

## CMOS Programmable Digital Output Correlators

4 x 32 Bit, 20MHz

1 x 128 Bit, 20MHz

The TMC2220 20MHz, TTL compatible CMOS correlator is composed of four separate 1 x 32 correlator modules. The correlation scores of the four modules are weighted, combined and output on two separate parallel, three-state ports.

Each module contains a 32-bit serial data register, a 32-bit serial reference preload register, a 32-bit parallel reference latch and a 32-bit parallel mask latch. Correlation is performed by 32 exclusive-NOR (XNOR) gates. Each XNOR gate compares one (single bit) data word against a corresponding (single bit) reference word. While correlation is being performed between the data and the present reference, the next reference pattern may be preloaded through one of two multiplexed input ports. Shorter sampling windows and bipolar correlation are also supported. Each module outputs a 6-bit binary correlation score. Either an unsigned (range 0 through 32) or bipolar (range -16 through +16) representation may be selected. The outputs of each pair of correlator modules is added, with user-selected weighting factors, producing intermediate correlation scores which can be combined or output directly to the main or auxiliary output ports.

Since the four modules can be cascaded serially or in parallel, the TMC2220 supports numerous single and dual channel applications involving 1, 2 or 4-bit wide data and window lengths up to 32, 64, 96 or 128 bits. Multiple devices can be combined to support large correlation operations.

The TMC2221 combines the four 32-bit modules in series for a fixed channel configuration of 1-bit by 128. The reduced complexity and package size of the TMC2221 is ideal for applications requiring less versatility than the TMC2220. By making use of the mask function, any size single channel length of up to 128 bits is possible.

With the TMC2221, the reference word is serially loaded through the single two-input multiplexed reference port of the first correlator module. Although the configuration is fixed, the reference loading process and basic operation for each module is similar to that of the TMC2220. The outputs are summed with equal weighting, and the result is output through the single 8-bit output port. Unsigned magnitude or two's complement (bipolar) output score may be selected.

### Features

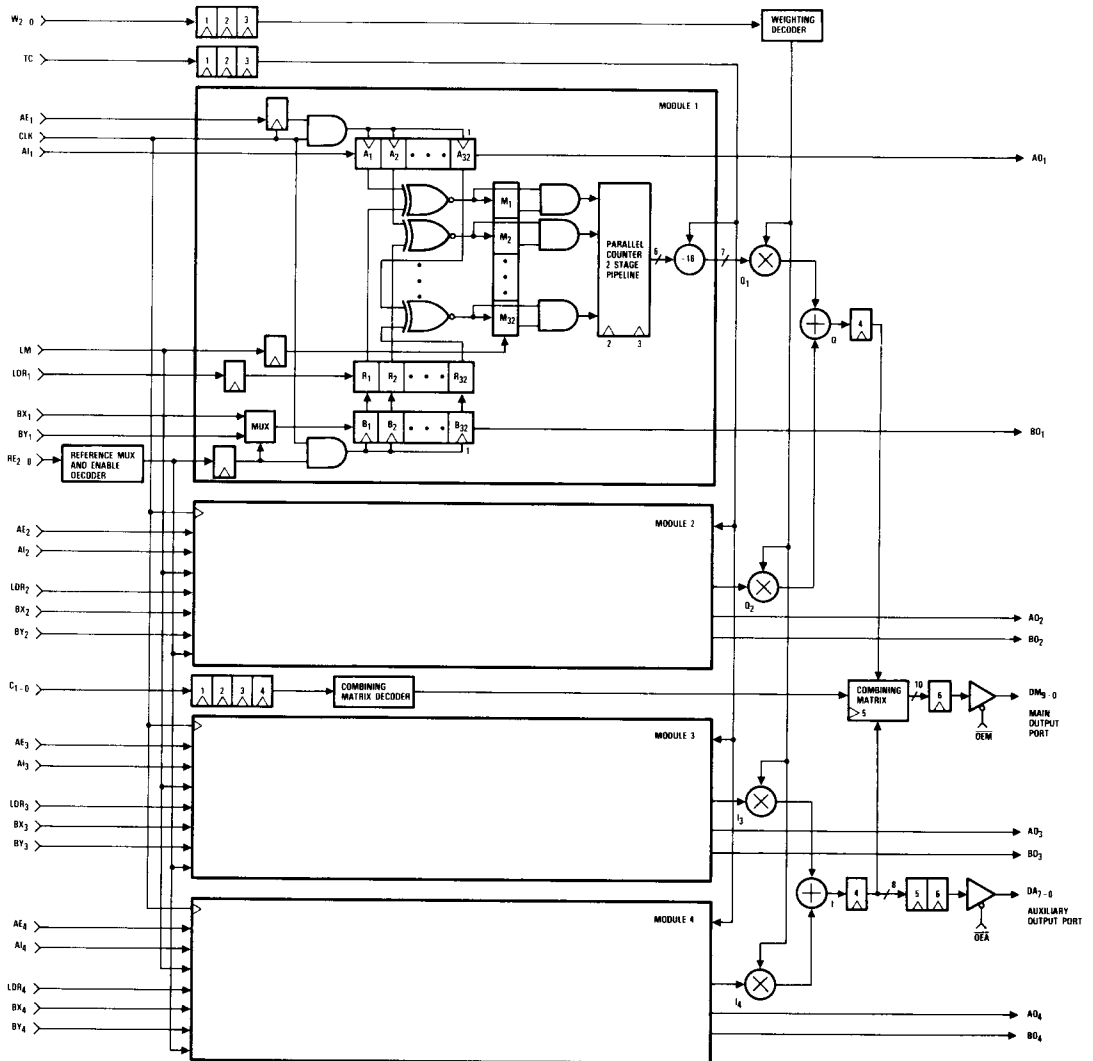
- 20MHz Continuous Correlation Rate
- Fully Programmable Masking
- Two's Complement Or Unsigned Magnitude Correlation Score
- User-Programmable Reference Load Multiplexing
- Channel Weighting And Output Formatting (TMC2220)
- Multi-Bit, Dual-Channel Or Non-Coherent (Quadrature) Correlation (TMC2220)
- Single +5V Power Supply
- Low Power CMOS Construction
- Three-State TTL Compatible Outputs
- TMC2220 Available In 68 Pin Grid Array And 69 Pin Plastic PGA Packages
- TMC2221 Available In 28 Pin CERDIP

### Applications

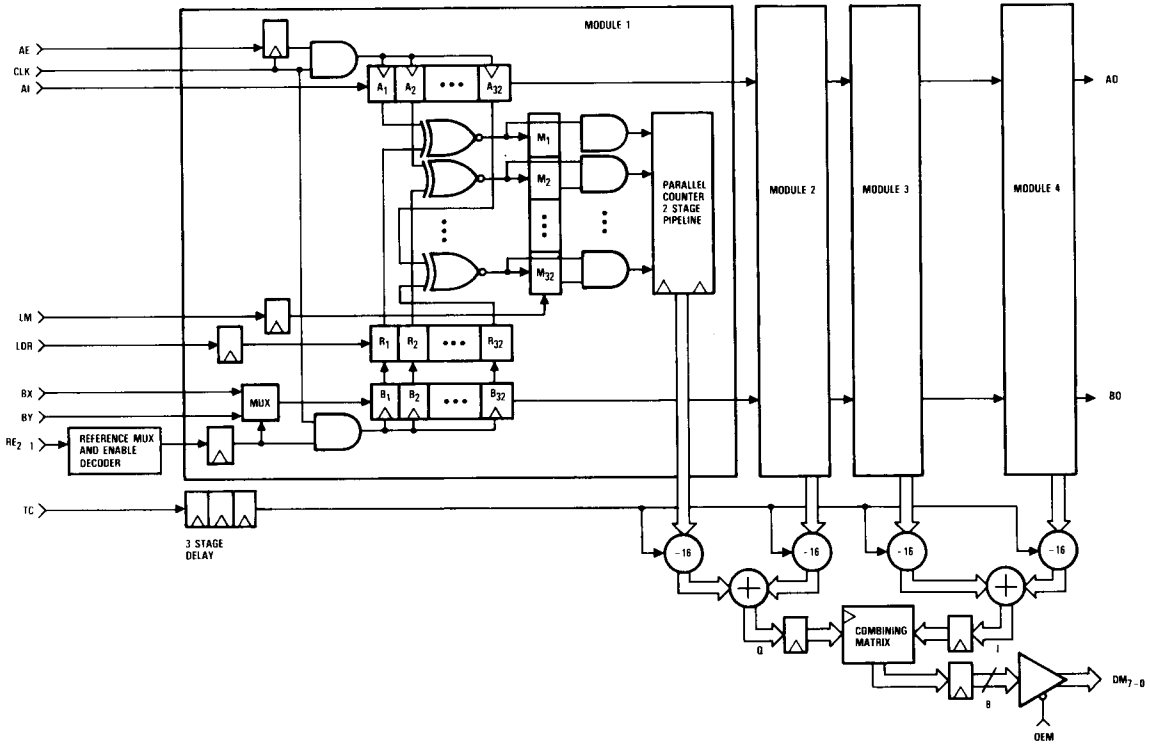
- Signal Detection
- Radar Signature Recognition
- Secure Communications
- Robotics/Automated Assembly
- Automatic Test Equipment
- Electro-Optical Navigation
- Pattern And Character Recognition
- Assembly Line Inspection



