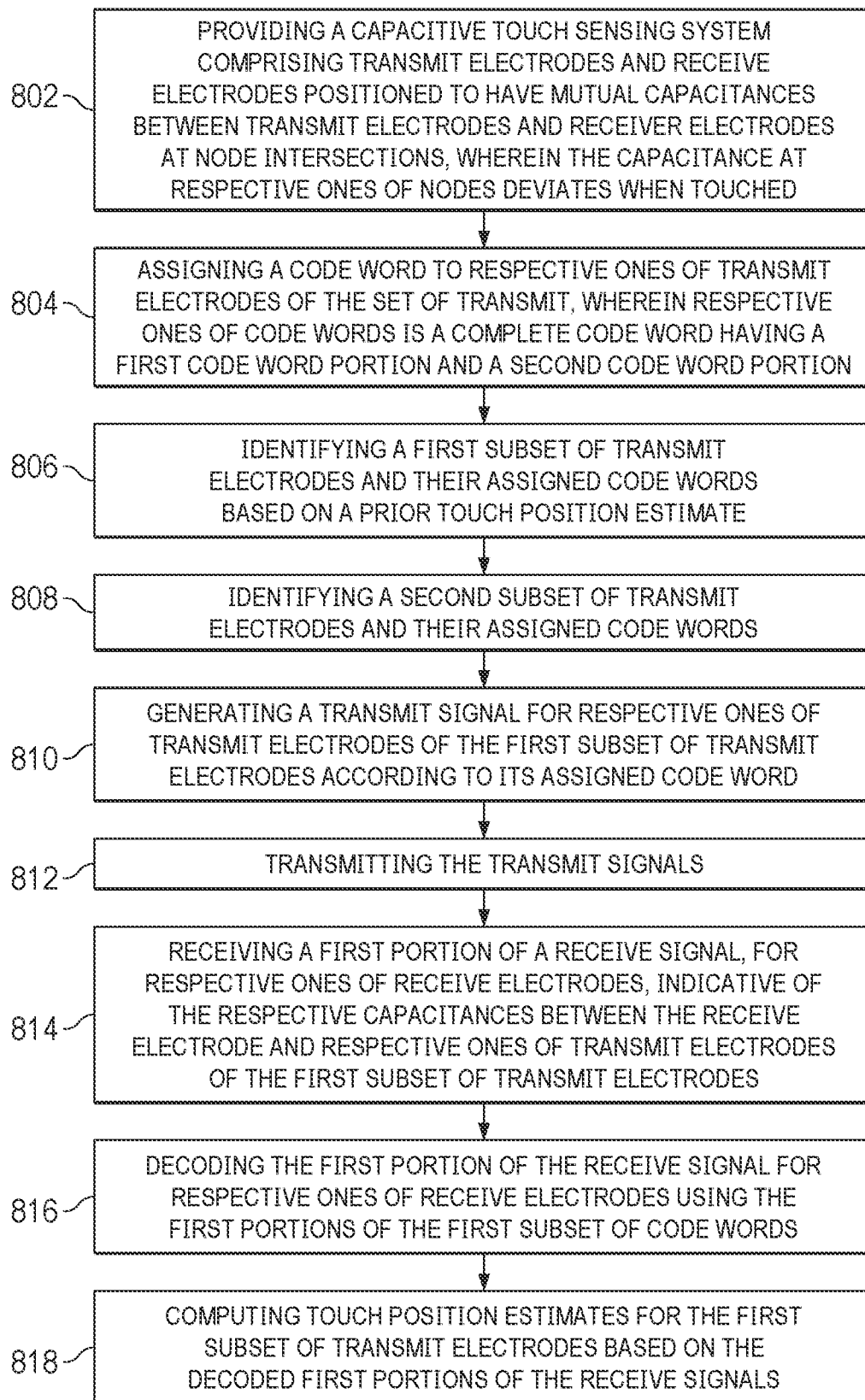


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2024/022717

A. CLASSIFICATION OF SUBJECT MATTER

INV. G06F3/041 G06F3/044
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2019/220141 A1 (SMALL JEFFREY A [US] ET AL) 18 July 2019 (2019-07-18) figure 2 paragraph [0044] - paragraph [0070] -----	1 - 15
A	US 10 474 291 B2 (IND TECH RES INST [TW]) 12 November 2019 (2019-11-12) the whole document -----	1 - 15
A	US 2022/043537 A1 (LEE JINCHUL [KR] ET AL) 10 February 2022 (2022-02-10) the whole document -----	1 - 15
A	WO 2018/211760 A1 (ALPS ELECTRIC CO LTD [JP]) 22 November 2018 (2018-11-22) figures 5-10 paragraph [0029] - paragraph [0049] ----- - / - -	1 - 15



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

9 July 2024

Date of mailing of the international search report

16/07/2024

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

de la Torre, David

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2024/022717

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 107 102 758 B (ANAPEX TECH INC) 10 April 2020 (2020-04-10) the whole document -----	1 - 15
A	CN 115 328 330 A (BEIJING ESWIN COMPUTING TECH CO LTD) 11 November 2022 (2022-11-11) the whole document -----	1 - 15
A	US 2021/055822 A1 (SMALL JEFFREY A [US] ET AL) 25 February 2021 (2021-02-25) figures 1-6 paragraph [0001] - paragraph [0073] -----	1 - 15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2024/022717

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2019220141 A1	18-07-2019	US 2019220141 A1	18-07-2019
		WO 2019138302 A1	18-07-2019
US 10474291 B2	12-11-2019	CN 108255332 A	06-07-2018
		TW 201824235 A	01-07-2018
		US 2018181258 A1	28-06-2018
US 2022043537 A1	10-02-2022	CN 114063811 A	18-02-2022
		KR 20220018364 A	15-02-2022
		US 2022043537 A1	10-02-2022
		US 2024045556 A1	08-02-2024
WO 2018211760 A1	22-11-2018	JP 2020118999 A	06-08-2020
		TW 201901165 A	01-01-2019
		WO 2018211760 A1	22-11-2018
CN 107102758 B	10-04-2020	NONE	
CN 115328330 A	11-11-2022	CN 115328330 A	11-11-2022
		US 2023418410 A1	28-12-2023
US 2021055822 A1	25-02-2021	NONE	