## TMC2220 Functional Block Diagram



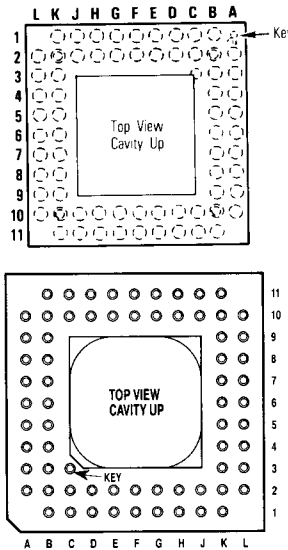
## Functional Block Diagram



## TMC2220 Pin Assignments

68 Pin Grid Array – G8 Package  
69 Pin Plastic Pin Grid Array – H8 Package 1

Pin	Name	Pin	Name	Pin	Name	Pin	Name
B2	DA <sub>1</sub>	K2	GND	K10	RE <sub>2</sub>	B10	LDR <sub>4</sub>
B1	DA <sub>0</sub>	L2	V <sub>DD</sub>	K11	AI <sub>2</sub>	A10	AE <sub>4</sub>
C2	DM <sub>0</sub>	K3	GND	J10	BY <sub>2</sub>	B9	LDR <sub>3</sub>
C1	DM <sub>1</sub>	L3	OE <sub>M</sub>	J11	BX <sub>2</sub>	A9	AE <sub>3</sub>
D2	DM <sub>2</sub>	K4	W <sub>2</sub>	H10	AI <sub>1</sub>	B8	OE <sub>A</sub>
D1	DM <sub>3</sub>	L4	W <sub>1</sub>	H11	BY <sub>1</sub>	A8	V <sub>DD</sub>
E2	DM <sub>4</sub>	K5	W <sub>0</sub>	G10	BX <sub>1</sub>	B7	AO <sub>4</sub>
E1	DM <sub>5</sub>	L5	C <sub>1</sub>	G11	GND	A7	BO <sub>4</sub>
F2	V <sub>DD</sub>	K6	C <sub>0</sub>	F10	CLK	B6	AO <sub>3</sub>
F1	DM <sub>6</sub>	L6	TC	F11	GND	A6	BO <sub>3</sub>
G2	DM <sub>7</sub>	K7	LM	E10	BY <sub>3</sub>	B5	DA <sub>7</sub>
G1	DM <sub>8</sub>	L7	LDR <sub>1</sub>	E11	BX <sub>3</sub>	A5	DA <sub>6</sub>
H2	DM <sub>9</sub>	K8	AE <sub>1</sub>	D10	AI <sub>3</sub>	B4	DA <sub>5</sub>
H1	BO <sub>1</sub>	L8	LDR <sub>2</sub>	D11	BY <sub>4</sub>	A4	DA <sub>4</sub>
J2	AO <sub>1</sub>	K9	AE <sub>2</sub>	C10	BX <sub>4</sub>	B3	DA <sub>3</sub>
J1	BO <sub>2</sub>	L9	RE <sub>0</sub>	C11	AI <sub>4</sub>	A3	DA <sub>2</sub>
K1	AO <sub>2</sub>	L10	RE <sub>1</sub>	B11	V <sub>DD</sub>	A2	GND



## TMC2221 Pin Assignments

LDR	1	28	LM
AE	2	27	TC
RE <sub>1</sub>	3	26	OE <sub>M</sub>
GND	4	25	GND
RE <sub>2</sub>	5	24	GND
AI	6	23	DM <sub>7</sub>
GND	7	22	V <sub>DD</sub>
CLK	8	21	DM <sub>6</sub>
BY	9	20	DM <sub>5</sub>
BX	10	19	DM <sub>4</sub>
V <sub>DD</sub>	11	18	DM <sub>3</sub>
AO	12	17	DM <sub>2</sub>
BO	13	16	DM <sub>1</sub>
NC	14	15	DM <sub>0</sub>

28 Pin Cerdip – B6 Package

Note: 1. Pin D4 is a mechanical orientation pin on the H8 package at manufacturer's option.

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## Functional Description

### General Information

The TMC2220 consists of four independent 1 x 32 correlator channels with weighted correlation scores which are combined and output on the two output ports (main and auxiliary). By taking advantage of the instruction set and I/O structure, the TMC2220 can be adapted to a wide variety of applications.

The TMC2221 consists of the four 1 x 32 correlator modules cascaded internally for a single 1 x 128 correlator. The outputs of each module are given a unity weighting, summed and placed on the output port.

### Correlator Channel Modules

Each of the four modules ( $i = 1$  to 4) contains two 32-bit serial synchronous shift registers,  $A_i$  (data) and  $B_i$  (reference preload); two 32-bit parallel latches,  $R_i$  (reference) and  $M_i$  (mask); 32 exclusive-NOR gates; 32 AND gates; a 32-bit parallel binary counter with a 6-bit unsigned output and a defeatable half-scale (-16) subtractor with a 7-bit two's complement output.

Whenever a given  $A_i$  or  $B_i$  register is enabled, the next rising edge of the clock loads the value at the corresponding  $A_i$  or  $BX_i/BY_i$  input port into the first cell of the register, and shifts the contents of each cell to the next, overwriting the contents of the last cell. These serial-in, parallel-tapped registers form the first of six registers which account for the six internal delays. After an output buffer delay  $t_D$ , the new contents of the last cell of  $A_i$  and  $B_i$  become available at the outputs  $AO_i$  and  $BO_i$  respectively. These outputs are used for cascading multiple devices. In addition, the  $B_i$  input multiplexer selects which of two input ports,  $BX_i$  or  $BY_i$ , is to be used on that cycle.

The reference latch  $R_i$  tracks the contents of  $B_i$  when control  $LDR_i$  was HIGH on the previous cycle and holds when  $LDR_i$  was LOW. A HIGH on  $LDR_i$  transfers the contents of  $B_i$  in parallel into  $R_i$  on the next clock cycle where correlation takes place. When  $LDR_i$  is held HIGH,  $R_i$  is transparent, enabling direct correlation between  $A_i$  and  $B_i$ .

Each of the 32 outputs of  $R_i$  is correlated against the corresponding tap of  $A_i$  by an XNOR gate whose output is connected to both the masking AND gate and the masking latch  $M_i$ .

Each  $M_i$  tracks if LM was HIGH on the previous cycle and holds if LM was LOW. When LM is held HIGH, all  $M_i$  latches are transparent and the output of each XNOR gate is sent to

both inputs of the corresponding AND gate to prevent masking or disabling from occurring. A LOW on LM loads the next unmasked correlation pattern (from the XNOR gates) into each  $M_i$ . Wherever the latch holds a logic one, normal correlation is enabled; wherever it is a logic zero, correlation is masked by the AND gate.

A 32-bit parallel counter encodes the number of logic ones emerging from the AND gates as a 6-bit binary number between 0 and 32 (100000). The clock drives the two pipeline registers in the counter (the second and third registers in the six register pipeline).

The 6-bit unsigned binary output of each parallel counter then enters a half-scale subtractor where it passes unchanged if the pipelined control TC is LOW and is reduced by 16 if TC is HIGH. If TC is HIGH, the range of correlation scores becomes -16 through +16 where +16 denotes a perfect match between the contents of  $A_i$  and those of  $R_i$  with no masking. A score of -16 denotes that no unmasked data bit matches the corresponding reference bit (anti-correlation). The TC control is pipelined by 3 registers, such that it is aligned with new data entering the  $A_i$  or  $B_i$  register.

### Weighting and Merging Circuitry

On the TMC2220, the 7-bit two's complement output of each correlator module ( $Q_1, Q_2, I_3, I_4$ ) is multiplied by a factor of 0, 1, 2, 3, 4 or 5 according to controls  $W_{2-0}$ . The outputs of each pair of multipliers is then added and the results  $Q$  and  $I$  are loaded into the fourth pipeline register.

Following two additional pipeline delays from the fifth and sixth registers, correlation sum  $I$  is available on the TMC2220 at the 8-bit auxiliary output port,  $DA_{7-0}$ , if the buffer is enabled ( $\overline{OE}A = \text{LOW}$ ).

Under controls  $C_{1-0}$ , the TMC2220 combiner blends  $Q$  and  $I$  into a single final correlation score which is sent to the 10-bit main output port,  $DM_{9-0}$ , if  $\overline{OEM}$  is LOW. The combiner pipeline register stage 5 and the main output register stage 6 are balanced by the auxiliary port double output register. In the simplest mode, the combiner outputs correlation sum  $Q$  permitting the TMC2220 to be used in two separate correlator channels. In this application, the combined results from modules 1 and 2 emerge through  $DM_{9-0}$  while the results from modules 3 and 4 emerge through  $DA_{7-0}$ . In the three remaining modes, the output at the main port will reflect the correlations of all four modules.

In the second mode, the combiner outputs the unweighted sum,  $Q + I$ . In the third mode, it outputs the weighted sum,  $Q + I/2$ , for single channel binary applications. In the fourth mode, the combiner extracts the absolute values of  $Q$  and  $I$  and adds the greater magnitude value to one half of the lesser value. This final mode is an approximation of the Pythagorean vector magnitude formula:

$$M = (\sqrt{x^2 + y^2})^{1/2}$$

The TMC2220 contains a total of five pipeline registers plus the data and reference preload shift registers making the total delay six clock cycles. Instructions and data paths are pipelined so the instructions presented on a given clock cycle apply to the value entering registers  $A_i$  and  $B_j$ . Instructions RE, LM, LDR and AE, all of which enable registers or latches, must be set one cycle early (see timing diagram).

For the TMC2221, the correlation score of each module is passed unchanged (TC = LOW) or reduced by sixteen (TC = HIGH). Each module score is given a unity weighting then sent to the combining matrix where the four scores are added and output on the 8-bit data bus if  $\overline{OEM}$  is LOW.

In magnitude mode (TC = LOW) and masking disabled, a perfect match between the data and reference will produce a correlation score of 128 (10000000<sub>B</sub>) and correlation score of 0 shall indicate no matches (anti-correlation). In two's complement mode (TC = HIGH), perfect correlation will produce a score of 64 (01000000<sub>B</sub>) and anti-correlation shall have an output of -64 (11000000<sub>B</sub>). A total of five register delays plus the input register cause the result to be available on the sixth clock cycle after the loading of the input data.

## Signal Definitions

### Power

$V_{DD}$ , GND The TMC2220/TMC2221 operate from a single +5V power supply. All power and ground pins must be connected.

### Inputs

$AI_{1-4}$  Each data input is a single-bit serial input to the  $A_i$  register of each correlator module.

$BX_{1-4}$ ,  $BY_{1-4}$  The main,  $BX_i$ , and alternate,  $BY_i$ , reference preload inputs to the  $B_j$  register of each correlator module are selected by controls  $RE_{2-0}$ .

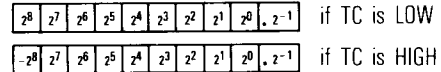
### Outputs

$AO_{1-4}$  Each cascade data output is a single-bit serial output from the  $A_i$  register of each correlator module.

$BO_{1-4}$  Each cascade reference preload output is a single-bit serial output from the  $B_j$  register of each correlator module.

$DM_{9-0}$  The 10-bit main correlation output (TMC2220 only) is a combination of the four module output scores,  $Q_1$ ,  $Q_2$ ,  $I_3$ ,  $I_4$ , which are dependent on the  $W_{2-0}$  weighted adder and  $C_{1-0}$  combining matrix controls. The main output port is enabled by  $\overline{OEM}$ .

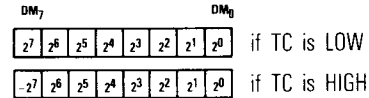
The TMC2220 10-bit output format is:



The TMC2221 has an 8-bit correlation output  $DM_{7-0}$  which always outputs the sum:

$$Q_1 + Q_2 + I_3 + I_4$$

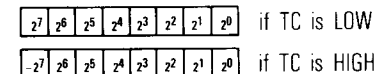
Where each term is either unsigned magnitude or magnitude minus 16 depending on the TC control. The TMC2221 8-bit output format is:



$DA_{7-0}$

(TMC2220 only) The 8-bit auxiliary correlation output is the sum of two module output scores,  $I_3$  and  $I_4$ , which are dependent on the  $W_{2-0}$  weighted adder controls. The auxiliary output port is enabled by  $\overline{OEA}$ .

The 8-bit binary output format is:



## Clocks

**CLK** The clock for  $A_i$  data and  $B_i$  reference preload registers can be toggled at up to 20MHz. All registers are strobed on the rising edge of CLK and dependent on the registered enable controls,  $AE_i$  for the  $A_i$  registers, and  $RE_{2-0}$  for the  $B_i$  registers. The pipeline delay registers for the controls,  $W_{2-0}$ ,  $C_{1-0}$  (TMC2220 only) and TC are also strobed on the rising edge of CLK.

## Controls

**$AE_{1-4}$**  The clock enable for the four  $A_i$  data registers is a registered, active HIGH control. When  $AE_i$  is LOW on the previous cycle, no shifting of data occurs on  $A_i$ .  $AE_i$  is read on the rising edge of CLK, thus the shifting of data in  $A_i$  will occur on the next rising edge of CLK.

**$C_{1-0}$**  (TMC2220 only) These pipelined instructions select the function to be executed by the combining matrix and output through the main output port,  $DM_{9-0}$ .

**$LDR_{1-4}$**  The Load Reference control copies the contents of register  $B_i$  into latch  $R_i$  for correlation. If  $LDR_i$  was LOW on the previous clock cycle, the present contents of the latch remain in  $R_i$ . If  $LDR_i$  was HIGH,  $R_i$  is transparent and the  $B_i$  are values used in the current correlation.

**LM** The Load Mask control allows the user to mask or select "no compare" bit positions in each channel. Inputs shifted into  $A_i$  and  $B_i$  produce a correlation pattern as the desired mask. Control LM must be HIGH on the previous cycle to track and LOW to store the pattern in the mask

latches  $M_i$ . If no masking is required, LM is kept HIGH, making  $M_i$  transparent.

**$\overline{OE_A}$**  (TMC2220 only) The asynchronous output enable for the auxiliary output port,  $DA_{7-0}$ , is an active LOW control. When  $\overline{OE_A}$  is HIGH, the output is in a high-impedance state.

**$\overline{OE_M}$**  The asynchronous output enable for the main output port,  $DM_{9-0}$  ( $DM_{7-0}$  on the TMC2221), is an active LOW control. When  $\overline{OE_M}$  is HIGH, the output is in a high-impedance state.

**$RE_{2-0}$**  The encoded clock enable and load selector controls determine the various combinations of  $BX_i$  and  $BY_i$  reference inputs that may be selected for the four reference preload registers  $B_i$ . The  $B_i$  register clocks may also be selectively enabled. Like LDR, LM and  $AE_i$ , this control is delayed by one clock cycle. ( $RE_{2-1}$  used on the TMC2221 to select BX or BY.) See Table 1.

**TC** The Two's Complement control forces the outputs of the four correlator modules to be unipolar (0 to 32) or bipolar (-16 to +16). When TC is LOW, the outputs of the correlator modules are passed unchanged to the weighting circuitry. When TC is HIGH, 16 is subtracted from each correlator output which is then interpreted as a two's complement value.

**$W_{2-0}$**  (TMC2220 only) The weighted adder controls determine the relative weightings of the four correlation module scores.

## TMC2220 Package Interconnections

Signal Type	Signal Name	Function	G8, H8 Package Pins
Power	V <sub>DD</sub>	Supply Voltage	F2, L2, B11, A8
	GND	Ground	K2, K3, G11, F11, A2
Inputs	AH <sub>1-4</sub>	Data Input	H10, K11, D10, C11
	BX <sub>1-4</sub>	Main Reference Preload	G10, J11, E11, C10
	BY <sub>1-4</sub>	Alternate Reference Preload	H11, J10, E10, D11
Outputs	AO <sub>1-4</sub>	Data Output	J2, K1, B6, B7
	BO <sub>1-4</sub>	Reference Preload Output	H1, J1, A6, A7
	DM <sub>g-0</sub>	Main Port	H2, G1, G2, F1, E1, E2, D1, D2, C1, C2
	DA <sub>7-0</sub>	Auxiliary Port	B5, A5, B4, A4, B3, A3, B2, B1
Clock	CLK	Master Clock	F10
Controls	AE <sub>1-4</sub>	Register Clock Enable	K8, K9, A9, A10
	C <sub>1-0</sub>	Combining Matrix	L5, K6
	LDR <sub>1-4</sub>	Reference Load	L7, L8, B9, B10
	LM	Mask Load	K7
	$\overline{OEA}$	Auxiliary Port Output Enable	B8
	$\overline{OEM}$	Main Port Output Enable	L3
	RE <sub>2-0</sub>	Reference Load Select	K10, L10, L9
	TC	Two's Complement	L6
	W <sub>2-0</sub>	Module Weighting Factor	K4, L4, K5



## TMC2221 Package Interconnections

Signal Type	Signal Name	Function	B6 Package
Power	V <sub>DD</sub>	Supply Voltage	11, 22,
	GND	Ground	4, 7, 24, 25
Inputs	AI	Data Input	6
	BX	Main Reference Preload	10
	BY	Alternate Reference Preload	9
Outputs	AO	Data Output	12
	BO	Reference Preload Output	13
	DM <sub>7-0</sub>	Main Port	23, 21, 20, 19, 18, 17, 16, 15
Clock	CLK	Master Clock	8
Controls	AE	Register Clock Enable	2
	LDR	Reference Load	1
	LM	Mask Load	28
	$\overline{OEM}$	Port Output Enable	26
	RE <sub>2-1</sub>	Reference Load Select	5, 3
	TC	Two's Complement	27
No Connection	NC		14

**Table 1. Reference Preload Register Input and Enable Operation**

RE <sub>i</sub> -0 Controls	Selected Reference Port (TMC2220)				Selected Reference Port (TMC2221)
	1	2	3	4	
000	Dis	Dis	Dis	Dis	Dis
001	Dis	Dis	Dis	BX <sub>4</sub>	
010	Dis	Dis	BY <sub>3</sub>	BX <sub>4</sub>	BY
011	Dis	Dis	BY <sub>3</sub>	BY <sub>4</sub>	
100	BX <sub>1</sub>	BX <sub>2</sub>	BX <sub>3</sub>	BX <sub>4</sub>	BX
101	BY <sub>1</sub>	BX <sub>2</sub>	BX <sub>3</sub>	BX <sub>4</sub>	
110	BY <sub>1</sub>	BX <sub>2</sub>	BY <sub>3</sub>	BX <sub>4</sub>	BY
111	BY <sub>1</sub>	BY <sub>2</sub>	BY <sub>3</sub>	BY <sub>4</sub>	

Notes:

1. Dis = B<sub>i</sub> register disabled (hold mode).
2. LSB (RE<sub>0</sub>) not used on the TMC2221.

**Table 2. Module Weighting Factor Operation (TMC2220 Only)**

W <sub>i</sub> Controls W <sub>2</sub> -0	Internal Channel Configuration	
	Q	I
000	Q <sub>1</sub> + Q <sub>2</sub>	I <sub>3</sub> + I <sub>4</sub>
001	3Q <sub>1</sub> + Q <sub>2</sub>	3I <sub>3</sub> + I <sub>4</sub>
010	4Q <sub>1</sub> + Q <sub>2</sub>	4I <sub>3</sub> + I <sub>4</sub>
011	Q <sub>2</sub>	I <sub>4</sub>
100	Q <sub>1</sub>	I <sub>3</sub>
101	3Q <sub>1</sub> + 2Q <sub>2</sub>	3I <sub>3</sub> + 2I <sub>4</sub>
110	4Q <sub>1</sub> + 2Q <sub>2</sub>	4I <sub>3</sub> + 2I <sub>4</sub>
111	5Q <sub>1</sub> + 2Q <sub>2</sub>	5I <sub>3</sub> + 2I <sub>4</sub>

**Table 3. Combining Matrix Operation (TMC2220 Only)**

C <sub>i</sub> Controls C <sub>1</sub> -0	Main Output Port Function DM <sub>9</sub> -0
	00
01	Q + I/2
10	Q + I
11	Max ( Q ,  I ) + 1/2 Min ( Q ,  I ) <sup>1</sup>

Notes:

1. The larger magnitude value of Q or I plus one-half of the smaller magnitude value.
2. The TMC2221 always outputs the sum Q<sub>1</sub> + Q<sub>2</sub> + I<sub>3</sub> + I<sub>4</sub>.

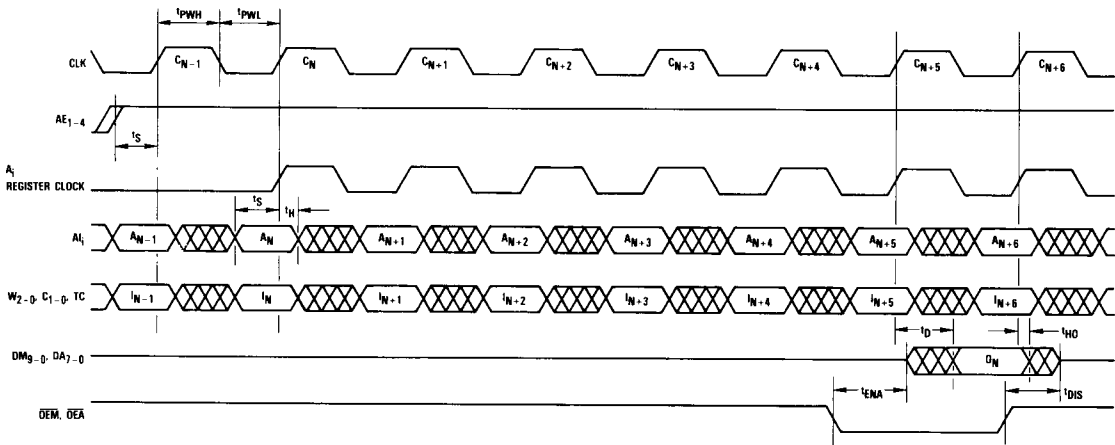
### Sliding Correlation Timing

The TMC2220 and TMC2221 have a six register pipeline. There are registers for the input data and reference, parallel counter, weighting circuitry, combining matrix, and output. CLK is used to load all A<sub>i</sub>, B<sub>i</sub> and instruction pipeline registers. With the register controls enabled, a data or reference word is loaded into its respective A<sub>i</sub> or B<sub>i</sub> register on every rising edge of CLK. Data A<sub>N</sub> enters register A<sub>i</sub> on the rising edge of clock C<sub>N</sub>. The reference latch is static if the previous LDR<sub>i</sub> was LOW or tracks B<sub>i</sub> if LDR<sub>i</sub> was HIGH. If reference preload is not desired, holding control LDR<sub>i</sub> HIGH makes latch R<sub>i</sub> transparent and direct correlation between A<sub>i</sub> and B<sub>i</sub> occurs. Data is valid if present at the input for a setup time t<sub>S</sub> before and a hold time t<sub>H</sub> after the rising clock edge. Setup and hold time requirements also apply to instructions and controls, however, AE, LDR, LM and RE must be valid one cycle before taking effect.

Because of the six internal pipeline delays, the correlation score for a given set of A<sub>i</sub> and B<sub>i</sub> register contents appears at the output ports six clock cycles plus an output delay t<sub>D</sub> later. When the main and auxiliary (TMC2220 only) output ports are enabled (OEM = LOW and OEA = LOW), the correlation score O<sub>N</sub> of data window A<sub>N-31</sub> through A<sub>N</sub> is output after rising clock edge C<sub>N+5</sub> (A<sub>N-127</sub> through A<sub>N</sub> on the TMC2221). Instructions TC, W and C are registered and pipelined so that the instructions will be aligned with the data. The instructions I<sub>N</sub> (see timing diagram) which are loaded on rising clock edge C<sub>N</sub> apply to a correlation between data and reference words N-31 (N-127) through N. Masking is assumed to be preset (previous LM = LOW) or unused (previous LM = HIGH). The same timing applies if the reference is shifting and data is fixed.



**Figure 1. Sliding Correlation Timing**



### Reference Register Load Timing

The HIGH on  $LDR_i$  transfers the contents of  $B_i$  in parallel into  $R_i$  in the next clock period.  $R_i$  tracks  $B_i$  when control  $LDR_i$  is HIGH and holds when  $LDR_i$  is LOW.  $N$  rising edges of CLK are required to load  $N$  reference words into the reference preload register  $B_i$ . The rising edge of clock  $C_N$  loads reference word  $B_N$  so that  $B_i$  contains words  $B_{N-31}$  through  $B_N$ .

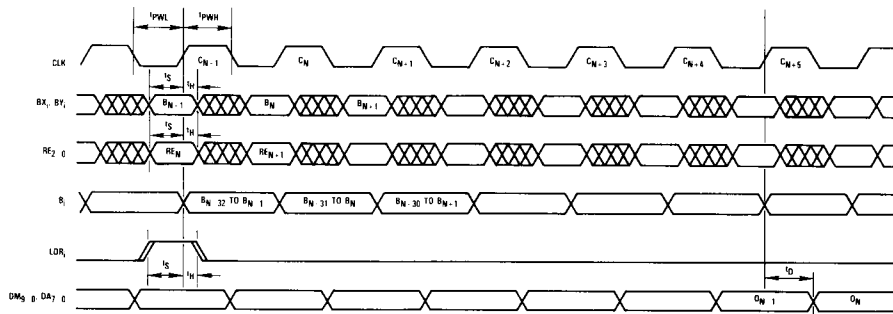
Figure 2 illustrates the  $LDR_i$  instruction timing to transfer reference window  $B_{N-31}$  through  $B_N$  into the reference latch. With this timing, correlation against the old reference pattern is preserved during the "LDR" clock cycle and that correlation against the new reference pattern  $B_{N-31}$  to  $B_N$  should commence immediately after the "LDR" clock cycle. The user must meet the normal input setup and hold time requirements and setup the instruction one clock cycle before the desired transfer.

A completely new reference can be loaded into latch R on every 32nd clock cycle. With the output ports enabled, the correlation score  $O_N$  (correlation between data  $A_{N-31}$  through  $A_N$  and reference  $B_{N-31}$  through  $B_N$ ) is available an output delay  $t_D$  after the rising edge of clock  $C_{N+5}$  because of the six register pipeline.



Operation of the TMC2221 is similar to the operation described for the TMC2220 except the length of the reference word is 128 bits rather than 32. The reference register will therefore contain the pattern  $B_{N-127}$  through  $B_N$ , and correlation occurs between this reference and data  $A_{N-127}$  through  $A_N$ . A new reference word therefore requires 128 clock cycles to completely load the new value. With the output ports enabled, the correlation score  $O_N$  (correlation between data  $A_{N-127}$  through  $A_N$  and reference  $B_{N-127}$  through  $B_N$ ) is available an output delay  $t_D$  after the rising edge of clock  $C_{N+5}$ .

**Figure 2. Reference Latch Load Timing**



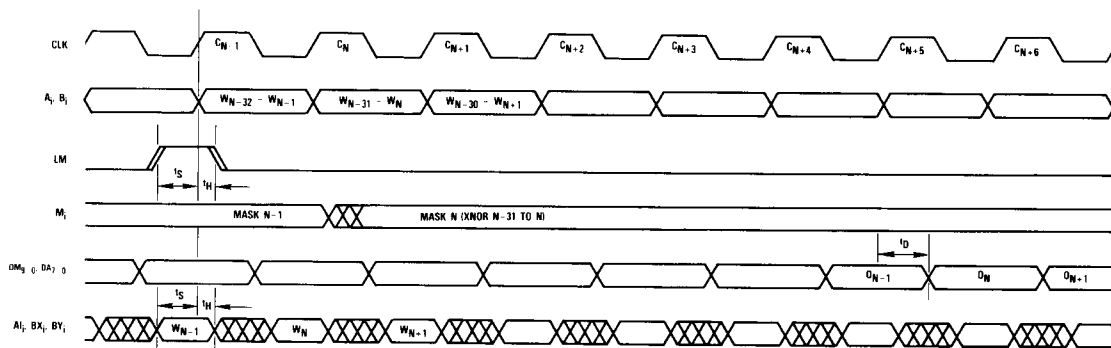
## Mask Register Loading

Control LM latches a mask pattern into  $M_i$  which selectively disables word positions in each correlator module. Masking latch  $M_i$  tracks the XNOR output if, on the previous clock cycle, LM was HIGH and holds if LM was LOW. Figure 3 illustrates the TMC2220 LM timing to latch a mask generated by the exclusive NOR of  $A_{N-31}$  through  $A_N$  with  $R_{N-31}$  through  $R_N$ . LM must be set HIGH  $t_S$  before the rising edge of clock  $C_{N-1}$  to load the mask for  $A_{N-31}$  thru  $A_N$ . LM must be set LOW before the next rising edge of  $C_N$  to ensure words  $N-31$  to  $N$  remain latched as the mask pattern. A completely new mask may be loaded on every 32nd clock cycle. However, to permit time for data and reference loading,

mask loading is generally limited to every 64th clock cycle. The first correlation score which reflects mask  $N$  is output  $t_D$  after the rising edge of clock cycle  $C_{N+6}$ .

Operation of the TMC2221 is similar that of the TMC2220 but requires 128 clock cycles to completely load a new mask pattern. To permit time to load new data and a new reference pattern once the mask is loaded, an additional 128 clock cycles is required. Therefore, mask loading is generally limited to every 256 clock cycles in the TMC2221. The mask pattern loaded will be the exclusive-NOR of  $A_{N-127}$  through  $A_N$  with  $R_{N-127}$  through  $R_N$ .

**Figure 3. Masking Latch Load Timing**



## Applications Discussion

The TMC2220 architecture provides the flexibility for a number of configurations. The cascade outputs and the internal weighting and adder logic allow a single TMC2220 to be configured as four independent 32-bit correlators, independent 96-bit and 32-bit correlators, two independent 64-bit correlators, or as a single 128 x 1 correlator. The TMC2220 may also be cascaded serially or in parallel to increase the length or width of correlation.

To increase the correlation length in a single TMC2220 system, the cascade outputs of a module ( $AO_i, BO_i$ ) can be connected to the inputs of the next module ( $AI_{i+1}, BI_{i+1}$ ). When using this configuration, the input enables and load controls should be connected together. Figure 4 shows the configuration for a dual 64 x 1 correlation. In this application, the outputs of module 1 are connected to the inputs of module 2 and the outputs of module 3 are connected to the inputs of module 4. The weighting and combining logic is set for 1:1 weighting and the combining logic is set to output  $Q_1 + Q_2$  on the main output  $DM_{9-0}$ , and  $I_3 + I_4$  on the auxiliary output  $DA_{7-0}$ .

Figure 4. Dual 64 x 1 Configuration

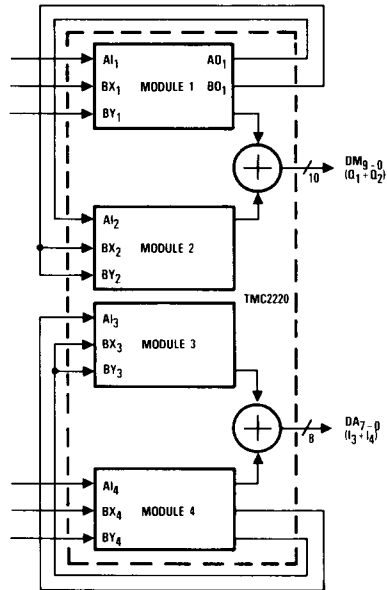
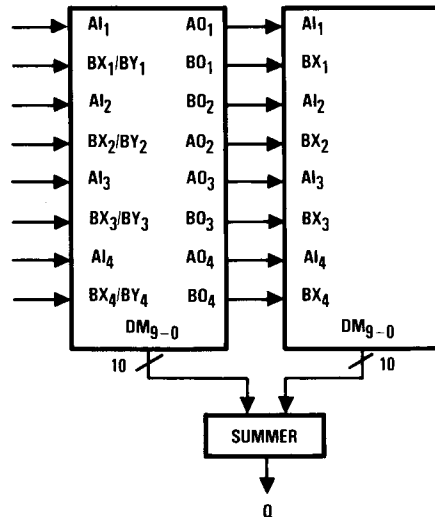


Figure 5. Cascading the TMC2220 for Extended-Length Correlation

Figure 5 shows an example of multi-bit correlation with extended length. This example shows 4-bit correlation with a length of 64-bits. The outputs of the two TMC2220s must be externally added to obtain the 64-bit correlation score. The weighting and combining of the module correlation scores should be set as required by the application.

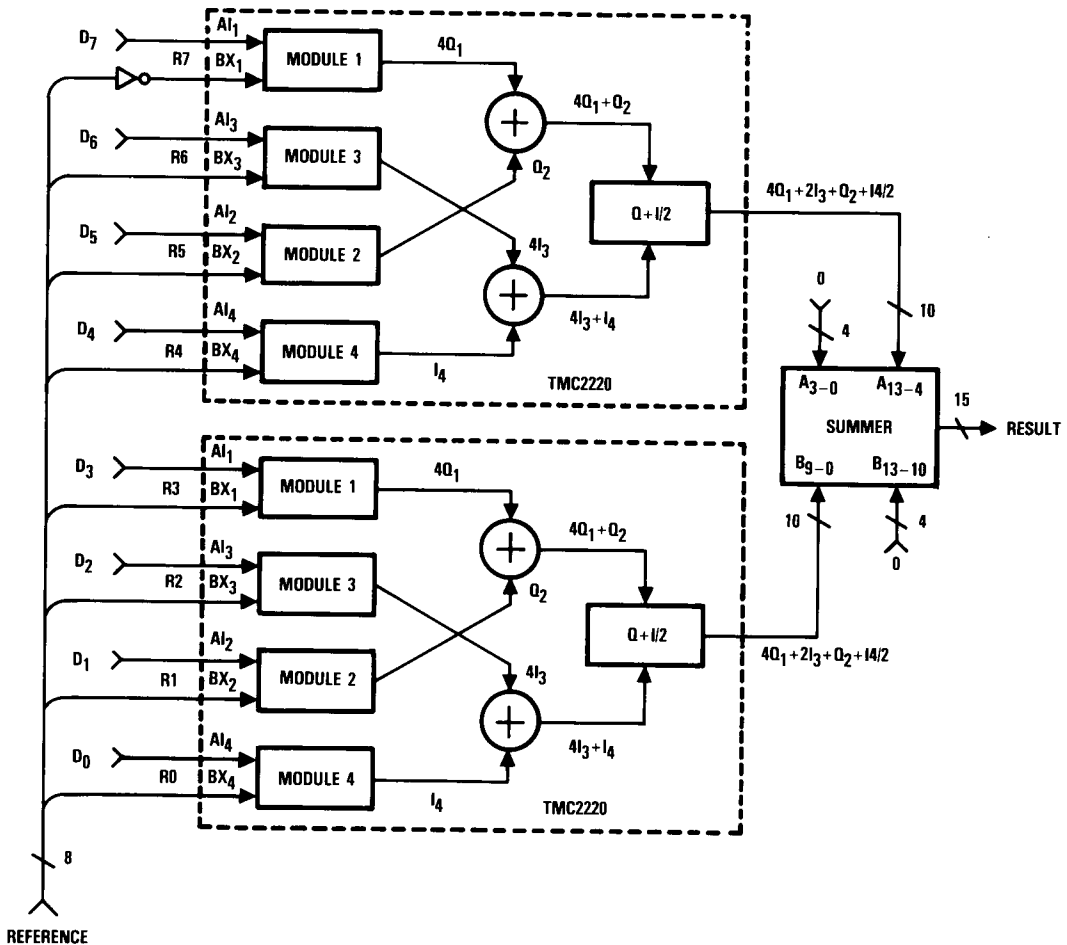


**Figure 6. 8-Bit Correlation with the TMC2220**

Figure 6 shows an example of 8-bit, two's complement correlation. Two TMC2220s are used in parallel and externally summed to obtain the properly weighted correlation score. To obtain a properly weighted correlation score, each bit of the output must be multiplied by an appropriate binary scaling factor. The 8-bit data input and reference are connected as shown. The weighting control of each TMC2220 is set for 4:1 weighting ( $W_{2-0} = 010$ ). This multiplies the upper two bits of each TMC2220 by a factor of 4 ( $Q_1, I_3$ ). The next step is to multiply the 2nd and 4th bits ( $Q_2, I_4$ ) by a factor of 2. An equivalent operation is to divide the 1st and 3rd bits by 2. This operation is accomplished by setting the combining logic to output the sum  $Q + I/2$  ( $C_{1-0} = 01$ ). The final output of each TMC2220 will be equivalent to:

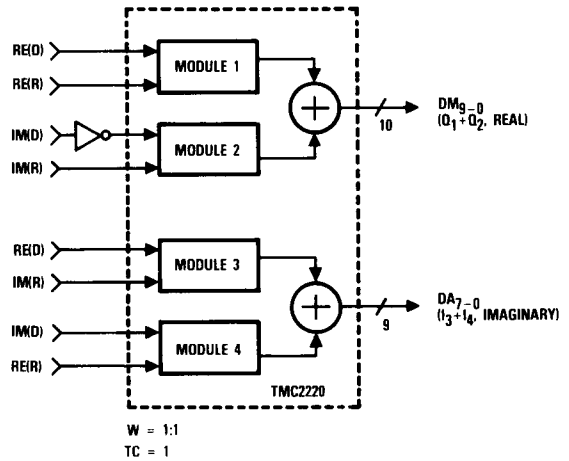
$$DM_{g-0} = (4 \times Q_1) + (2 \times I_3) + (1 \times Q_2) + (1/2 \times I_4)$$

Setting the weighting and combining controls as described will produce a correlation score with each bit properly weighted based on its 4-bit binary position. The final step is to multiply the correlation output of the most-significant TMC2220 (bits 7-4) by a factor of 16 then combine the outputs of the two TMC2220s. This is done using external adder circuitry. Multiplication is performed by simply shifting the output lines of the upper TMC2220 by four places at the input to the adder logic. The output of the summer, therefore, shall give the binary weighted correlation score of a quantized 8-bit input. The same circuit can be used with unsigned data if the inverter on the most-significant-bit of the reference input is omitted.



**Figure 7. Full Complex Correlation with the TMC2220**

Figure 7 is an example of full complex correlation. In this example, separate real and imaginary terms are multiplied and summed internally to provide a real and imaginary result. This method preserves the phase information of the input. Inputs are connected as shown in the figure. The imaginary term in  $Im(D) \times Im(R)$  is negated (inverted) for proper sign in the summation. The TMC2220 is set for 1:1 ( $Q_1 + Q_2, I_3 + I_4$ ) weighting, two's complement mode, and the combining control is set to output Q on the main output and I on the auxiliary output. All 32 internal taps are used.



A simple example would be to find a sine wave in a demodulated data stream. The references would be set to:

$$Re(R) = \cos(\omega t) \text{ and } Im(R) = \sin(\omega t)$$

where,  $\omega$  is the modulation frequency. Each term is set to:

$$1 \text{ for positive and } 0 \text{ for negative}$$

The data inputs are set to:

$$Re(D) = data_{in} \times \cos(ft) \text{ and } Im(D) = data_{in} \times \sin(ft)$$

where,  $f$  is the mixer or carrier frequency.

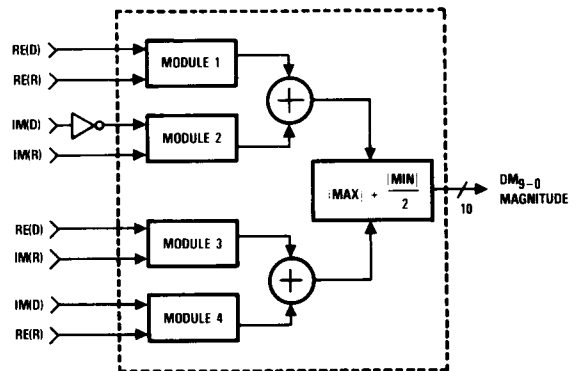


**Figure 8. Complex Correlation with Magnitude Result**

Figure 8 is similar to full complex correlation, however, in this example the output is magnitude only. This application is used when the phase relationship is not required. The inputs are connected as in the previous example, however, rather than a full complex output, the outputs are combined internally to:

$$\text{Max}(|Q|, |I|) + 1/2 \text{Min}(|Q|, |I|)$$

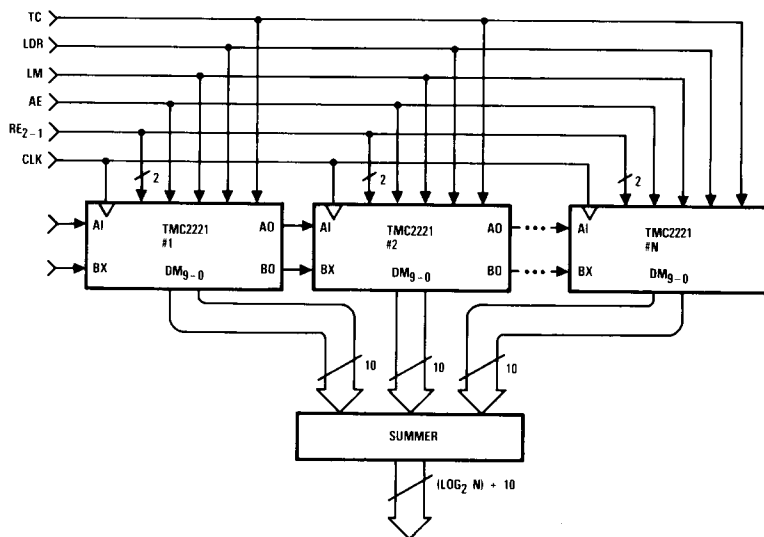
( $C1_0 = 11$ ) to obtain the approximate magnitude output. Multiplying the output by 15/16 will reduce the error in the magnitude approximation.



**Figure 9. Cascading the TMC2221 for Extended-Length Correlation**

The TMC2221 can be cascaded to implement correlations of more than 128-bits. Typically all clocks, reference inputs and enables are connected together and the A and B outputs of

preceding stages are connected to the respective inputs of subsequent stages. An external summer is required to generate the composite correlation score.



**Figure 10. Multi-Bit x 1 Bit Correlation**

The TMC2221 may also be used to compare multi-bit words with a single-bit reference. When this is done, the output of each TMC2221 must be appropriately weighted to the adder

circuitry. The weighting reflects the relative importance of the different bit positions. Weighting can normally be accomplished by simple bit shifts at the input to the summer.

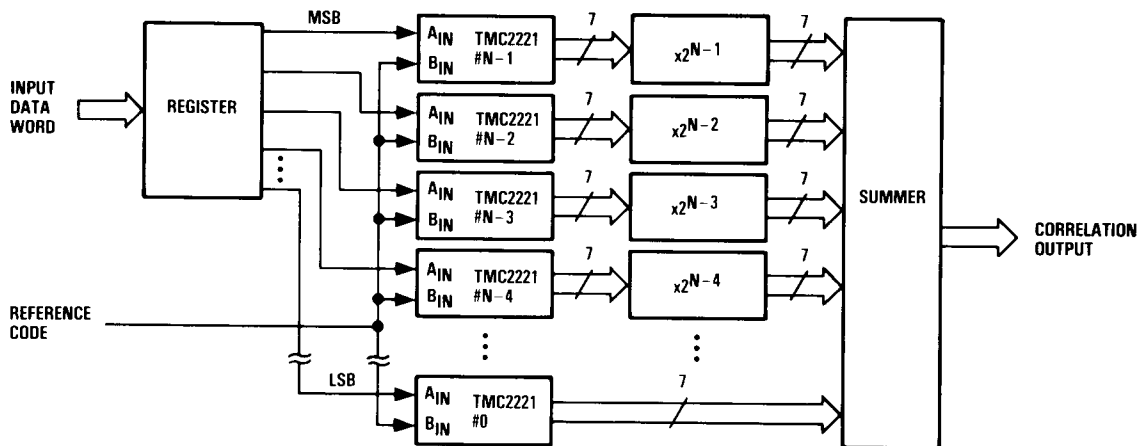


Figure 11. Equivalent Input Circuit

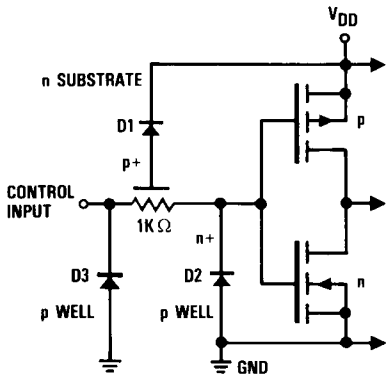


Figure 12. Equivalent Output Circuit

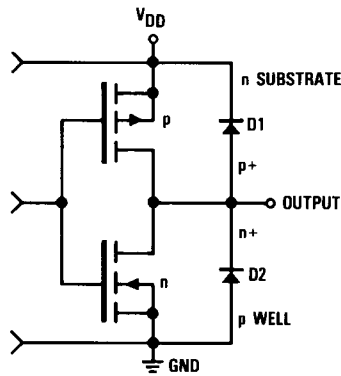
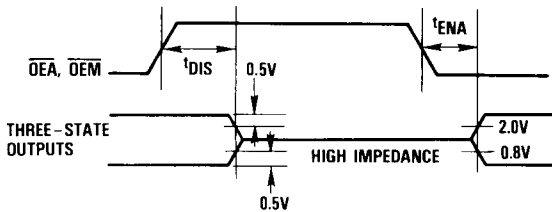


Figure 13. Threshold Levels for Three-State Measurements



### Absolute maximum ratings (beyond which the device may be damaged)<sup>1</sup>

Supply Voltage .....	-0.5 to +7.0V
Input Voltage .....	-0.5 to (V <sub>DD</sub> + 0.5V)
<b>Output</b>	
Applied voltage <sup>2</sup> .....	-0.5 to (V <sub>DD</sub> + 0.5V)
Forced current <sup>3,4</sup> .....	-1.0 to +6.0mA
Short-circuit duration (single output in HIGH state to ground) .....	1 sec
<b>Temperature</b>	
Operating, case .....	-60 to +130°C
junction .....	175°C
Lead, soldering (10 seconds) .....	300°C
Storage .....	-65 to +150°C

Notes:

1. Absolute maximum ratings are limiting values applied individually while all other parameters are within specified operating conditions. Functional operation under any of these conditions is NOT implied.
2. Applied voltage must be current limited to specified range, and measured with respect to GND.
3. Forcing voltage must be limited to specified range.
4. Current is specified as conventional current flowing into the device.

## Operating conditions

Parameter	Temperature Range						Units
	Standard			Extended			
	Min	Nom	Max	Min	Nom	Max	
V <sub>DD</sub> Supply Voltage	4.75	5.0	5.25	4.5	5.0	5.5	V
V <sub>IL</sub> Input Voltage, Logic LOW			0.8			0.8	V
V <sub>IH</sub> Input Voltage, Logic HIGH	2.0			2.0			V
I <sub>OL</sub> Output Current, Logic LOW			4.0			4.0	mA
I <sub>OH</sub> Output Current, Logic HIGH			-2.0			-2.0	mA
T <sub>A</sub> Ambient Temperature, Still Air	0		70				°C
T <sub>C</sub> Case Temperature				-55		125	°C

## DC characteristics within specified operating conditions <sup>1</sup>

Parameter	Test Conditions	Temperature Range				Units
		Standard		Extended		
		Min	Max	Min	Max	
I <sub>DDQ</sub> Supply Current, Quiescent	V <sub>DD</sub> = Max, V <sub>IN</sub> = 0V, $\overline{OEM}$ , $\overline{OEA}$ = 5V		10		10	mA
I <sub>DDU</sub> Supply Current, Unloaded	V <sub>DD</sub> = Max, f = 20MHz, $\overline{OEM}$ , $\overline{OEA}$ = 5V		70		80	mA
I <sub>IL</sub> Input Current, Logic LOW	V <sub>DD</sub> = Max, V <sub>IN</sub> = 0V	-40		-40		μA
I <sub>IH</sub> Input Current, Logic HIGH	V <sub>DD</sub> = Max, V <sub>IN</sub> = V <sub>DD</sub>		+40		+40	μA
V <sub>OL</sub> Output Voltage, Logic LOW	V <sub>DD</sub> = Min, I <sub>OL</sub> = Max		0.4		0.4	V
V <sub>OH</sub> Output Voltage, Logic HIGH	V <sub>DD</sub> = Min, I <sub>OH</sub> = Max	2.4		2.4		V
I <sub>OZL</sub> Hi-Z Output Leakage Current, Output LOW	V <sub>DD</sub> = Max, V <sub>IN</sub> = 0V	-40		-40		μA
I <sub>OZH</sub> Hi-Z Output Leakage Current, Output HIGH	V <sub>DD</sub> = Max, V <sub>IN</sub> = V <sub>DD</sub>		+40		+40	μA
I <sub>OS</sub> Short-Circuit Output Current	V <sub>DD</sub> = Max, Output HIGH, one pin to ground, one second duration max.		-150		-150	mA
C <sub>I</sub> Input Capacitance	T <sub>A</sub> = 25°C, f = 1MHz		10		10	pF
C <sub>O</sub> Output Capacitance	T <sub>A</sub> = 25°C, f = 1MHz		10		10	pF

Note:

1. Actual test conditions may vary from those shown, but guarantee operation as specified.



## AC characteristics within specified operating conditions

Parameter	Test Conditions	Temperature Range								Units
		Standard				Extended				
		-1				-1				
		Min	Max	Min	Max	Min	Max	Min	Max	
$f_C$ Clock (Correlation) Rate	$V_{DD} = \text{Min}$		20		17		20		17	MHz
$t_{PWL}$ Clock Pulse Width, LOW	$V_{DD} = \text{Min}$	25		30		25		30		ns
$t_{PWH}$ Clock Pulse Width, HIGH	$V_{DD} = \text{Min}$	15		15		15		15		ns
$t_S$ Input Setup Time		15		15		17		17		ns
$t_H$ Input Hold Time		0		0		0		0		ns
$t_D$ Output Delay	$V_{DD} = \text{Min}, C_{LOAD} = 40\text{pF}$		25		25		25		25	ns
$t_{HD}$ Output Hold Time	$V_{DD} = \text{Max}, C_{LOAD} = 40\text{pF}$	3		3		3		3		ns
$t_{ENA}$ Three-State Output Enable Delay <sup>1</sup>	$V_{DD} = \text{Min}, C_{LOAD} = 40\text{pF}$		17		17		17		17	ns
$t_{DIS}$ Three-State Output Disable Delay <sup>1</sup>	$V_{DD} = \text{Min}, C_{LOAD} = 40\text{pF}$		22		22		22		22	ns

Note: 1. All transitions are measured at a 1.5V level except for  $t_{DIS}$  and  $t_{ENA}$ .

## Ordering Information

Product Number	Temperature Range	Screening	Package	Package Marking
TMC2220G8C	STD - $T_A = 0^\circ\text{C}$ to $70^\circ\text{C}$	Commercial, 17MHz	68 Pin Grid Array	2220G8C
TMC2220G8V	EXT - $T_C = -55^\circ\text{C}$ to $125^\circ\text{C}$	MIL-STD-883, 17MHz	68 Pin Grid Array	2220G8V
TMC2220G8C1	STD - $T_A = 0^\circ\text{C}$ to $70^\circ\text{C}$	Commercial, 20MHz	68 Pin Grid Array	2220G8C1
TMC2220G8V1	EXT - $T_C = -55^\circ\text{C}$ to $125^\circ\text{C}$	MIL-STD-883, 20MHz	68 Pin Grid Array	2220G8V1
TMC2220H8C	STD - $T_A = 0^\circ\text{C}$ to $70^\circ\text{C}$	Commercial, 17MHz	69 Pin Plastic Pin Grid Array	2220H8C
TMC2220H8C1	STD - $T_A = 0^\circ\text{C}$ to $70^\circ\text{C}$	Commercial, 20MHz	69 Pin Plastic Pin Grid Array	2220H8C1
TMC2221B6C	STD - $T_A = 0^\circ\text{C}$ to $70^\circ\text{C}$	Commercial, 17MHz	28 Pin Cerdip	2221B6C
TMC2221B6V	EXT - $T_C = -55^\circ\text{C}$ to $125^\circ\text{C}$	MIL-STD-883, 17MHz	28 Pin Cerdip	2221B6V
TMC2221B6C1	STD - $T_A = 0^\circ\text{C}$ to $70^\circ\text{C}$	Commercial, 20MHz	28 Pin Cerdip	2221B6C1
TMC2221B6V1	EXT - $T_C = -55^\circ\text{C}$ to $125^\circ\text{C}$	MIL-STD-883, 20MHz	28 Pin Cerdip	2221B6V1

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